AN ABSTRACT OF THE THESIS OF

Fouad S. Abd-El-Khalick for the degree of Doctor of Philosophy in Science Education presented on July 29, 1998. Title: The Influence of History of Science Courses on Students' Conceptions of the Nature of Science.

Abstract approved: Signature redacted for privacy.

Norman G. Lederman

This study assessed the influence of three history of science (HOS) courses on college students and preservice science teachers' conceptions of the nature of science (NOS), and examined whether participants who entered the investigated HOS courses with a conceptual framework consistent with current NOS views achieved more elaborate NOS understandings. The study also explored the aspects of the participant HOS courses that may have rendered them more effective in influencing students' conceptions.

Participants were 141 undergraduate and graduate students enrolled in three HOS courses and 15 preservice science teachers enrolled in a science methods course in a mid-sized state university on the West Coast. Ten of the preservice teachers were enrolled in one of the participant HOS courses. An open-ended questionnaire was used to assess participants' pre- and post-instruction NOS views. Individual interviews were used to establish the questionnaire's validity. Twenty percent of the participants were randomly selected for the pre-instruction interviews and an equal percentage were interviewed at the end of the study. Other data sources included field notes, lecture audiotapes, and interviews with the HOS course professors.

Almost all participants held inadequate views of several NOS aspects. Very few and limited changes were evident in participants' NOS views at the conclusion of the study. 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 participant 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 the HOS would necessarily enhance students and preservice science teachers' NOS views. Explicitly addressing specific NOS aspects might enhance the effectiveness of HOS courses in influencing students' views. 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 would be changed or enriched as a result of their experiences with HOS.

THE INFLUENCE OF HISTORY OF SCIENCE COURSES ON STUDENTS' CONCEPTIONS OF THE NATURE OF SCIENCE

by

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A THESIS
Submitted to Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

Completed July 29, 1998
Commencement June 1999

ACKNOWLEDGEMENTS

I would like to extend my thanks and deepest gratitude to my major professor Norman G. Lederman for his support, guidance, and friendship throughout the "whole shebang." During the past three years I have learned a great deal from Norm—the countless defeats in pool at the Peacock included, probably more than I will ever realize or admit to!

I would like to extend my thanks and appreciation to my committee members, professors Paul Farber, James Krueger, Larry Flick, and Barbara Crawford for their valuable guidance and input. I would also like to thank professors Paul Farber, Mary Jo Nye, and Robert Morris for their collaboration and support. Thanks also go to all the students who took the time and effort to participate in this study.

Special thanks go to Rima and Haitham Akkary for their enduring friendship and continued support. This whole endeavor would not have been possible without Rima and Haitham's unlimited support throughout my stay in the United States. For their friendship and for countless conversations and adventures of the fifth kind, I would also like to thank Valarie Dickinson, Randy Bell, Renee Schwartz, Fehmi Karami, and Khalil Dirani.

Last but not least, I would like to thank my family in Lebanon. Thanks and gratitude go to my sisters Hiam and Hala, my brother-in-law Zuhair Al-Ahmadieh, and my nephews Samer, Ousama, Makram, Nader, and Sami for their love and support, and more importantly for understanding my being away from them during difficult and sad times.

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Dedicated to the loving memory of my brother-in-law,

Atef Ahmed Al-Kadi

He taught me a great deal and shaped many aspects of my being

And with love to my mother,

Badrieh Al-Marsi Abd-El-Khalick

Whose courage and smiles are enduring sources of hope and joy in my life

THE INFLUENCE OF HISTORY OF SCIENCE COURSES ON STUDENTS' CONCEPTIONS OF THE NATURE OF SCIENCE

Chapter I

The Problem

Introduction

The preparation of scientifically literate students is a perennial goal of science education (American Association for the Advancement of Science [AAAS], 1990, 1993). Furthermore, an adequate understanding of the nature of science (NOS) is a central component of scientific literacy (Klopfer, 1969; National Science Teachers Association [NSTA], 1982). Indeed, the objective of helping students develop adequate understandings of the NOS is "one of the most commonly stated objectives for science education" (Kimball, 1967-68, p. 110). This objective has been agreed upon by most scientists and science educators for the past 85 years (Lederman, 1992), and has recently been reemphasized in the major reform efforts in science education (AAAS, 1990, 1993; National Research Council [NRC], 1996).

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, no consensus presently exists among philosophers of science, historians of science, scientists, and science educators on a specific definition for the NOS (Lederman & Niess, 1997). This lack of consensus, however, should not be disconcerting or surprising given the multifaceted nature and complexity of the scientific endeavor. Conceptions of the NOS have changed throughout the development of science and systematic thinking about science and are reflected in the ways the scientific and science education communities have defined the phrase "nature of science" during the past 100 years (e.g., AAAS, 1990, 1993; California Department of Education, 1990; Center of Unified Science Education at Ohio State University, 1974; Central Association for Science and Mathematics Teachers, 1907; Klopfer & Watson, 1957; NSTA, 1982).

Recently, Lederman and Abd-El-Khalick (1998) have argued that many of the disagreements about the definition or meaning of the NOS that continue to exist among philosophers, historians, and science educators are irrelevant to K-12 instruction. The issue of the existence of an objective reality as compared to phenomenal realties is a case in point. Lederman and Abd-El-Khalick suggested that there is an acceptable level of generality regarding the NOS that is accessible to K-12 students and relevant to their daily lives. Moreover, at this level, little disagreement exists among philosophers, historians, and science educators. 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. These aspects of the NOS are adopted and emphasized in the present study.

The phrase "the NOS" is occasionally used in the present paper. This phrase cannot be avoided due to linguistic and grammatical considerations. It cannot be overemphasized, however, that the use of the phrase "the NOS" should not be taken to imply that there is a singular NOS or general agreement on what the phrase specifically means.

Lederman (1992), in a comprehensive review of the literature, noted that research related to the NOS has been conducted along four parallel but distinct lines. Investigators started, within the first line of research, by assessing students' conceptions of the scientific enterprise. Studies were consistent in showing that students have not acquired adequate conceptions of the NOS. This lack of understanding was attributed to the failure of curricula in fostering more adequate conceptions among students. As such, within the second line of research, several units, courses, and curricula geared toward conveying accurate conceptions of the NOS were designed, implemented, and tested. Some of these units and curricula were shown to significantly increase students' scores on instruments that assessed their conceptions of the NOS. Such efforts, however, denied the importance of the teacher. Students' gains were assumed to be independent of the teachers' understandings of the NOS. However, in later studies that controlled for variables such as pre-testing, teachers' experiences, and students' prior knowledge, the developed units and curricula were shown to give different results with different teachers. Researchers started to realize the influence of teachers' understandings, interests, attitudes, and classroom activities on student learning. Thus, researchers, within the third line of research, turned their attention toward teachers' conceptions. Studies were consistent in showing that science teachers possessed inadequate conceptions of the NOS. As such, ensuing research efforts focused on improving teachers' conceptions of the scientific enterprise.

Attempts to enhance science teachers' conceptions of the NOS were undertaken within the context of preservice teacher education programs (Akindehin, 1988; Barufaldi, Bethel, & Lamb, 1977; Carey & Stauss, 1968, 1970; Ogunniyi, 1983; Olstad, 1969; Riley, 1979; Shapiro, 1996; Trembath, 1972), inservice programs (Billeh & Hasan, 1975; Lavach, 1969; Scharmann & Harris, 1992), and undergraduate science content courses (Haukoos & Penick, 1983, 1985; Jones, 1969; Scharmann, 1990; Spears & Zollman, 1977). Generally speaking, these attempts used one of two approaches. Within the first, labeled here as an *explicit* approach, researchers (Akindehin, 1988; Billeh & Hasan, 1975; Carey & Stauss, 1968, 1970; Jones, 1969; Lavach, 1969; Ogunniyi, 1983) utilized elements from the history and philosophy of science and/or instruction geared toward the various aspects of the NOS to improve science teachers' conceptions. Within the second approach, labeled here as an *implicit* approach, researchers utilized science process skills instruction and/or scientific inquiry activities (Barufaldi et al., 1977; Riley, 1979; Trembath, 1972) or manipulated certain aspects of the learning environment (Haukoos & Penick, 1983, 1985; Scharmann, 1990; Scharmann & Harris, 1992; Spears & Zollman, 1977) in their attempts to enhance teachers' conceptions of the NOS.

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 instructional sequence in the history (or philosophy) of science is an explicit attempt to enhance learners' conceptions of the NOS, nor is every science process-skills instructional sequence or scientific inquiry activity an implicit approach to achieve that end. An instructional sequence in the history of science (HOS) can be labeled as an implicit approach if it were devoid of any discussion of one or more aspects of the NOS. Similarly, involving learners in scientific inquiry can be more of an explicit approach if the learners were provided with opportunities to reflect on their experiences from within a conceptual framework that explicates some aspects of the NOS. The basic difference between implicit and explicit approaches, it follows, lies in the extent to which learners are provided, or helped to come to grips with the conceptual tools, in this case aspects of the NOS, that would enable them to think about and reflect on the activities in which they are engaged.

Lederman (1992) noted that research concerned with improving teachers' conceptions of the NOS was guided by two assumptions. The first was that teachers' conceptions directly transfer into their classroom practices, and the second was that teachers' conceptions directly affect students' conceptions. Such assumptions, however, were not explicitly tested. Testing the first assumption was the focus of the fourth line of research. In general, this research has indicated that the relationship between teachers' conceptions of the NOS 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' conceptions of the NOS into practice (Abd-El-Khalick, Bell, & Lederman, 1998; Brickhouse & Bodner, 1992; Duschl & Wright, 1989; Hodson, 1993; Lantz & Kass, 1987; Lederman, 1995).

It is obvious that teachers cannot possibly teach what they do not understand. To be able to convey to their students appropriate conceptions of the NOS, teachers should themselves possess adequate 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 the NOS can be thought of as a necessary condition, these conceptions, nevertheless, should not be considered sufficient (Lederman, 1992). The implication for research is apparent. Research efforts, it is argued, should focus on the factors and constraints that mediate the translation of teachers' conceptions into practice, and on the effects that these practices have on students' conceptions.

Statement of the Problem

The recommendation that research efforts should focus on the factors and constraints that mediate the translation of teachers' conceptions of the NOS into classroom practice, however, is itself based on an assumption. It assumes that attempts to improve teachers' conceptions of the NOS have been "successful." That is, the teachers' resultant understandings of the NOS would enable them to convey appropriate conceptions of the scientific enterprise to their students. In other words, the assumption is that the *necessary condition has been sufficiently met.* The question that follows is: To what extent is this assumption supported by the empirical literature? This question necessitates a *critical* appraisal of the success of the various attempts and approaches undertaken to improve teachers' conceptions of the NOS.

This critical appraisal should be undertaken from the standpoint that effective teaching requires more than basic knowledge of a target topic and mastery of general pedagogical principles (Shulman, 1986, 1987; Wilson, Shulman, & Richert, 1987). To be able to effectively teach the NOS to K-12 students, science teachers need to have more than a rudimentary or superficial knowledge and understanding of various aspects of the NOS. Teachers need to know a wide range of related examples, activities, illustrations, explanations, demonstrations, and historical episodes. They should be able to comfortably discourse about the NOS, lead discussions regarding various aspects of the NOS, design science-based activities that would make those aspects accessible and understandable to K-12 students, and contextualize their teaching about the NOS with some examples or "stories" from the HOS.

Appraised against the above background, it is safe to conclude that the aforementioned attempts were *not* successful in fostering among science teachers understandings of the NOS that would enable them to effectively teach this valued aspect of science. Moreover, a critical appraisal of the approaches utilized indicates that an *explicit* approach that utilizes *elements* from the history and philosophy of science might be more effective than an implicit approach in helping science teachers develop adequate conceptions of the NOS.

A Role for HOS in Improving Teachers' Conceptions of the 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 the scientific enterprise (Gess-Newsome & Lederman, 1993; Lederman & Latz, 1995; Nordland & Devito, 1974; Stofflett & Stoddart, 1994). Science teacher education programs should continue their attempts to promote among prospective teachers more adequate conceptions of the NOS. However, given that the agendas of teacher education programs are already extensive and overly long, there is a limit to what can be done within the context of those programs.

The relative ineffectiveness of the attempts undertaken to enhance science teachers' conceptions of the NOS should not be surprising given that the durations of the treatments were very short. For the majority of those attempts, the treatments were framed within the context of science methods courses or inservice programs and typically lasted a few hours (e.g., Scharmann, 1990; Trembath, 1972) or a few days (e.g., Akindehin, 1988; Billeh & Hasan, 1975). 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 in science methods courses or inservice programs to dealing with the NOS. It is highly unlikely that prospective and practicing teachers' views of the scientific enterprise, views that have developed over the course of at least 14 years of high school 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' conceptions of the scientific endeavor undertaken within science teacher education programs need to be augmented with relevant coursework in other disciplinary departments (Bork, 1967; Brush, 1969; Matthews, 1994). *Intuitively*, coursework in the philosophy and history of science, disciplines which respectively deal with the epistemology of scientific knowledge and its development, serve as primary candidates. Indeed, many science educators have argued that coursework in the history and/or philosophy of science can serve to improve science teachers' conceptions of the NOS (Abimbola, 1983; Brush, 1969, 1989; Duschl, 1989;

King, 1991; Klopfer & Watson, 1957; Matthews, 1994; O'Brien & Korth, 1991; Robinson, 1969; Rutherford, 1964; Scheffler, 1973).

The notion that HOS can be used to "explain the meaning of science, its function, its methods, its logical, psychological and social implications" (Sarton, 1952, p. 59) is not new. During the past 70 years, science educators (e.g., Conant, 1947; Duschl, 1990; Haywood, 1927; Klopfer, 1964, 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 appropriate conceptions of the scientific enterprise.

However, despite the longevity of these arguments, and to the best of the researcher's knowledge, there is *not* one single empirical study in the science education literature that examined the influence of college level HOS courses on learners' conceptions of the NOS. Recommendations for the inclusion of HOS courses 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 of the scientific enterprise (Russell, 1981) and inferred a potentially useful role for HOS courses in improving prospective teachers' conceptions of the NOS.

Some may argue, and understandably so, that what has been stated earlier about 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' conceptions of the NOS, it may be plausible to infer that HOS can also have a similarly positive influence on learners' conceptions of the scientific enterprise. The plausibility of such an inference hinges, however, on the extent to which the attempts to include HOS in science teaching were successful in improving students' understandings of the NOS.

A review of the efforts that aimed to assess the influence of incorporating the HOS in science teaching on students' conceptions of the NOS (Klopfer & Cooley, 1963; Solomon, Duveen, Scot, & McCarthy, 1992; Welch & Walberg, 1972; Yager & Wick, 1966) indicates that evidence concerning the effectiveness of the historical approach is, at best, inconclusive. It follows that recommendations to include HOS courses in the preparation of science teachers based on inferences derived from using HOS in science teaching do not seem to be grounded in any firm empirical literature.

In this regard, interestingly enough, discussions about the effectiveness of the historical approach by its originators and reviewers brings back to light the earlier discussion about implicit and explicit approaches to improving learners' conceptions of the NOS. Klopfer (1969) notes that for the historical approach to be effective in enhancing learners' conceptions of science, "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, argues 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 the 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 the scientific enterprise.

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 seventeenth-century mechanics. Kuhn reasoned that he first needed to understand what Galileo and Newton's predecessors had known about the subject. This attempt to understand the early history of mechanics led him to Aristotle's *Physica* and ensuing writings on motion. Kuhn started by asking questions of these historical 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* [italics added]" (Kuhn, 1977, p. xi). Kuhn, however, found this to be very perplexing. After all:

> Aristotle had been an acute and naturalistic observer . . . his interpretations of phenomena had often been . . . both penetrating and deep. How could his characteristic talents have failed him so when applied to motion? How could he have said about it so many apparently *absurd* things [italics added]. (Kuhn, 1977, 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" (Kuhn, 1977, p. xii).

This short narrative serves at once to outline Kuhn's philosophical views about science and HOS, and to highlight the difficulty inherent to using HOS to acquire an understanding of the NOS. Kuhn's (1970) ideas about paradigms, their particular role in guiding scientific research, and their more general role in constituting worldviews, 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 (1970) 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 his questions of Aristotelian writings on motion—one piece of a more global and pervasive cosmology, 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 Aristotelian's. In a similar fashion, when learners are faced with historical narratives in the form of readings or lectures, they tend to ask questions of those narratives from within certain conceptual frameworks. These frameworks are mainly what the learners happen to know about the target subject *now*. As far as prospective science teachers are concerned, their frameworks of the scientific endeavor have developed over years of high school and college science and, as noted earlier, these frameworks are mainly incongruent with current conceptions of the NOS. The 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*, so do learners often dismiss historical scientific notions as *wrong* ways of explaining the natural world. As such, 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 the 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, at least, "though experience as a historian can teach philosophy by example, the lessons vanish from finished historical writings" (Kuhn, 1977, p. x). Learners are usually exposed to such finished historical products. 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 writing 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 the scientific enterprise. 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 "cap" or 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 the 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. Here, the earlier discussion of attempts to enhance science teachers' conceptions of the NOS comes into play. That discussion indicated that, within science methods courses, an *explicit* approach that utilizes *elements* from the history and philosophy of science might be most effective in helping prospective teachers develop an adequate conceptual framework of the NOS. Providing student teachers with such a framework may be a way to take advantage of the difficulty inherent to the use of the historical approach. This difficulty being that learners tend to interpret new experiences from within their own conceptual frameworks. Such a framework may serve as an alternate way of reading HOS. Prospective teachers are thus more likely to look for aspects of the NOS consistent with their view of the scientific enterprise. HOS courses can thus serve to elaborate and deepen student teachers understandings of the NOS and to enrich their framework with examples, analogies, metaphors, and stories related to the various aspects of the NOS; aspects deemed necessary to successfully teach the NOS to K-12 students. This enriched understanding *may* in turn impact those student teachers' instructional practices related to the NOS.

Another, yet less problematic aspect, is the fact that HOS is a discipline with its legitimate concerns and problems (Kuhn, 1977). It might well be the case that HOS courses are not designed to meet the needs of prospective teachers. This problem can be overcome by a concerted effort on the part of science educators and historians of science. The latter can be made aware of the needs of teachers. However, such a cooperation is usually impaired by institutional, disciplinary, and personal factors (Anderson, 1987). Again, having developed within science methods courses a conceptual framework consistent with the NOS prior to enrollment in HOS courses may help prospective teachers to direct their efforts toward those aspects that will contribute to their professional needs.

The purpose of the present study was to assess the influence of HOS courses on college students' conceptions of the NOS. The study also aimed to examine whether students, including student teachers, who entered HOS courses with a conceptual framework consistent with current conceptions of the scientific enterprise were more likely to achieve, if any, more elaborate and enriched understandings of the NOS. Additionally, the study aimed to assess what aspects, if any, of the investigated courses tended to render the courses more effective in influencing students' conceptions. Such aspects included course objectives, instructor priorities, such as the commitment to enhance learners' conceptions of the NOS, teaching approach, such as explicit attention to the NOS or striving to help students develop alternate ways of reading HOS, and classroom dynamics, such as large, lecture-oriented versus small, discussion-oriented courses. The research questions that guided the present investigation were:

1. Do HOS courses influence college students' conceptions of the 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 NOS more likely to achieve, if any, more adequate and enriched understandings of the NOS?

3. To what extent, if any, do various course aspects (e.g., course objectives, instructor priorities, teaching approach, and classroom dynamics) influence students' conceptions of the NOS?

Significance of the Study

In addition to attempting to fill an important gap in the science education literature, the results of the present study, whether positive or otherwise, will have significant implications for the preparation of science teachers. If HOS courses do influence students' conceptions of the NOS, then recommendations for the inclusion of HOS courses in the preparation of science teachers will gain some support in the empirical literature. If not, then such recommendations need to be reexamined in light of more research on the use of the historical approach in enhancing learners' conceptions of the NOS.

Alternatively, if students who enter HOS courses with a conceptual framework consistent with current conceptions of the NOS tend to gain more adequate and enriched conceptions of the scientific enterprise, then this result has implications for the sequencing of coursework related to the NOS. For instance, it might prove more appropriate for the needs of science teachers to enroll in science methods courses that explicitly attempt to challenge their misconceptions of the NOS prior to enrollment in HOS courses. Finally, the present study will hopefully generate more interest in a much needed area of investigation concerning the role of history of science in college science teaching in particular, and in developing scientific literacy in general.

Chapter II

Review of the Literature

Introduction

Science educators and major science education organizations are increasingly advocating the preparation of scientifically literate students (e.g., AAAS, 1990, 1993; NRC, 1996). The notion of scientific literacy is difficult to define with any specificity (Shamos, 1995). Nevertheless, in general terms, scientific literacy refers to one's understanding of the concepts, principles, theories, and processes of science, and one's awareness of the complex relationships among science, technology, and society. Additionally, a scientifically literate person should possess adequate understandings of the nature of science (NOS). Finally, a scientifically literate person should be able to apply the aforementioned knowledge and understandings of science to decisions concerning science-related personal and societal issues (Klopfer, 1969; NSTA, 1982).

Lederman (1992) traced the call for helping students develop adequate conceptions of the NOS to 1907 by the Central Association of Science and Mathematics Teachers. Lederman noted that most scientists and science educators have agreed upon this objective for the past 85 years. By the early 1960s "one of the most commonly stated objectives for science education [was] the attainment of an understanding of the nature of science" (Kimball, 1967-68, p. 110). Presently, and despite their varying pedagogical or curricular emphases, agreement among the major reform efforts in science education (AAAS, 1993; NRC, 1996) seems to center around the goal of enhancing students' conceptions of the NOS. In fact, "the longevity of this educational objective has been surpassed only by the longevity of students' inability to articulate the meaning of the phrase 'nature of science,' and to delineate the associated characteristics of science" (Lederman & Niess, 1997, p. 1).

NOS

The phrase "nature of science" has typically been used to refer 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). These characterizations, nevertheless, remain fairly general and no consensus presently exists among philosophers of science, historians of science, scientists, and science educators on a specific definition for the NOS. This lack of consensus, however, should not be disconcerting nor surprising given the multifaceted nature and complexity of the scientific endeavor. The NOS is a tentative construct in the same manner that scientific knowledge is necessarily tentative. Conceptions of the NOS have changed throughout the development of the scientific enterprise and its various disciplines. These changes have been reflected in the ways the scientific and science education communities have defined the phrase "nature of science" during the past 100 years.

Lederman (1992) noted that during the early 1900s, understanding the NOS was equivalent to understanding "the scientific method." The 1960s witnessed an emphasis on inquiry and science process skills (e.g., observing, hypothesizing, inferring, interpreting data). By the 1970s a shift in the definition of the nature of scientific knowledge was apparent. The Center of Unified Science Education at Ohio State University (1974) characterized scientific knowledge as being tentative (subject to change); public (shared); replicable; probabilistic (predictions based on scientific knowledge are never absolute); humanistic (reflects human attempts to impose order on nature); historic (past knowledge should be judged in its historical context and should not be compared to contemporary conceptions); unique (has its own set of rules and values); holistic (internally consistent); and empirical (based on and/or derived from observations of the natural world). The NSTA (1982) advanced that an adequate understanding of the NOS entails an understanding of the empirical and tentative nature of scientific knowledge, and an appreciation of the central role of theory and inquiry in science. More recently, in defining the NOS, the California Department of Education (1990) emphasized the uniqueness and openness of the scientific enterprise. It also emphasized that science depends on evidence but that scientific activities are theory-driven and that scientists conduct their investigations from within certain frameworks of reference. The AAAS (1990) outlined three basic components that underlie an adequate understanding of the NOS. The first is viewing the world as understandable, and yet understanding that science cannot provide answers to all questions. The second component relates to the nature of scientific inquiry. It entails understanding that although inquiry in science relies on logic and is empirically based, it nevertheless involves imagination and the invention of explanations. The third component emphasizes an understanding of the social and political aspects of science.

Recently, it has been argued that most of the disagreements about the definition or meaning of the NOS are irrelevant to K-12 instruction (Lederman & Abd-El-Khalick, 1998). Lederman and Abd-El-Khalick argued that:

> The disagreements that continue to exist among philosophers, historians, and science educators are far too abstract for K-12 students to understand and far too esoteric to be of immediate consequence to their daily lives. For example, the notion of whether there is an objective reality or only mental constructions is, perhaps, only of importance to the graduate student in philosophy. There is, however, an acceptable level of generality regarding the NOS that is accessible to K-12 students and also relevant to their daily lives. It is at this level of generality that connections can be seen between students'/citizens' knowledge about science and decisions made regarding scientific claims. It is also at this level of generality that little disagreement exists among historians, philosophers, and science educators. (p. 4)

They further stated that 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) necessarily involves human inference, imagination, and creativity, and (e) is socially and culturally embedded. These aspects of the NOS were adopted and emphasized in the present study.

The phrase "the NOS" was occasionally used in the present paper. This phrase cannot be altogether avoided totally due to linguistic and grammatical considerations. It should be emphasized, however, that the use of the phrase "the NOS" should not be taken to imply that there is a singular NOS or a general agreement on what the phrase specifically means.

Research on the NOS

The NOS has been the subject of intensive research during the past 40 years. Lederman (1992) presented a comprehensive review of this research. He claimed that research related to the NOS has been conducted along four parallel but distinct lines.

Assessment of student conceptions of the NOS.

Given the interest in helping students develop adequate understandings of the NOS, it was only natural that investigators, within the first line of research, started by assessing students' conceptions of the scientific enterprise. Results were consistent regardless of the assessment instruments used in individual studies. Research has shown that "students typically have *not* acquired a valid understanding of what is meant by the nature of science [italics in original]" (Kimball, 1967-68, p. 110). For example, students thought that scientific knowledge was absolute, that scientists' main concern was to collect and classify facts in order to uncover natural laws, and that hypotheses can be proven true. In addition, students had inadequate understandings of the role of creativity in science, the role of theories in guiding research, the differences between experimentation, models, hypotheses, laws, and theories, as well as inappropriate understandings of the interrelations and interdependence of the different branches of science. Lederman (1992) stated that such conceptions were attributed to a lack of knowledge of these issues even among the most capable students and those most interested in science. Researchers thus reasoned that curricula were not successful in imparting such knowledge, and this initiated the second line of research.

Development and assessment of curricula designed to enhance student conceptions of the NOS.

Research efforts to design, implement, and test curricula aimed at conveying accurate conceptions of the NOS began. Several units, courses, and curricula geared toward this end were shown to significantly increase students' scores on posttests that assessed students' conceptions of the NOS. These curricula utilized the history and philosophy of science and/or instruction that emphasized the NOS to foster adequate conceptions among students. *History of Science Cases for High Schools* developed by Klopfer and Cooley (1963) and *Harvard Project Physics Course* developed by Rutherford et al. (1970) were examples of such curricula. Such efforts, however, denied the importance of the teacher as a variable. Researchers concluded that students' gains were independent of the teachers' understandings of the NOS. The assumption was that when given the "right" curricula, appropriate materials, and when shown how to use them, teachers would be successful in helping students develop conceptual understandings of the NOS.

Later studies, however, came to cast doubt on such results and conclusions. When variables such as pre-testing, teachers' experience, and students' prior knowledge were controlled for, ambiguous results emerged. The developed units and curricula seemed to give different results with different teachers. Researchers started to realize the role of teachers as the main intermediaries of the science program (Brown & Clarke, 1960). More studies came to support the claim that teachers' understandings, interests, attitudes, and classroom activities influence student learning to a large extent (Merill & Butts, 1969; Ramsey & Howe, 1969). This turned attention toward teachers' conceptions and initiated the third line of research.

Assessment of and attempts to improve teachers' conceptions of the NOS.

Studies were consistent in showing that science teachers possessed inadequate conceptions of the NOS. A significant proportion of teachers, for example, believed that scientific knowledge is not tentative (Lederman, 1992). Many others still held a positivistic, idealistic view of science (Pomeroy, 1993). The concern with the primacy of teachers' conceptions of the NOS was gaining more attention:

> Regardless of the curriculum materials being developed and "used" in the teaching process, the teacher continues to play the key role in instruction. If the teacher's understanding and philosophy of science is not congruent with the current interpretations of the nature of science . . . then the instructional outcomes will not be representative of science. (Carey & Stauss, 1970, p. 366)

As such, within this third line of research, science educators turned their attention toward improving science teachers' conceptions of the NOS.

Attempts to enhance science teachers' conceptions of the scientific enterprise started with an examination of the effects of summer institutes and Academic Year Institutes funded by the National Science Foundation (NSF) on teachers' conceptions of the NOS (Gruber, 1960, 1963; Welch & Walberg, 1967-68). These initial assessments of the influence of existing programs were followed by attempts to examine the background and academic variables related to teachers' understandings of the NOS (Carey & Stauss, 1969; Kimball, 1967-68; Scharmann, 1988a, 1988b; Wood, 1972). Teachers' conceptions were found to be independent of virtually all the investigated variables. Intervention studies aimed to improve prospective and practicing science teachers' conceptions of the NOS followed and were undertaken within the context of preservice teacher education programs (Akindehin, 1988; Barufaldi, Bethel, & Lamb, 1977; Carey & Stauss, 1968, 1970; Ogunniyi, 1983; Olstad, 1969; Riley, 1979; Shapiro, 1996; Trembath, 1972), inservice programs (Billeh & Hasan, 1975; Lavach, 1969; Scharmann & Harris, 1992), and undergraduate science content courses (Haukoos & Penick, 1983, 1985; Jones, 1969; Scharmann, 1990; Spears & Zollman, 1977).

Generally speaking, these studies used one of two approaches. Researchers who adopted the first approach (Akindehin, 1988; Billeh & Hasan, 1975; Carey & Stauss, 1968, 1970; Jones, 1969; Lavach, 1969; Ogunniyi, 1983) utilized *elements* from the history and philosophy of science and/or instruction geared toward the various aspects of the NOS to improve science teachers' conceptions. This approach, labeled here as an *explicit* approach to improving teachers' understandings of the NOS, was advanced by educators such as Billeh and Hasan (1975), Hodson (1985); Kimball (1967-68), Klopfer (1964), Lavach (1969), Loving (1991), Matthews (1994), O'Brien and Korth (1991), Robinson (1965), and Rutherford (1964).

The second approach, advocated by science educators such as Gabel, Rubba, and Franz (1977), Haukoos and Penick (1983, 1985), Lawson (1982), and Rowe (1974), suggested that an understanding of the NOS is a learning outcome that can be facilitated through process skill instruction, science content coursework, and "doing science." This approach was labeled here as an *implicit* approach to improving teachers' understandings of the NOS. Researchers who adopted this implicit approach utilized science process skills instruction and/or scientific inquiry activities (Barufaldi et al., 1977; Riley, 1979; Trembath, 1972) or manipulated certain aspects of the learning environment (Haukoos & Penick, 1983, 1985; Scharmann, 1990; Scharmann & Harris, 1992; Spears & Zollman, 1977) in their attempts to enhance teachers' conceptions of the NOS.

Relationships among teachers' conceptions and classroom practice: Necessary and sufficient conditions.

Lederman (1992) noted that research concerned with improving teachers' conceptions of the NOS was guided by two assumptions. The first was that teachers' conceptions directly transfer into their classroom practices, and the second was that teachers' conceptions directly affect students' conceptions. Such assumptions, however, were not explicitly tested. This was the focus of the fourth line of research.

In general, this research has indicated that the relationship between teachers' conceptions of the NOS 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 conceptions of the NOS into practice. The constraining factors that have been reported include pressure to cover content (Abd-El-Khalick et al, 1998; Duschl & Wright, 1989; Hodson, 1993), classroom management and organizational principles (Abd-El-Khalick et al., 1998; Hodson, 1993; Lantz & Kass, 1987; Lederman, 1995), concerns for student abilities and motivation (Abd-El-Khalick et al., 1998; Brickhouse & Bodner, 1992; Duschl & Wright, 1989; Lederman, 1995), institutional constraints (Brickhouse & Bodner, 1992), and teaching experience (Brickhouse & Bodner, 1992; Lederman, 1995). Additionally, in the case of preservice teachers, other factors have been identified. These factors included discomfort with understandings of the NOS, the lack of resources and experience for teaching and/or assessing understandings of the NOS, and constraints specific to student teaching, especially those imposed by cooperating teachers (Abd-El-Khalick et al., 1998).

It is obvious that teachers cannot possibly teach what they do not understand. To be able to convey to their students appropriate conceptions of the NOS, teachers should themselves possess adequate 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 the NOS can be thought of as a *necessary* condition, these conceptions, nevertheless, should not be considered as *sufficient* (Lederman, 1992). The implication for research is apparent. Research efforts, it is argued, should focus on the factors and constraints that mediate the translation of teachers' conceptions of the NOS into classroom practice. This latter recommendation, however, is itself based on an assumption. It assumes that attempts to improve teachers' conceptions of the NOS have been "successful." In other words, the assumption is that the aforementioned *necessary condition has been sufficiently met*. The question that follows is: To what extent is this assumption supported by the empirical studies that attempted to improve teachers' conceptions of the NOS? In an attempt to answer this question, the following section presents a critical review of the various attempts undertaken to enhance science teachers' conceptions of the NOS.

Success of the Attempts and Approaches to Improve Teachers' Conceptions of the NOS: A Critical Appraisal

The 25 studies reviewed below were organized into five sections that were intended to reflect, more or less, the temporal progression of the attempts to enhance science teachers' conceptions of the NOS.

The Influence of NSF Institutes on Teachers' Conceptions of the NOS

As early as 1960 it was evident that teaching the NOS requires that science teachers possess adequate understandings of the scientific enterprise (Rutherford, 1964). Research on teachers' conceptions of the NOS, however, has shown that teachers lack such understandings (e.g., Anderson, 1950; Behnke, 1961). The need to enhance teachers' understandings became apparent. It was natural that researchers started with assessing the influence of existing programs on science teachers' conceptions of the NOS. The three studies reviewed in this section examined the effectiveness of Academic Year Institutes (AYI) and summer institutes funded by the NSF in fostering adequate views of the NOS among science teachers.

Gruber (1960) noted that the AYI program provided high school science and mathematics teachers (referred to as Fellows) with stipends for one year of advanced university training. This training, Gruber continued, focused mainly on the content of science and mathematics rather than on teaching methods. The institutes were conducted throughout the United States and their number grew from two in 1956 to about 32 in 1960.

The purpose of Gruber's (1960) study, although not clearly articulated in the report, was to "evaluate the methods and effects" of the 1957-58 AYI at the University of Colorado (p. 467). The evaluation was conducted by the University's Behavior Research Laboratory. Neither the focus of the evaluation nor the research question(s) were provided. However, later in the report, the author noted that helping teachers to develop an understanding of the "general character of science" was among the faculty's envisioned goals for the institute (Gruber, 1960, p. 468).

The sample comprised 54 high school science and mathematics teachers enrolled in the University AYI. Participants came from different parts of the United States. Their ages ranged from 25 to 48 years with a median of 32 years and their teaching experience ranged from 3 to 15 years with a median of seven years. The participants' studies in education ranged from 5 to 69 semester hours with a median of 27 hours and their coursework in science and mathematics content ranged from 19 to 106 semester hours with a median of 55 hours. The Fellows were described as a group of "mature, intelligent and experienced teachers" with "mediocre but not unusually poor" training in science and mathematics (Gruber, 1960, p. 467). It should be noted that the present study dealt with the participants as a single group. Descriptions of the sample and further discussions did not distinguish between science and mathematics teachers. For instance, it was not possible to know the number of participant science or mathematics teachers and the extent to which those teachers differed in their academic preparation in science and mathematics content. Such information would prove crucial in interpreting the results of the present study.

The research design was not clearly presented and procedures were, at best, poorly delineated. Two instruments were used to assess participants' understanding of the NOS. The first was a test of knowledge of the history of science. The test comprised eight sets of three scientists' names. Teachers were asked to put the names in each set in chronological order. The names in each set (e.g., Copernicus, Galileo, Newton) were chosen such that knowledge of the scientists' contributions, rather than the specific periods in which they lived, would suffice to figure out the order. The test then asked the teachers to match the scientists' names with their major contributions. The level of "adequate" performance on the test was determined by four of the institute faculty members. No evidence regarding the validity of this "adequate level" was provided. It was not clear from the report whether this instrument was administered as a pre- and posttest or whether it was given only at the conclusion of the institute. The second instrument assessed the participants' views of the philosophy of science prior to and at the conclusion of the institute. The instrument aimed to document "signs of growth of appreciation and grasp of problems" related to the philosophy of science (Gruber, 1960, p. 467). The number of questions on the instrument, their format or the assessment criteria were not provided. Only one question was presented as an example. This question furnished the participants with a set of terms (e.g., mountains, genes, trees, gravity) and asked them to decide whether these terms referred to conceptual inventions or observable physical realties. It should be noted that any evidence for validity or reliability in the case of both instruments was not provided. This casts serious doubts on the results and conclusions of the present study.

Evidence for the participants' understandings of the NOS was also derived from their "teaching performances." These were half-hour talks that the Fellows gave about teaching certain topics of their choice to high school students. These performances were also used to assess the participants' ability "to teach students . . . about the way in which scientific progress is achieved" and were given by a "representative group of Fellows" (Gruber, 1960, p. 468). No information was provided regarding the manner in which this "representative group" was selected, the number of teachers who delivered talks or performances, the number of these performances and their sequence within the institute, or the instrument or protocol used to assess teachers' performances.

On the history of science test, 92% of the teachers performed below the adequate level. For example, of the 52 teachers who took this test, only 13 knew that Darwin came after Linnaeus and Lamarck. As far as the philosophy of science was concerned, participants' views were initially inconsistent and very little change was detected in these views as a result of participating in the institute. The pretest and posttest medians for the philosophy of science questionnaire were equal. No further data on the pre- or posttest scores were provided.

Nevertheless, some changes in the Fellow's views were noted. For instance, while seven more participants viewed "genes" as conceptual inventions on the posttest, seven more saw "photons" as physical entities. Moreover, most participants abandoned the view that mathematical axioms are self-evident truths and adopted the view that they are arbitrary conventions. In this respect the author noted that, although some faculty dealt with a few philosophical issues, these issues were not emphasized in any manner that would allow growth in teachers' understandings of philosophy. The author continued that the few changes in teachers' views on philosophical issues that were observed, however, indicated that growth can be induced given specific attention to the issue.

Regarding the "teaching performances," participants focused on the facts and principles of science and mathematics. They paid little attention, if any, to the "way in which scientific thinking unfolds" or to "the history leading up to a scientific discovery and the consequences of such a discovery" (Gruber, 1960, p. 468).

It should be emphasized that the above results, as mentioned earlier, were not discussed for science and mathematics teachers separately. It is doubtful that science and mathematics teachers' knowledge of science content, its history or philosophy, and its teaching are not appreciably different. Consequently, given the lack of information in this regard, it was difficult to tell the extent to which the results reported for the history of science test, the philosophy of science questionnaire, and the teaching performances were biased by the knowledge or lack thereof of these topics by the participant mathematics (or science) teachers. However, the author concluded that there was every indication that "little if any progress was made in the development of [participants'] general understanding of the nature of scientific knowledge" (Gruber, 1960, p. 467).

The author noted that the program was successful in certain respects. The participants made "good academic progress" as was evident by achieving an average grade of *B* on all their courses (Gruber, 1960, p. 467). It was not clear, however, whether the participants were pre-tested on their content knowledge. The author failed to explain how "academic progress" was assessed. The participants were also satisfied with their studies. They assigned the program an average rating of 5.5 on a seven-point scale. However, no information was provided regarding the validity or reliability of the instrument used to assess teachers' attitudes toward the institute.

Despite these "successes," the program faced some difficulties. These included the participants' disorientation engendered by changing their status from teacher to student, and their desire to focus on teaching methods rather than on the content of science and mathematics which were emphasized by the program. However, the major problem of the program was the tension between focusing on specific subject matter versus emphasizing the general character of scientific knowledge. Gruber (1960) noted that the institute's preoccupation with covering specific content resulted in its "failure to transmit attitudes and information relevant to teaching science, not only as a body of knowledge, but as a way of thinking" (p. 467). In this respect, Gruber concluded that the institute's failure to achieve this goal was the result of a flawed assumption: "The working assumption of the institute . . . was that if subject matter is adequately taught, other things will take care of themselves. The main conclusions of the evaluation group is that such an assumption is at best questionable" (p. 468).

Thus, as early as 1960, Gruber realized that the assumption that science teachers would learn about the NOS by learning science content was not valid. He noted that science teachers should be helped to understand not only *what* scientists know, but *how* scientists develop this knowledge. Otherwise science teachers will only focus on the technological fruits of science and neglect the intellectual and cultural aspects of science as an activity closely associated with developing an understanding of and an appreciation for the natural world.

In another study, Gruber (1963) assessed the impact of nine AYIs on Fellows' understandings of the NOS. In this study, Gruber aimed to test the validity of his earlier conclusion regarding the 1957-58 AYI at the University of Colorado. This earlier institute, as noted before, failed "to transmit attitudes and information relevant to teaching science . . . as a way of thinking" (Gruber, 1960, p. 467). The specific research question(s) for the present study were not provided. However, the criterion variable was defined as "the extent to which science teaching emphasizes science as a way of thought" (Gruber, 1963, p. 124).

In April 1959 "sample teaching outline" tasks and complementary questionnaires were mailed to all 15 AYIs that were conducted in 1958-59. Respondents were 314 Fellows from nine institutes. The sample comprised about 70% of the Fellows in these nine institutes. The median age of the respondents was 32.5 years with 68.5% in the 25-35 year group. The median number of their years of teaching experience was 5.8 with 66.6% in the 2-7 year group. The participants' median number of science and mathematics semester hours prior to joining the AYIs was 56.8 hours with 68.5% in the 30-80 semester hours group. About 22% of the respondents had 80 semester hours in science and mathematics. Contrary to his 1960 study in which data obtained from science and mathematics teachers were pooled for analysis, Gruber (1963) only analyzed the tasks and questionnaires completed by the 202 science teachers in the sample.

Gruber (1963) claimed that "all in all, . . . the 314 Fellows and the nine responding institutions are quite representative of the 15 programs in operation in 1958-59" (p. 124). Gruber, however, did not provide evidence that the responding institutes were representative of all operating AYIs especially in terms of instructional emphases and program orientations. Such emphases, as will shortly become clear, were used as correlates in deriving those factors that accounted for participants' gains in developing understandings of science as a way of knowing. Furthermore, Gruber did not provide any data regarding the total number of Fellows in each of the respondent institutes and the number of respondents per institute. As such, even though the sample represented 70% of all the Fellows in the nine institutes, the number of respondents from one or more institutes might have been fairly small. Additionally, data analysis only included 202 of the 314 respondents. Again, Gruber provided no data to show that the 102 excluded Fellows (32% of all respondents) did not compromise the claimed "representativeness" of his sample. All this, in addition to the fact that responses were volunteered, cast doubt on Gruber's assertion that the 314 (or 202!) Fellows were representative of the larger population. Any decision in this regard cannot be made given the lack of relevant data.

The present study surveyed a group of AYI participants toward the end of their programs. Two instruments were used in collecting data. The first was a "sample teaching outline" task that asked respondents to prepare an outline for a half-hour talk on a topic of their choice to be presented to high school students. The outline was to be written such that it can be used by another teacher. The respondents, however, were not asked to write the actual talk they planned to deliver. The resulting "sample teaching outlines" were used to measure the criterion variable (the extent to which science teaching emphasizes science as a way of thought). It should be noted that this task was modeled after the "teaching performance" task used in the previous study (Gruber, 1960). However, contrary to the earlier study, the Fellows' actual teaching was not observed in the present one. As such, it seemed more likely that the researcher was assessing the respondents' conceptions of science and science teaching rather than their actual teaching. Additionally, the researcher had no control over the administration of the task. This might have introduced several intervening variables (e.g., time and seriousness devoted to accomplishing the task, consulting other teachers or texts, etc.) that seem to be difficult to control for or to take into account.

The second instrument was a questionnaire to be filled out after the completion of the sample teaching outline task. The nature of the questionnaire (open ended, short answer, Likert-type, etc.) was not explicated, nor was any evidence for its validity or reliability provided. The questionnaire aimed to collect demographic and background data about the respondents. It also asked respondents about the goals, teaching methods, and instructional emphases of their institutes. Responses were used to derive the AYIs' program characteristics. These included the instructional emphases of, and time devoted to various educational activities. These activities were classified as emphasizing passive-receptive learning, active Fellow participation, or independent study. As the nature of the questionnaire was not clarified, it was difficult to judge whether the program characteristics were provided as choices on the questionnaire or whether they were derived from the Fellows' responses. If the latter was the case, the researcher made no attempt to clarify how these characteristics were defined or derived. Additionally, it was not clear how the characteristics for a certain institute were decided upon especially in case its Fellows had different perceptions of their institute's instructional emphases or the time devoted to each type of educational activity. Finally, given the self-report nature of the responses and the fact that the information provided by the questionnaires were not validated by reference to other data sources (e.g., institute directors' perceptions of the instructional emphases in their programs and the time devoted to each instructional sequence) might impinge on the validity of the conclusions derived from the study.

Data analyses were better articulated than other aspects of the study. Of the 314 outlines returned, only 202 that dealt with science teaching were rated on the extent to which they presented science as a way of thought. This was because the rater was not proficient in mathematics and the rating scheme did not lend itself to analyzing outlines that dealt with mathematical topics. The ratings were blind as to the Fellows' institutional memberships. Two four-point rating scales were used in analyzing the outlines. The first focused on "science as thought." On this scale, the respondent was assigned a zero if his/her outline presented science as a body of facts. A score of three was assigned to an outline that presented science "as a way of studying, of investigating and of viewing things [with] attention to theory, uncertainty, development, leading to information or comparison of ideas or approaches" (Gruber, 1963, p. 125). The second scale assessed the "historical orientation" of the outline. An outline that gave no attention to the background of the information presented was assigned a zero. A score of three was assigned to outlines that traced the development of the ideas it presented either by following the procedures of a single scientific investigation or by relating the efforts of several such investigations. The author claimed that the reliability of the scheme was established by having another rater score 43 outlines on the two scales. It was not clear why 43 outlines were used in the process and whether these were randomly selected from among the 202 available outlines. The ratings were reduced to a 2 x 2 contingency table and chi-square values were computed to assess the agreement between the two raters. For the "science as thought" scale a chi-square value of 13.7 was computed ($p < 0.001$). The chi-square value for the "historical orientation" scale was 14.2 ($p < 0.001$). The rating scheme reliability was thus judged to be good. It should be noted, however, that this procedure does not establish the reliability of the rating scheme. It merely establishes inter-rater agreement indicating that the two judges gave similar ratings to the analyzed outlines.

Although correlation coefficients were not reported, Gruber (1963) noted that the ratings on the two scales were highly correlated. The outlines were thus divided into three categories reflecting negligible, moderate, or strong emphasis given to "science as a way of knowing." Percentages of respondents that fell in each category were then reported by subject matter (biology, physics, chemistry, and miscellaneous including general science, geology, psychology, etc.). Overall, 25% of the Fellows rated as "strong" in their emphasis on science as a way of knowing, while 60% neglected this aspect of science. There were generally no relations between subject matter and the emphasis given to the NOS. The author thus concluded that "high school teachers generally approach science teaching as a matter of conveying science as established facts" (Gruber, 1963, p. 127). However, in light of the problematic nature of the author's claim regarding the representativeness of the sample, this generalization seems unwarranted. The data in the present study might support conclusions regarding the 202 respondents whose teaching outlines were analyzed. And as noted earlier, any conclusion about the respondents' teaching is not justified given the fact that their teaching was not observed. At best, the study indicated that the 202 respondents failed to perceive science as a way of knowing.

Gruber (1963) noted that responses to the questionnaire showed that the institutes emphasized science content knowledge rather than science teaching methods. The

Fellows felt that the institutes should place more emphasis on the latter aspect. These results were comparable to those reported in the previous study (Gruber, 1960).

To assess the possible relationships among the AYIs' program characteristics, the Fellows' backgrounds, and their emphasis on science as a way of knowing, Gruber (1963) ranked the institutes according to seven variables. These were: (a) mean percent time devoted to passive-receptive educational activities, (b) mean percent time devoted to independent study, (c) mean percent time devoted to active-participatory educational activities, (d) percent of Fellows whose individual study programs mostly comprised elective courses, (e) mean hours per week dedicated to academic work, (f) median semester hours of science and mathematics before joining an AYI, and (g) the percent of Fellows in each institute that ranked "strong" in their emphasis on science as a way of knowing. The researcher then conducted rank-order correlations between all pairings of the seven variables. In this procedure, Gruber appropriately used the institute as the unit of analysis ($N = 9$).

The analysis revealed a relatively high correlation ($r = 0.700$, $p < 0.05$) between the criterion variable and the time devoted to educational activities classified as active-participatory. Also a moderately high correlation ($r = 0.688$, $p < 0.05$) was found between the criterion variable and the extent to which the Fellows' programs comprised elective courses. The author noted that programs that ranked high in using seminars and laboratory work and which allowed its Fellows more freedom in choosing their courses ranked high on the criterion variable, while those that emphasized lectures and provided Fellows with packaged program courses ranked low. The author thus concluded that "training programs stressing active participation by the Fellows may lead to an approach to science teaching in which science is treated as a way of thought . . . [while those] . . . stressing passive-receptive teaching methods do little to alter this approach" (Gruber, 1963, p. 1963). These conclusions of possible cause-effect relationships were not warranted given the correlational nature of the study. Moreover, inferences regarding gains in Fellows' emphasis on the NOS as a result of participating in the AYIs were not justified given the fact that those Fellows were only post-tested at the conclusion of their programs. The study did not account in any manner for the Fellows' understandings of science prior to joining the institutes.

Moreover, in concluding that participation in laboratory and similar activities may improve teachers' views of science as a way of knowing, Gruber (1963) harbored an implicit bias. The author based his conclusion on the assumption that one learns about the NOS by doing science. This bias was evident in Gruber's interpretation of another finding which he labeled "surprising." There was a significant, moderate and negative correlation ($r = -0.400$, $p < 0.05$) between the criterion variable and time devoted to independent study (e.g., master's thesis research). Rather than suggesting a possible inverse relation or the lack of a relation between doing research and developing understandings of the NOS, the author was quick to offer an alternative interpretation. He concluded that this "surprising" result may be due to the fact that the Fellows' research was in the domain of education rather than science proper. He continued that Fellows might not have been able to derive the desired benefits from doing research given all the academic work they were undertaking. The author made this latter conclusion even though evidence of a strong correlation between time devoted to independent study and time per week devoted to academic work was lacking. In fact only a low, insignificant correlation ($r = 0.267$, $p > 0.05$) between these two variables was reported.

In addition, there was a relatively high negative correlation ($r = -0.783$, $p < 0.05$) between emphasizing science as a way of thought and time per week spent on academic work. And despite of the correlational nature of the study, the author suggested that the amount of academic work might affect performance on the criterion variable. The author noted that busy academic work might deprive Fellows the time needed for thoughtful reflection on and discussion of science. The author also reported that Fellows with less than seven years of teaching experience did better on the criterion variable. However, no data to support this claim was presented.

In his previous study, Gruber (1960) concluded that learning science content did not improve teachers' understanding of the NOS. He continued that teachers should be specifically helped to develop an understanding of *how* scientific knowledge is generated. Nevertheless, despite the fact that there were no indications that any of the AYIs in the present study targeted teaching the Fellows about the NOS, Gruber (1963) did not make a similar recommendation. Instead he suggested that teachers' views of science as a way of knowing can be improved through doing science-based activities.

Welch and Walberg (1967-68) noted that between 1953 and 1966 the NSF sponsored about 3500 summer institutes designed to enhance the subject matter competence of secondary school science and mathematics teachers. The authors continued that studies that aimed to systematically assess the success of such institutes were few. Moreover, most of these studies focused on the subjective reactions of teachers attending the institutes. Thus, the aim of the present study was to measure science teachers' gains in: (a) subject matter knowledge, and (b) general understanding of scientific methods and processes as a result of participating in summer institutes that focused on physics. The present review was mainly concerned with the latter research question.

The selection of the institutes was based on several criteria. Single-summer, six-week institutes that did not start prior to June 27, 1966 and that were exclusively designed for physics teachers were eligible for study. The authors did not articulate the logic underlying these criteria. Of the 31 institutes offered in the summer of 1966, 8 met the selection criteria. Of those, five institutes representing different geographical locales throughout the United States were selected. Only four institutes with a total of 162 physics teachers agreed to participate in the study. The authors made no claims concerning the representativeness of these institutes. No description of the institutes' instructional activities or emphases were provided. Moreover, the authors furnished no information whatsoever about the participant teachers.

Teachers were pre- and post-tested with a battery of three instruments administered during the first and last days of the institutes. The instruments were administered by the institutes' directors. The first was a multiple-choice test designed to assess teachers' knowledge of physics content. The other two instruments aimed to assess teachers' understanding of scientific methods and processes. The first was the *Test on Understanding Science* (TOUS). The TOUS was developed by Cooley and Klopfer (1961) to assess high school students' understandings of the scientific enterprise, scientists, and the aims and methods of science. The TOUS comprises 60 four-option multiple-choice items. Welch and Walberg (1967-68) did not provide evidence regarding the validity of the TOUS in assessing science teachers' understandings of the NOS science despite the fact that the instrument was originally validated with a sample of high school students. The authors, however, used the Kuder-Richardson 20 (KR-20) formula to calculate the instrument's reliability using the scores obtained from their sample. They reported a reliability coefficient of 0.87.

The Welch *Science Process Inventory* (SPI) (Welch, & Pella, 1967-68) was the second instrument used to assess teachers' understandings of the NOS. The SPI aims to measure understandings of the methods and processes of science. The instrument was originally validated with a sample of research scientists from various disciplines. The Form T used in the present study was an adapted version of the original and longer Form D. The SPI Form T comprises 87 agree/disagree type question. The authors noted that the instrument "was considered to be appropriate for teachers" (Welch & Walberg, 1967-68, p. 107) but provided no evidence to support this claim. The instrument's KR-20 reliability coefficient for the sample in the present study was 0.88.

One-tailed t-tests were used to assess the significance of the gain scores on each of the three instruments. The authors did not provide any evidence that the t-test assumptions of normal distribution and homogeneity of variance were met by the research sample. The authors argued that one-tailed tests were used because there was no intention to compare the relative effects of the four institutes (labeled A, B, C, and D). This justification, however, was not completely valid. It provided no basis for an *a priori* directionality of the t-tests that would justify the use of one-tailed tests. It should be noted that compared to two-tailed tests, one-tailed t-tests have more statistical "power." As such, significance can be achieved with smaller gain scores than would be required were two-tailed t-tests used in the analysis (Gall, Borg, & Gall, 1996). The t-tests were carried out for each institute separately. In the analyses reported, the authors used teachers within a certain institute as the unit of analysis. However, given the fact that each institute was an intact entity, the proper unit of analysis would be the institute rather than the individual teacher. The sensitivity of t-tests increases with sample size, as such the larger the sample the more likely that the test would pick up significant differences when such differences do not actually exist (Ramsey & Schafer, 1997). As such, by using the teacher as the unit of analysis (the four institutes A, B, C, and D had 35, 49, 39 and 30 teachers respectively), the researchers were more likely to end up with statistically significant gains in participants' scores. Such gains might have turned out to be non-significant were the proper unit of analysis used ($N = 4$). All this, coupled with the inappropriate use of one-tailed tests, cast serious doubts on the conclusions of the present study.

Teachers in all four institutes showed significant gains ($p < 0.005$) on the physics content knowledge test. The mean posttest scores, nevertheless, varied among the four institutes. The authors concluded that the objective of enhancing teachers' content knowledge was achieved. Welch and Walberg (1967-68), however, did not comment on the practical significance of the reported gains. Out of 40 possible points on the physics content knowledge test, the gains ranged from 2.31 to 4.48 points. The gains thus ranged from 6 to 11 percentage points.

The TOUS gain scores were also significant for three institutes (A at the 0.05 level, and B and D at the 0.005 level). The authors concluded that these institutes were successful in improving teachers' conceptions of the NOS. However, a closer look at the results raised serious doubts about the meaningfulness of this conclusion especially in light of the fact that the practical significance of the reported gains was completely ignored by the researchers. For instance, teachers in institute B achieved the largest mean gain score (the pre- and posttest mean TOUS scores were 44.25 and 47.47, respectively). Out of 60 possible points on the TOUS, this gain (+3.22), however, turns out to be very small (about 5 percentage points). More importantly, this gain was very small when compared to the value of the standard deviations for the pre- and posttest mean TOUS scores (9.36 and 5.97, respectively). This trend was characteristic of the remaining results. As such, if the cautions noted earlier regarding the statistical significance of the results were put aside, the practical significance of the reported results would still have to be considered with extreme skepticism.

The SPI gain scores achieved significance at the 0.05 level for institutes A and B and at the 0.1 level for institute D. Again, the authors concluded that teachers in these institutes made significant gains in their understandings of the processes of science. The problems concerning the TOUS gain scores noted above also apply in the case of the SPI gain scores and the associated conclusion. For instance, the largest mean gain (+3.06) was achieved by teachers in institute B. Out of 87 possible points on the SPI, this gain was very small (about 3.5 percentage points). Moreover, the gain was also small when compared to the value of the standard deviations of the pre- and posttest mean SPI scores for teachers in institute B (7.07 and 6.13, respectively). Like the case of the TOUS, these latter results seemed to have, at best, minimal practical significance. This was especially the case given the fact that the authors did not provide further evidence to demonstrate that meaningful gains in understanding the NOS were achieved by the teachers. Welch and Walberg (1967-68) did not elucidate the teachers' understandings that were reflected in the relatively higher TOUS and SPI scores obtained on the post-tests.

Finally, it should be noted that the characteristics of the four institutes were not documented. The authors made no attempt to identify the aspects of the institutes that might have contributed to the claimed success in enhancing teachers' understanding of the NOS. As such, even if the reported statistical results and associated conclusions were considered to be valid (which was not the case), the usefulness of the present study in informing efforts geared toward improving science teachers' understanding of the NOS would still be severely limited.

Summary

Gruber (1960) concluded that participants in the 1957-58 AYI at the University of Colorado made very little progress in their understandings of the NOS. He continued that it was flawed to assume that science teachers would learn about the NOS by learning science content. In his survey of 15, 1958-59 AYIs, Gruber (1963) reported that 25% of the respondents demonstrated some knowledge of the NOS. However, given that the participants were only post-tested, it was difficult to attribute their understandings of the NOS to the experiences at the institutes. Welch and Walberg (1967-68) indicated that participants in nine NSF summer institutes for physics teachers achieved statistically significant gains in their understandings of the NOS as measured by the TOUS and the SPI. Those gains, however, were very small to be of practical significance.

Variables Related to Teachers' Conceptions of the NOS

"Just how a better understanding of the nature of science by . . . science teachers is to be achieved . . . cannot be determined until an identification and analysis of the contributing factors has been made" (Carey & Stauss, 1969, p. 148). Researchers thus turned their attention toward identifying the background and academic variables that were related to science teachers' understandings of the NOS.

Kimball (1967-68) argued that studies that aimed to assess science teachers' conceptions of the NOS often attributed any deficiencies in their understandings of this valued aspect of science to teacher training programs. However, the major problem with such investigations, the author continued, was the use of non-representative samples. Such samples were usually cross-sections of all those who were assigned to teach school science, rather than of "qualified" science teachers. Qualified science teachers were defined as those who go through a science teacher education program. As such, Kimball argued, criticisms directed toward teacher education programs may not be justified. Before making any recommendations for substantial changes in such programs, research studies should focus on "qualified" science teachers' understanding of the NOS or at least control for the qualifications and training of the sampled teachers.

The present study aimed to answer the following questions: How do qualified science teachers' conceptions of the NOS compare to the conceptions of scientists of similar academic backgrounds? How do qualified science teachers' and scientists' conceptions of the NOS change as a function of time since graduation and as a function of experience? How do philosophy majors' conceptions of the NOS compare to those of science majors? The only prediction that the authors made was that as a result of their "explicit study of the structure of knowledge . . . philosophy majors might display a better understanding of the nature of science than science majors" (Kimball, 1967-68, p. 111). This represented one of the earliest suggestions that developing adequate understandings of the NOS was contingent upon explicit instruction in the nature of knowledge construction.

The author developed an instrument, the Nature of Science Scale (NOSS), to assess the participants' understandings of the NOS. The instrument was based on a model of the NOS developed by the author. Departures from this model were considered indicative of the lack of understanding of certain aspects of the NOS. The model, based on the work of several scientists and philosophers of science such as Conant, Bronowski and others, contained eight assertions. These were, (a) curiosity and the desire to generate knowledge about natural phenomena are the driving forces in science, (b) science is not a static accumulation of information but rather is a dynamic, process-oriented activity, (c) science aims to achieve an increasingly comprehensive knowledge and understanding of the natural world, (d) the existence of the "scientific method" is a myth propagated by school science textbooks, (e) scientific methods emphasize a set of values rather techniques including dependence on empirical experiences and operational definitions, reproducibility, and a recognition of the conceptual and arbitrary nature of scientific constructs and classification schemes, (f) science assumes that the natural world is understandable, (g) science is characterized by open-mindedness and is not constrained by religious, geographical, and political factors, and (h) all scientific knowledge is tentative.

Based on these assertions, 200 short statements about the NOS were produced. To establish their face and content validity, the statements were scrutinized by a panel of two science teachers, two school science supervisors, three science professors, and three science education professors. The approved items, the number of which was not reported, were arranged into a Likert-scale instrument. The instrument was pilot-tested with a sample of 54 college graduates of whom 32 held degrees in the biological or physical sciences. The rest of the sample comprised graduates in non-science fields. Following this initial administration, certain items were discarded according to set criteria. Only those items that had fewer neutral responses, that discriminated against non-science graduates, and that were judged by 80% of the experts panel to be in agreement with the adopted model of the NOS were kept. This process was used to establish the discriminate and construct validity of the instrument. The process, however, introduced into the instrument some bias in favor of science majors. The 31 selected items were arranged into a second form of the instrument and administered to a sample of 97 graduates half of whom have majored in science. The Spearman-Brown split-half reliability for the instrument (0.72) was adequate. Two more items were discarded for lack of discrimination power. Thus, the resultant instrument (NOSS) included 29, three-point Likert-type items (agree, disagree, and neutral). A response that agreed with the adopted NOS model was assigned two points, whereas one that did not was assigned a zero. As such, scores on the NOSS can range from 0 to 59 points. Neutral responses, it should be noted, were assigned a score of one.

The population in the present study comprised science and philosophy majors who graduated from Stanford University and San Jose State College in the years 1952, 1958, 1962, 1963, and 1964. The author did not explain why these specific graduation years were selected. The NOSS and an accompanying questionnaire eliciting occupational information were originally mailed to 965 individuals including 119 philosophy majors. Mailed reminders were used to increase the response rate. A total of 712 individuals replied (a 74% response rate). Next, out of the 253 non-respondents, 60 randomly selected individuals were polled by special delivery mail. A total of 39 replied. To test for sampling bias, responses from the latter sample of non-respondents were compared with those of the original sample. The analysis, using t-tests, revealed no significant differences between the mean scores and the variances of the two samples at the 0.10 significance level. This indicated that the original sample was not biased. The corrected split-half reliability of the NOSS calculated for the original sample of 712 respondents was 0.54; a moderately low value. The authors attributed the decrease in the instrument's reliability to the less-homogenous nature of the research sample compared to the sample used in developing the instrument. This argument, it should be noted, did not justify disregarding the relatively low reliability obtained for the sample in the present study or using the instrument. Indeed, the decrease in the instrument's reliability might indicate that the study sample was substantially different from the sample used to validate the instrument.

Of the 625 science-major respondents, 128 reported that they were not scientists or science teachers, nor were they "intending" to become either. Their replies were thus dropped. The author, however, did not report conducting an analysis similar to the one described above to test for sampling bias that might have resulted from this attrition. As such, the final research sample comprised a total of 584 individuals. It should be noted, however, that those respondents who reported that they intended to become scientists or science teachers were included in the final sample of 584 individuals. Of those, 408 were scientists or intended to become scientists, 91 were teachers or intended to become teachers, and 85 had majored in philosophy. The numbers of scientists and science teachers were broken down by year of graduation and school of graduation. However, the author did not report the number of respondents who were actually practicing teachers or scientists. This might cast some doubts on the conclusions of the study. Moreover, the author did not provide further information about the respondents.

Kimball (1967-68) adequately used t-tests to compare the differences between the means of the various sub-groups. The author, notably, provided evidence that the homogeneity of variance assumption of the t-test was met by the research sample. The variance ratio for each comparison was calculated. In all cases, the F value did not reach the 0.1 level of significance. Next, the chi-square method was used compare the sub-groups item by item.

Eight t-test group comparisons were made to answer the question of whether scientists and science teachers of similar academic backgrounds differ in their understandings of the NOS. Four of these comparisons were made according to year of graduation, two according to school of graduation, and two compared all scientists with all teachers in the sample. In all comparisons the null hypothesis was not rejected at the 0.05 significance level indicating no difference between the scientists' and teachers' mean scores on the NOSS. The validity of this conclusion was corroborated by the fact that the estimated population variances of the sub-groups used in the comparisons were also not different at the 0.05 significance level. To the extent that the instrument was valid and reliable, these results indicated that there was "no difference in the concept of the nature of science held by scientists and qualified science teachers when their academic backgrounds were similar" (Kimball, 1967-68, p. 113). The author did not draw any other conclusions from these results. However, the same results may also indicate that "doing science" does not necessarily improve one's conceptions of the NOS. Finally, except for the science teachers as a whole, mean NOSS scores for the various subgroups were not reported. As such, it was not possible to judge the extent to which the groups' views were aligned with or departed from the model of the NOS adopted in the present study. The mean NOSS score for science teachers was 35 out of a possible 58. As such, even though teachers' conceptions of the NOS were not significantly different from those of the scientists', their understandings were "less than satisfactory" (Kimball, 1967-68, p. 115).

One way analysis of variance (ANOVA) was adequately used to test whether science teachers' and scientists' conceptions of the NOS changed as a function of time since graduation and experience. In the case of both science teachers or those who intended to become teachers, and scientists or those who intended to become scientists, comparisons were made between three subgroups. The first group comprised 1964 graduates who indicated that they intended to become scientists or science teaches. The second comprised 1962 and 1963 graduates who were still doing graduate work in pursuit of a career in science or science teaching. The third group comprised 1952, 1958, and 1962 graduates who were active scientists or science teachers. The analyses indicated that there were no significant differences ($F > 1$) in mean NOSS scores among the subgroups of either teachers or scientists. The author thus concluded that conceptions of the NOS were not significantly related to time since graduation or occupational experiences.

Kimball (1967-68) continued that conceptions of the NOS seem to be well established by the time science majors graduate from college. In this regard, it should be noted that all conclusions related to changes in respondents' conceptions of the NOS as a function of time since graduation were limited by the cross-sectional nature of the present study. In the absence of pre- and posttest data in the context of longitudinal studies, these conclusions should be considered with caution.

To test whether science majors and philosophy majors differed in their understandings of the NOS, mean NOS scores of both groups were compared using the t-test. The analysis indicated that philosophy majors, irrespective of school of graduation, had significantly higher scores than science majors ($p < 0.01$). Additional comparisons indicated no significant differences between the scores of science teachers and philosophy majors. The practicing scientists group, however, scored significantly lower than philosophy majors ($p < 0.01$). In all these comparisons, however, Kimball (1967-68) did not report the mean NOSS scores for the groups compared. As such, it is not possible to assess the extent to which these scores differed in terms of the NOSS scale that ranged from 0 to 58 points.

Finally, the chi-square method was used to compare the scores of the various groups on the individual NOSS items. No systematic differences were found between science teachers and scientists at the 0.05 significance level. On the other hand, there was a systematic difference when an item by item comparison was conducted between science majors and philosophy majors. On 6 out of 7 items that dealt with the methods of science, the philosophy majors were in significantly more agreement than science majors with the NOS model developed by the author. The author concluded that philosophy majors demonstrated a better understanding of the methodological aspects of science. Kimball (1967-68) noted that this is "a remarkable outcome, for it would seem reasonable that the one area of science with which the scientists would be most familiar is methodology" (p. 115). Kimball continued that the inclusion of philosophy of science courses in the undergraduate study of science majors in general or in teacher preparation programs might be useful in improving prospective teachers' conceptions of the NOS. This issue, Kimball noted, should be the focus of experimental investigations.

Kimball (1967-68) concluded that any deficiencies in qualified science teachers' understandings of the NOS were also characteristic of scientists and science majors in general. Thus, criticisms of teacher preparation programs were not justified. Attention should focus more on undergraduate science programs. This recommendation was supported by the finding that science majors' conceptions of the NOS seemed to be fairly stable upon graduation from college. The author finally noted that the conclusions of the present study should be tentatively considered pending replication studies and further investigations. The results of this study, it should be emphasized, indicated that understandings of the NOS seemed not to be related to years of teaching experience or to "doing science." Furthermore, explicit instruction in the philosophy of science might contribute to an enhanced understanding of at least some aspects of the NOS.

Carey and Stauss (1969) attempted to identify the relationship that might exist between prospective elementary and secondary science teachers' understandings of the NOS and certain academic variables. In this respect, the authors noted that the assumption that "one learns the nature of science by doing science . . . do not appear to [be supported] . . . by research studies" (Carey and Stauss, 1969, p. 150).

The sample comprised all 35 prospective secondary and 221 prospective elementary science teachers enrolled in secondary and elementary methods courses at the University of Georgia between the fall of 1967 and the fall of 1968. No further information (e.g., demographic profile, background variables) regarding the participants was provided. The authors made no claims regarding the representativeness of their sample and explicitly noted that the conclusions of the present study should not be generalized beyond the participant teachers.

The *Wisconsin Inventory of Science Processes* (WISP) (Scientific Literacy Research Center, 1967) was used to assess participants' understandings of the NOS. The WISP consists of 93 items concerned with the assumptions, activities, objectives, and products of science. The items fall under two general subsets. The first relates to the Assumptions of Science (36 items) and the second to the Operations of Science (57 items) (Carey & Stauss, 1969). Respondents are asked to evaluate the statements as "accurate," "inaccurate," or "not understood." The items, however, are boiled down to "agree/disagree" type questions by combing the "inaccurate" and "not understood" responses when the instrument is scored (Lederman, Wade, & Bell, 1998). The WISP scores range from 0 to 93. The WISP was developed and validated for high school students. The authors presented no evidence regarding the validity of the instrument in measuring prospective science teachers' understandings of the NOS. The WISP reliabilities calculated for the teacher groups (elementary and secondary) and the combined group using the KR-21 formula were 0.68, 0.66, and 0.66, respectively. The reliabilities for the Assumptions of Science subset adjusted by the Spearman-Brown formula were 0.91 for all three groups, whereas the reliabilities for the Operations of

Science subset were 0.79, 0.75, and 0.80 for the elementary, secondary, and combined groups, respectively.

The WISP was administered to all participants at the beginning of their respective methods courses. Additionally, the participants' academic variables as of the quarter immediately preceding their enrollment in the methods courses were collated. The selected variables were high school science units, college mathematics hours, college biological science hours, college physical science hours, total college science hours, college mathematics grade average, college biological science grade average, college physical science grade average, total college science grade average, and total college grade average. Means and standard deviations for the various variables were calculated and reported for the elementary, secondary, and combined groups. The prospective secondary science teachers had, on the average, more school and college hours in all the selected variables. The academic achievement of both groups, however, was comparable. Additionally, the prospective secondary science teachers' mean college physical science hours was larger than their mean college biological science hours.

Next, correlation coefficients were calculated between each of the academic variables and the total WISP, the Assumptions of Science subset, and Operations of Science subset scores. All these correlations were calculated for the elementary and secondary teacher groups separately as well as for the combined sample. Two tailed t-tests were used to test the significance of the correlations at the 0.05 significance level between the mean WISP scores, total and subset, and the means of the academic variables. The authors took no measures to guard against the accumulation of error that would result from conducting multiple tests. This cast some doubts on the validity of the reported significant correlations given that thirty tests were conducted in the present study.

The prospective secondary science teachers' total WISP, Assumptions of Science, and Operations of Science mean scores (68.00, 26.57, and 41.31, respectively) exceeded those of prospective elementary teachers (59.84, 23.95, and 35.89). The authors, however, did not elucidate the aspects of the NOS that might have discriminated between the two groups or even search the data for any systematic trends in the groups responses.

In the case of prospective secondary science teachers there were no significant correlations between the WISP scores, total test and subsets, and the selected academic variables. The same results were obtained in the case of prospective elementary science teachers with one exception. There was a significant positive correlation ($p < 0.05$) between the Operations of Science subset scores and the elementary teaches' total college grade average. The correlation, however, was very small ($r = 0.1422$) to be of any practical significance. It should be noted that this correlation value explains only about 2% (R^2) of the total variance in the sample. In the case of the combined sample, the authors reported several significant correlations ($p < 0.05$). The WISP scores, total and subsets, were significantly correlated with the number of college physical and biological hours, total college science hours, and high school science units. Significant correlations were also obtained between the total WISP and Operations of Science subset scores and college science grade averages and overall grade point average. However, the values of the correlation coefficients were small and ranged between 0.1489 and 0.3746. As such, the largest correlation would explain about 14% of the total variance in the combined sample. Carey and Stauss (1969) concluded, and rightly so, that "though these relationships are . . . significantly different from zero, it is noted that the coefficients are still relatively small, and therefore the apparent relationships are not very impressive" (p. 157).

The authors concluded that the present study indicated that little, if any, relationship existed between the participant prospective elementary and secondary science teachers' understandings of the assumptions and processes of science, as measured by the WISP, and the various academic variables investigated. In particular, undergraduate science courses did not seem to contribute to teachers' understandings of the NOS. This was the case despite the extensive science background of the secondary science teachers who had an average of 68 total college science hours. Moreover, Carey and Stauss (1969) noted that prospective teachers "may not develop an understanding of the nature of science . . . through participation in the activities of science" in their undergraduate courses (p. 157). This was one of the earliest statements that explicitly denied a relationship between "doing science" and developing an understanding of the NOS. However, the correlational nature of this study should be kept in mind when considering its conclusions.

Wood (1972) aimed to assess prospective elementary and secondary (science) teachers' conceptions of the NOS and to identify any differences between the two groups' understandings. The author also aimed to test whether the participants' understandings of the NOS were related to certain demographic and academic variables. These variables included sex, number of years of high school science, number of university science credits, and the average grade in university science courses.

The present study surveyed a total of 443 participants. The sample comprised all 365 elementary education students and 78 secondary education students respectively enrolled in elementary and secondary science methods courses at five State Universities in Wisconsin during the fall term of 1969. The author did not provide any information regarding the selection of the participants. He also did not furnish any demographic or background data about the participants.

The WISP was used to assess the participants' understandings of the NOS. The author presented no evidence regarding the validity of the instrument, originally developed and validated for high school students, in measuring prospective elementary and secondary (science) teachers' understandings of the NOS. Moreover, the instrument's reliability for the total sample or the prospective teacher groups was not reported. As such, the results should be viewed with caution. The WISP was administered by the instructors of the various science methods courses surveyed before the end of the third week of classes. In addition, demographic and background data were elicited from the participants. These data included sex, teaching area (elementary or secondary), secondary school science major (biology, physics, chemistry, or general science), the number of years of secondary science taken, the number of university science credits, and university level science average. Mean values for these variables were not reported.

The mean WISP score for the whole sample was 65.89 (with a range of 45 to 81, and a standard deviation of 6.04) out of 93 total possible points. The prospective secondary science teachers' mean WISP score (68.67 with a standard deviation of 5.55) was significantly higher than that of prospective elementary school teachers at the 0.01 level. Wood (1972) used the t-test to ascertain the significance of this difference. The author, however, did not employ the appropriate unit of analysis. Instead of using the individual science methods course as the unit of analysis (N = 10), Wood erroneously used the individual participant as the unit of analysis (N = 443). Given the fact that the statistical power of the t-test increases with an increased sample size, the author might have ended up with a statistically significant difference where such a difference might not actually have existed. Moreover, the author did not discuss the practical significance of this difference that amounted to about 3.5 percentage points, and whose value (3.32) was smaller than the reported standard deviations of the mean WISP scores for the two groups compared. Despite all this, Wood (1972) made the unwarranted broad generalization that compared to prospective elementary school teachers, prospective secondary science teachers possessed better understandings of the NOS. The author did not limit his conclusion to the sample studied.

Wood (1972) conducted an analysis of the participants' answers to the 93 WISP items. These items, it should be noted, fall in two general subsets: the Assumptions of Science subset (36 items) and the Operations of Science subset (57 items). Wood noted that "only 8 statements were inaccurately answered by more than 60% of the students, whereas twenty (20) of the statements were accurately answered by more than 90% of the students" (p. 76). The author listed the eight erroneously answered statements and noted that they were not related to a specific aspect of the NOS. He continued that a further analysis showed that about 90% of the participants had a good understanding of the operations of science. No evidence was provided to support this statement. Moreover, the author did not comment on the participants' understandings of the assumptions of the science and the nature of the scientific enterprise even though these aspects of the NOS are assessed by the WISP. Nevertheless, it should be noted that this analysis was among the first documented attempts to go beyond merely reporting the numerical scores of the instrument used to assess the participants' conceptions. Wood attempted to elucidate the teachers' conceptions of the NOS as evident in their responses to the WISP items.

The WISP scores were regressed against the participants' academic variables. The author presented no evidence to show that the distribution of the data for the sample in the present study met the assumptions of regression analysis (normal distributions, equal variances, and independence of data points within a certain population). The regression analysis revealed that only the coefficient of the average university science grades ($\beta = 2.26$) was significantly different from zero at the 0.01 level. Next, correlation coefficients between the WISP scores and the selected demographic and academic variables were calculated. The author used t-tests to assess whether the correlation coefficients were significantly different from zero ($p < 0.01$). He, however, did not take any measures to guard against the bias that might be generated due to the accumulation of error by virtue of repeated tests (25 tests were performed). The WISP scores were only significantly correlated with the average university science grades. The correlation coefficient, however, was low ($r = 0.266$). The average university science grades only accounted for about 5% of the total variance in the sample. The author thus concluded that little, if any, relationship existed between the selected demographic and academic variables and prospective elementary and secondary (science) school teachers' understandings of the NOS.

The sample in the present study was not chosen to be representative of any larger population of elementary and secondary education majors. Nevertheless, in stating his conclusions, Wood (1972) made broad generalizations that went beyond the sample studied to include elementary and secondary education majors in general. The author finally noted that university science and science methods courses respectively should place more emphasis on teaching the nature and process of science and methods by which these aspects of science can be communicated to elementary and secondary students.

Scharmann (1988a) noted that many elementary teacher educators view science as an enterprise with three components: content, process, and attitudes. This view of science, the author continued, is simplistic since it overlooks the philosophical and conceptual underpinnings of the scientific enterprise. What is more, Scharmann noted, was that this view encouraged an implicit approach to teaching the NOS. In accordance with this view elementary teachers were led to believe that science instruction should focus on "content with examples of scientific applications, in hopes that an understanding of the nature of science will occur through repetition and maturation" (p. 453). In many ways, this approach reflected preservice elementary teacher education programs' failure to make the crucial distinction "between the learning and implementation phases of elementary science teaching" (Scharmann, 1988a, p. 453). In other words, these programs often conflated teaching prospective elementary teachers *about* the NOS and teaching them *how* to convey conceptions of the NOS to elementary students.

Based on Kimball's (1967-68) finding that students' conceptions of the NOS were fairly stable by the time they graduated from college, Scharmann (1988a) argued that teaching prospective elementary teachers about the NOS should take place during their undergraduate years. However, attempts to improve college students' understandings of the NOS have only been met with limited success. For these attempts to be more fruitful, Scharmann noted, a more elaborate understanding of the nature and characteristics of students in relation to developing conceptions of the NOS was needed. In this regard, the author continued, studies have focused on cognitive variables such as logical thinking ability, science content knowledge, science achievement, and academic achievement. However, several psychologists have emphasized that social-personal variables might be equally important in facilitating the learning and acquisition of critical aptitudes and skills. In particular, the author noted, some science educators have argued that locus of control orientation may greatly influence learners' ability to develop understandings of the NOS. This argument was based on the premise that students with an "external" locus of control have a low tolerance for ambiguity, suffer from difficulties in processing information, and usually demonstrate low science achievement. These factors may impede their ability to develop desired understandings of the NOS. If research studies lent support to this suggestion, Scharmann continued, then elementary science educators should attempt to identify the locus of control orientation of prospective elementary teachers early on. Instructional sequences designed to shift them to an "internal" locus of control orientation should then be attempted in the hope of facilitating their acquisition of proper conceptions of the NOS. The author, however, did not provide an operational definition for locus of control.

The present study, thus, aimed to investigate the relationship between preservice elementary education majors' locus of control orientation, critical aptitudes and developmental variables, and their understandings of the NOS. In particular, the study aimed to answer three research questions: (a) To what extent do external and internal locus of control participants differ in their logical thinking ability, science content knowledge, academic achievement, science achievement, verbal aptitude, or quantitative aptitude? (b) How much of the total variance between internals' and externals' understandings of the NOS is explained by each of the aforementioned variables? (c) Which of the above variables has the greatest discriminatory power in predicting externals' and internals' understandings of the NOS? It should be noted that none of these research questions aimed to assess directly or explicitly the extent to which participants with internal or external locus of control differed in their understandings of the NOS. Scharmann (1988a) did not attempt to investigate this relationship specifically. This may reflect an inherent bias in the study. Scharmann seemed to assume that internals and externals differed in their understandings of the NOS. And given his introductory arguments, the author was most likely to have taken for granted that participants with an internal locus of control possessed more adequate conceptions of the NOS.

The study was correlational in nature. Nevertheless, there were indications that the author wanted to draw conclusions beyond those warranted by the design of the study. For instance, Scharmann (1988a) noted that "locus of control . . . served as the independent variable in this investigation" (p. 456). Given that in the present study correlations between participants' locus of control orientation, critical aptitudes and developmental variables, and their understandings of the NOS were merely calculated, locus of control could not have served as an "independent" variable. This terminology might convey the impression that the variable was manipulated when in fact it was not. In regression analysis such variables are more appropriately labeled as "explanatory" variables (Ramsey & Schafer, 1997). Data about the participants' academic achievement, science achievement, verbal aptitude, and quantitative aptitude were collated from their personal files. Academic achievement and science achievement were respectively defined as a participant's grade point averages (on a 0 to 4 point scale) from *all* and *exclusively* science undergraduate coursework up to the term immediately preceding the study. Verbal aptitude and quantitative aptitude were respectively defined as a participant's scores on the verbal and quantitative components of the *Scholastic Aptitude Test* (SAT).

Several instruments were used to collect data on the participants' logical thinking ability, science content knowledge, locus of control orientation, and understandings of the NOS. The *Test of Logical Thinking* (TOLT) was used to assess participants' proportional, combinatorial, probabilistic, and correlational reasoning skills as well as their ability to control variables. Tobin and Capie (1980) developed the TOLT. The test consists of 10 items and its scores range from 0 to 10. To receive full credit (1 point) on an item, a respondent must select both the correct answer and the appropriate reason for selecting that answer. Scharmann (1988a) noted that the TOLT developers reported an internal consistency reliability of 0.74. As for validity, TOLT scores were highly correlated with the *Test of Integrated Science Processes* (TISP) scores (Dillashaw & Okey, 1980) (0.74) and with scores derived from individual interviews conducted by the developers (0.76). The author did not comment on whether the test was validated with a group compatible with the one in the present study. In this regard it should be noted that the TISP was validated for use with high school students.

The participants' content knowledge of the physical, biological, earth, and space sciences was assessed using the *Metropolitan Achievement Series--Science subscale 11* (Metropolitan Achievement Series, 1978). The instrument comprises 53 multiple choice items and its scores range from 0 to 53. The split-half and alternate forms reliabilities reported by the test developers were 0.87 and 0.85, respectively. The test's concurrent validity was established by achieving a high correlation with the *Otis-Lennon IQ test*.

The Rotter's (1966) *Internal-External Locus of Control Scale* (I-E scale) was used to assess the participants' locus of control orientation. The I-E scale has 29, two-point forced-choice items. Six of the items are distracters. Respondents are assigned one point for answers consistent with an internal locus of control, and none for those consistent with an external locus of control. The I-E scale scores thus range from 0 to 23. Based on a study conducted with a sample of female, senior elementary education majors (a group comparable with the participants in the present study), scores of 14 or higher were taken to reflect an internal locus of control orientation. The I-E scale developers reported a test-retest and internal consistency reliabilities of 0.83 and 0.79, respectively. The author noted that the validity of the scale has been confirmed by a host of published studies.

Finally, the NOSS (Kimball, 1967-68) was used to assess participants' understandings of the NOS. The instrument has 29, three-point Likert type items. In the present study, responses consistent with the developer's model for the NOS were assigned three points. Neutral responses were assigned two points, and responses inconsistent with the model were assigned one point. Thus, the NOSS scores in the present study ranged from 29 to 87. (It should be noted that the corresponding scores assigned by Kimball (1967-68) were +2, +1, and 0. As such, the NOSS scores would range from 0 to 58.) Kimball reported a split-half reliability of 0.72 for the NOSS. It should be noted that in the case of all the above instruments the author did not calculate any kind of reliability coefficients for the sample in the present study. Additionally, the author did not present evidence to show that these instruments were validated with groups comparable with the one in the present study. Moreover, it was not clear when or under what conditions these instruments were administered.

The sample comprised 135 preservice elementary education majors (127 female and 8 male). Participants were selected on the basis of three criteria: being enrolled in a terminal elementary science methods course, having finished all required science content courses, and being seniors registered for student teaching in the term immediately following the study. It was not clear whether the participants came from one or more institutions. Fifty-three of the participants possessed an internal locus of control while 82 possessed an external locus of control. The participants had a mean age of 21.5 years with a standard deviation of 0.6 years. They were thus judged to be homogenous with respect to age.

The participants' average verbal and quantitative SAT scores were 427 and 434, respectively. Their composite average score was 861. Scharmann (1988a) noted that relative to:

> The 1982 national average . . . for all freshmen electing education as a major (same national population from which the subjects of this study were drawn) . . . the subjects used in this study were comparatively 'good.' Such a comparison supports . . . the validity for generalizing the results of this study to all preservice (and/or science) teachers. (p. 456)

This latter conclusion did not seem to follow from the author's argument due to several reasons. First, the sample in this study was not drawn from the same population that constituted the aforementioned national sample. By virtue of the selection criteria summarized above, the sample in the present study only comprised seniors. As such, the populations that the author considered to be equivalent (freshmen students electing education as a major and senior prospective elementary teachers) are, in fact, very different. Second, granted that the two populations were identical, the author could claim that the present sample was representative of any larger population based solely on the comparability of composite SAT scores. Such a claim could only be made if the sample was randomly drawn from the larger population. As noted above, the author did not initially define the larger population nor did he present any evidence to indicate that the present sample was in any respect representative of that population. As such, any claims to the generalizability of the results of the present study to any lager population were not valid.

The author reported the mean scores and standard deviations on the aforementioned instruments for the internal and external locus of control groups. Out of a possible 87 points, the mean NOSS scores for the internals and externals were 54.02 (with a standard deviation of 8.98) and 53.44 (with a standard deviation of 5.81), respectively. This difference, it should be noted, was less than one percentage point. Moreover, even though Scharmann (1988a) did not comment on the issue, these mean NOSS scores indicated only about 60% agreement with the model for the NOS underlying the NOSS. As such, both internals and externals did not seem to possess adequate conceptions of the NOS. The internals also achieved higher mean scores than the externals on the TOLT, and the *Metropolitan Achievement Series--Science subscale 11*. This was also the case with the mean total and science grade point averages as well as the mean verbal and quantitative SAT scores. However, like the case of the mean NOSS scores, the differences between the two groups mean scores were small and ranged between 1 and 7 percentage points. Moreover, the author did not test the statistical significance of these differences nor did he comment on the practical implications of such small differences. Nevertheless, and without presenting any statistical evidence consistent with the nature of the present study, Scharmann (1988a) concluded that "internal locus of control subjects are superior to externals for all study variables" (p. 460). However, given the mean NOSS scores reported above, it can, at least, be concluded that compared to the externals, participants with an internal locus of control orientation did not demonstrate better understandings of the NOS. This result did not agree with the author's introductory argument and undermined the relevancy of the conclusions derived from the present study to efforts directed toward enhancing elementary science teachers' conceptions of the NOS.

Multiple regression analysis was used to assess the influence of the predictor variables (academic achievement, science achievement, science content knowledge, logical thinking, quantitative aptitude, and verbal aptitude) upon understandings of the NOS (as measured by the NOSS) for internal and external locus of control orientations. Prior to the analysis, the significance of the correlations between the predictor variables and the NOSS scores were tested. The results, arranged in decreasing order of correlation coefficient values, were as follows: logical thinking ability ($r = 0.25$, $p < 0.01$), science content knowledge ($r = 0.20$, $p < 0.05$), academic achievement ($r = 0.18$, $p < 0.05$), science achievement ($r = 0.17$, $p < 0.05$), verbal aptitude ($r = 0.08$), and quantitative aptitude ($r = 0.05$). These correlation coefficients, it should be noted, were low. The largest ($r = 0.25$) accounts for about 6% of the total variance in the NOSS scores. Next, forced-entry regression analysis was used. The predictor variables were entered into the various regression equations in the above order.

None of the predictor variables were found to be statistically significant in predicting understandings of the NOS for participants with an external locus of control orientation. However, all six variables achieved statistical significance in the case of participants with an internal locus of control orientation. Nevertheless, and except for logical thinking ability, the amount of the total variance in internals' NOSS scores explained by each of the predictor variables was very small. Academic achievement, science achievement, and verbal attitude accounted for 1% of the total variance each. Science content knowledge and quantitative aptitude accounted for 4% and 2% of the total variance, respectively. However, 16% of the variance found among internals' NOSS scores was accounted for by their logical thinking ability ($R^2 = 0.16$, $F = 9.83$, $p < 0.01$). This explanatory power, however, was still small. The entire set of predictor variables could only account for 23% of the total variance in NOSS scores for participants with internal locus of control orientation. Nevertheless, Scharmann (1988a) arrived at the over-generalized conclusion that "there appears to be a *tremendous* difference [italics added] between the capabilities of the predictor variables to provide information with respect to enhancing an understanding of the nature of science on the basis of internal versus external locus of control orientation" (p. 462).

Discriminant analysis was also used to determine which of the variables in the study were most valid in predicting participants' group membership, as discriminated by locus of control orientation, when achievement on the NOSS was used as a criterion variable. The largest positive discriminant coefficients were obtained for quantitative aptitude (0.82) and science achievement (0.79). Logical thinking and science content knowledge had limited discriminatory power with coefficient values of 0.26 and 0.23, respectively. Academic achievement and verbal aptitude had the least discriminating power with coefficient values of -0.84 and -0.51, respectively. These results, Scharmann (1988a) noted, were "useful in generalizing the results of regression analyses" (p. 459). It should be noted, however, that the results of discriminant analysis did not corroborate the results of regression analysis to an extent that would warrant this latter conclusion. For instance, according to regression analysis, logical thinking ability accounted for the largest amount of variance in internals' NOSS scores. This variable, however, was shown to have only limited discriminating power in predicting participants' membership to the "internals" or "externals" group.

Finally, while Scharmann (1988a) noted that "it was not possible to conclude that an internal locus of control resulted in a significantly greater understanding of the nature of science," he nevertheless continued that "the importance of the locus of control construct for science teacher preparation cannot be underestimated" (p. 462). This conclusion, like others reported in the present study, did not seem to be warranted by the aforementioned results. Throughout the study, the author was not careful to limit his conclusions to the sample at hand nor to confine those conclusions to the limits imposed by the correlational nature of this investigation. In general, given all the cautions noted above, the significance of the locus of control orientation in enhancing prospective elementary teachers' understanding of the NOS remained highly suspect.

Scharmann (1988b) reported on a second part of the previous study (Scharmann, 1988a). As such, participant selection criteria, sample descriptions, and the instruments used in data collection were identical to those previously described. Moreover, and unless otherwise noted, the same data analysis procedures were used in the present study.

Scharmann (1988b) noted that some science educators advocate that specialized courses in the history and philosophy of science can serve to improve prospective science teachers' conceptions of the NOS. Given the special needs of elementary education majors, Scharmann continued, such an approach is “too narrow . . . and its value has not been demonstrated within a unified approach to the preparation of elementary teachers” (p. 590). An alternative approach was needed. Developing an understanding of the NOS, Scharmann argued, is a “learning outcome [that can be] facilitated through process skill instruction, appropriate science content coursework, and early field experiences” (pp. 589-590). Such an implicit approach to teaching about the NOS, Scharmann advanced, has not only “proven more fecund, [its] potential value has been demonstrated in relation to complementary positions adopted by developmental, social, and psychological theorists” (p. 590). The author, however, did not refer to any literature that would support this latter claim. Indeed, some researchers have concluded that field experiences (e.g., Kimball, 1967-68) and process skill instruction (e.g., Riley, 1979) did not substantially contribute to science teachers’ understandings of the NOS.

Scharmann (1988b) noted that a review of the literature indicated that various science teacher educators have advocated three conceptual models of preservice elementary (science) teacher preparation. The first, the “content and methods” (CM) model, only incorporates coursework in science and science teaching methodology. In addition to these latter two aspects, the second model, the “process/content and methods” (PCM) model, incorporates training in science process skills prior to enrollment in science coursework. Science educators who champion the PCM model, Scharmann noted, argue that training in science process skills provides preservice elementary teachers with examples of activities that they might be expected to teach and helps them to acquire formal operational and logical thinking skills. The third model, the “process/content and integrated field experience teaching methodology” (PCIFM) model, augments the PCM model with field-based teaching experiences. Such experiences, Scharmann noted, have positive socializing influences on preservice elementary teachers.

In the present report, Scharmann (1988b) aimed to assess the influence of locus of control orientation and sequenced instructional approaches on elementary education majors' understandings of the NOS. The specific research questions were: (a) How well do different approaches to preservice elementary teacher education (CM, PCM, or PCIFM) impact prospective teachers' conceptions of the NOS? (b) Does locus of control orientation impact prospective elementary teachers' understandings of the NOS? (c) To what extent does participants' science content knowledge, logical thinking ability, academic achievement, science achievement, quantitative aptitude, and verbal aptitude affect their understandings of the NOS? The latter two research questions, it should be noted, corresponded to ones investigated in the previous study (Scharmann, 1988a). However, data analyses in the present report were performed separately for each of the three prospective elementary teacher groups (CM, PCM, and PCIFM) as compared to the total composite sample in the previous study (Scharmann, 1988a).

The participants were 135 preservice elementary teachers. They differed in their locus of control orientation and sequenced instructional approach. The CM model was represented by 22 participants, 11 with an internal locus of control and 11 with an external locus of control. The PCM model comprised 49 participants, 21 internals and 28 externals. Sixty-four participants, 21 internals and 43 externals, represented the PCIFM model. The author noted that a chi-square test revealed that the groups were not significantly different as far as locus of control orientation was concerned ($\chi^2 = 2.48 < {}_{0.95}\chi^2 = 5.99$). The author, however, did not provide any information as regard the comparability of the groups on the other investigated variables (science content knowledge, logical thinking ability, academic achievement, etc.). Moreover, no additional information about the participants was provided.

The study had a "static-group" comparison design. Scharmann (1988b) noted that the "design enables the control of several sources of potential invalidity" (p. 593). The design however, suffers from several threats to internal validity (selection, mortality, and interaction of selection and other factors) and external validity (interaction of selection and treatment) (Campbell & Stanley, 1963). It should be noted that in the previous report, Scharmann advanced that the study was correlational in nature. Moreover, there were no indications that the three teacher groups had similar experiences save the science process skill training or field based teaching experiences. Indeed, no information was provided about the teacher preparation programs from which the three groups must have been selected. As such, history and maturation were additionally introduced as potential threats to internal validity.

To assess the main effects of the instructional model used and locus of control orientation as well as their possible interactions, two-way ANOVA followed by the Scheffe pair-wise comparison procedure were used. The Scheffe technique, it should be noted, is highly conservative and serves to guard against the accumulation of error due to repeated testing. However, the use of this conservative technique increases the likelihood of obtaining type II errors. The use of the Tukey technique, a relatively less conservative test, would have decreased the likelihood of obtaining type II errors and simultaneously served to guard against the accumulation of error. As far as the NOS was concerned, the analysis revealed no significant main effect for locus of control or for group by locus of control interaction. The mean NOSS (Kimball, 1967-68) scores for participants with an internal locus of control orientation in the PCM and CM groups were higher than those of participants with an external locus of control. These differences, however, were very small (about 4 percentage points). The reverse was observed in the case of the PCIFM group where the externals had a higher mean NOSS score. Again, the difference was very small to be of any practical significance. With the absence of statistically or practically significant differences, locus of control orientation seemed to have virtually no influence on the participants' understandings of the NOS.

The ANOVA test, however, revealed a significant main effect for the instructional model used ($F = 4.03$, $p < 0.05$). The Scheffe pair-wise comparison procedure revealed that the mean NOSS score for the CM group was significantly higher than that of the PCIFM group. Scharmann (1988b) invoked two possible explanations for this result. First, he noted that the CM model may allow students to avoid the dilemma associated with the distinction between science as a body of knowledge and science as a process. This may lead elementary education majors to respond in a manner consistent with the model for the NOS used by Kimball (1967-68). This interpretation, it should be noted, was not supported by any relevant research studies. The second interpretation that Scharmann advanced was supported, to some extent, by empirical studies. He suggested that early field-based teaching experiences do not serve to enhance prospective teachers' attitudes toward science or science teaching. This may result in poor application of their content knowledge and science process skills. These experiences may, in turn, hinder the development of appropriate conceptions of the NOS among those prospective teachers.

The linear regression model was used to test which one of the above two explanations was more plausible. Scharmann (1988b) performed three linear regression analyses to assess the influence of the various predictor variables investigated on participants' understandings of the NOS for the CM, PCM, and PCIFM groups. Forced-entry regression analyses were used with the predictor variables entered into the models in the following order: logical thinking ability, science content knowledge, academic achievement, science achievement, verbal aptitude, and quantitative aptitude. This order was based on the significance of the correlations between the predictor variables and NOSS scores (see Scharmann, 1988a). The analyses revealed that none of the predictor variables was statistically significant in accounting for the variance in the NOSS scores for the PCIFM and CM groups. The amount of the total variance explained by the whole set of predictor variables for the PCIFM and CM participants was only 9% and 26%, respectively. Scharmann (1988b) noted that "the results of the regression analysis for the CM group is limited by the small sample size (n = 22) and missing measures of verbal and quantitative aptitude" (p. 598). The author, nevertheless, justified comparing the relative results of the PCM and PCIFM groups with those of the CM group on the basis that no significant results were obtained for this latter group. This argument, it should be noted, was circular. For had the CM group had a larger sample size and had the data on verbal and quantitative aptitude been available for this group, then some of the predictor variables might have achieved statistical significance. As such relative comparisons with the CM group did not seem to be totally justified.

In the case of the PCM group, the analysis revealed that all six predictor variables were significant in accounting for the variance in the participants' NOSS scores. Logical thinking ability accounted for 25% of the total variance in NOSS scores ($R^2 = 0.25$, $F = 16.01$, $p < 0.001$). Academic achievement ($R^2 = 0.029$, $F = 6.17$, $p < 0.001$) and quantitative aptitude ($R^2 = 0.033$, $F = 3.37$, $p < 0.01$) each accounted for 3% of the total variance. The rest of the predictor variables (verbal aptitude, science content knowledge, and science achievement) each accounted for less than 1% of the total variance. The whole set of predictor variables accounted for 33% of the total variance.

The author concluded that contrary to what is advocated in the literature, the PCIFM model did not seem to be superior to the CM or PCM models in developing prospective elementary teachers' conceptions of the NOS. As such, Scharmann (1988b) noted, it might be inferred that field-based teaching experiences did not significantly contribute to elementary education majors' understandings of the NOS. The author continued that the PCM model seemed to be more effective than the CM model in fostering appropriate understandings of the NOS. This might be the case, Scharmann suggested, because process skill training might help elementary teachers to integrate both the content and the process dimensions of science. This inference, however, was problematic for two reasons. First, the mean NOSS score achieved by the CM group was significantly higher than that achieved by the PCM group. Secondly, and despite the aforementioned fact, the author built a case for his conclusion by reference to the relative discriminatory power of the investigated variables to predict the two groups' mean NOSS scores. However, as noted above, the regression analysis for the CM group was problematic and relative comparisons were not totally warranted. It follows that inferring that the PCM model might be more effective than the CM model in fostering understandings of the NOS did not seem to be totally justified.

More importantly, Scharmann (1988b) noted, and rightly so, that "in practical terms not one of the three models promoted an acceptable understanding of the nature of science" (p. 600). Even though statistically significant differences in mean NOSS scores were obtained for participants in the various models, such differences had very little practical significance. In this regard, out of 87 possible points, the highest mean NOSS score was achieved by the CM group (58.27). Such a score indicates slightly better than 50% agreement with the NOS model developed by Kimball (1967-68) for the NOSS. As such, the present study lent little support to the effectiveness of locus of control orientation, field-based teaching experiences, and science process skill training in fostering better understandings of the NOS among prospective elementary school teachers.

Summary

The studies reviewed in this section indicated that virtually none of the factors or variables investigated was found to be significantly related to science teachers' understandings of the NOS. No statistically significant correlations were obtained between participants' scores on the instruments used to assess their understandings of the NOS and their: college mathematics, biological science, and physical science hours; college mathematics, biological science, and physical science grade average (Carey & Stauss, 1969); high school science units; total college science hours; total college science grade average; total college grade average (Carey & Stauss, 1969; Scharmann, 1988a, 1988b; Wood, 1972); logical thinking ability; quantitative aptitude; verbal aptitude

(Scharmann, 1988a, 1988b); sex; and teaching level (Wood, 1972). Even in the few cases were the correlations achieved statistical significance, the coefficients were too small (on the order of 0.2) to have any practical implications.

In particular, conceptions of the NOS were not related to the extensive science background of secondary science teachers (Carey & Stauss, 1969). Moreover, understandings of the NOS were not significantly related to the years of occupational experience of science teachers and practicing scientists (Kimball, 1967-68). In this regard, it seemed that "doing science" through professional practice or through participation in the activities of science in undergraduate science courses might not enhance prospective teachers' understandings of the NOS (Carey & Stauss, 1969).

Scharmann (1988a, 1988b) was not able to conclude that an internal locus of control orientation resulted in a significantly greater understandings of NOS. Moreover, the results of Scharmann's (1988b) study lent little support to the effectiveness of field-based teaching experiences and science process skill training in fostering better understandings of the NOS among prospective elementary school teachers.

Finally, Kimball (1967-68) found that philosophy majors had significantly higher NOSS scores than science majors. He advanced that the inclusion of philosophy of science courses in the undergraduate study of science majors or in teacher preparation programs might be useful in enhancing prospective teachers' conceptions of the NOS. However, given that mean NOSS scores for science majors and philosophy majors were not provided, it was difficult to assess the meaningfulness of the gains that may be attributed to explicit instruction in the structure of knowledge. Kimball also concluded that students' conceptions of the NOS seem to be fairly stable by the time they finish their undergraduate studies.

Initial Attempts to Influence Teachers' Conceptions of the NOS

Research concerned with isolating the variables related to teachers' understandings of the NOS was continued. In addition to this goal, the studies reviewed in this section aimed to assess the effectiveness of science methods courses or packages designed by science educators in improving science teachers' conceptions of the NOS. The following five studies all employed an explicit approach to enhancing science teachers' conceptions of the NOS. The investigated science methods courses and packages used elements from the history and philosophy of science and/or instruction on the NOS.

In two separate but similar studies, Carey and Stauss (1968, 1970) continued their efforts to identify variables that might positively contribute to science teachers' understandings of the NOS. The authors noted that science educators are increasingly emphasizing an approach to science teaching that recognizes science as an activity concerned with explaining nature. And even though science as a body of knowledge should not be overlooked, its dimensions as a mode of inquiry and a human endeavor should be conveyed to students. Such a teaching approach, they continued, requires that science teachers possess conceptions of the NOS that are congruent with the advocated image of science. Implicit to this argument is the assumption that teachers' conceptions of the NOS directly translate into their classroom practice. This assumption was not validated by studies that investigated the relationship between science teachers' conceptions of the NOS and their classroom practice (Abd-El-Khalick et al., 1998).

The first study (Carey & Stauss, 1968) focused on prospective secondary science teachers, while the second (Carey & Stauss, 1970) was concerned with practicing secondary science teachers. In both studies the WISP (Scientific Literacy Research Center, 1967) was used to assess participants' understandings of the NOS. The authors did not provide any evidence to support the validity of using the WISP, originally validated with a sample of high school students, to assess prospective or practicing science teachers' conceptions of the NOS. Both studies aimed to test the relationship that might exist between participants' conceptions of the NOS and certain academic variables, and to assess whether a secondary science methods course can significantly improve teachers' conceptions. In addition to these objectives, Carey and Stauss (1968) aimed to describe the participant prospective science teachers' conceptions of the NOS, while Carey and Stauss (1970) attempted to assess the relationship that might exist between practicing teachers' understandings of the NOS and their teaching experience.

The NOS was an underlying theme in the science methods courses investigated in the two studies. In both courses the participants were introduced to the NOS through lectures and discussions. They also read articles and books related to the history and philosophy of science. The authors did not provide any information about these readings or about the instructional activities and emphases that were employed in these courses. Nevertheless, throughout the courses and irrespective of the activity or topic discussed (writing objectives, planning, teaching methods, evaluation, etc.) the participants were always asked to discuss whether the activities or topics were compatible with the image of the NOS presented in the courses. No observations of instruction were conducted in both studies.

The sample in the first study (Carey & Stauss, 1968) comprised all 17 prospective secondary science teachers enrolled in the science methods course at the University of Georgia. No further information whatsoever about the sample (e.g., demographic profile) was provided. The academic variables selected for study included high school science units, botany credits, zoology credits, chemistry credits, physics credits, mathematics credits, total biological science credits, total physical science credits, total science credits, biological science grade average, physical science grade average, mathematics grade average, total university science grade average, and total university grade point average. These academic variables were collated for all participants as of the quarter prior to enrolling in the science methods course and were updated following the conclusion of the term. These data were not reported neither for individual participants nor for the sample as a whole.

At the beginning of the methods course, the participants were asked to write an essay in response to the question "What is your concept of the nature of science?" (Carey & Stauss, 1968, p. 359). In writing their responses, the teachers did not consult any references related to the NOS. This was one of the first reported attempts to elicit teachers' conceptions of the NOS instead of using forced-type-item instruments that usually impose on the respondents the researchers' or instrument developers' own model of the NOS. Next, the participants were administered the WISP. The WISP was re-administered at the conclusion of the methods course. The KR-21 WISP pretest and posttest reliabilities for the study sample were 0.76 and 0.79, respectively. The authors, however, did not use the open-ended essay task to post-test the participants. In doing so, Carey and Stauss (1968) relied on the WISP's numerical scores to assess any gains in teachers' conceptions of the NOS as a result of participating in the course. They failed to make similar use of the richer data that would have been generated from the responses to the open-ended task were this task administered at the end of the course. This was especially the case in light of the fact that such data were available to them from the pretest phase.

The essays were analyzed and statements that elucidated the participants' views of the NOS were identified. These statements were categorized as pertaining to one of 10 categories. The categories were science as a body of knowledge, mode of inquiry, a human endeavor, a manifestation of the truth, technology, and something mystical. The other four categories focused on science-technology, science-nature, and science-scientists relationships. The identified statements were tabulated both by category and teacher. The authors did not explicate how the essays were analyzed nor who conducted the analysis. Next, correlation coefficients were calculated between and pretest WISP scores and the pre-course enrollment academic variables and between the posttest WISP scores and the updated academic variables. Two-tailed tests were used to test whether the correlation coefficients were significantly different from zero at the 0.05 level. The authors inappropriately used the teachers as the unit of analysis (N = 17). For intact classes the appropriate unit of analysis would be one (N = 1). Moreover, the authors took no measures to guard against the accumulation of error that would result from conducting multiple tests (28 tests were conducted). All this cast some doubts on the validity of the reported significant correlations. Finally, the ANOVA test was used to compare pre- and posttest WISP scores.

The authors explicitly noted that the conclusions of the present study should be limited to the population studied and are constrained by the employed instruments and procedures. Analysis of the essays revealed that a majority of the prospective secondary teachers (12 out of 17) view science as a human endeavor. Nevertheless, only four simultaneously viewed science as a body of knowledge, a mode of inquiry, and a human enterprise. Moreover, teachers who believed that science is a human endeavor (12) were more than those who viewed it as a mode of inquiry (10) who in turn were more in number than the teachers (8) who equated science with a body of knowledge. Eight teachers thought that science and technology were synonymous, while only two equated it with truth. One teacher viewed science as something mystical. The authors reported several quotations to support their conclusions regarding prospective teachers' views of science prior to their enrollment in the course. Carey and Stauss (1968) concluded that the prospective secondary teachers in the present study did not possess the understandings necessary to convey to their students adequate conceptions of the NOS.

With a single exception, analyses revealed no statistically significant correlations between pre- or posttest WISP scores and any of the academic variables that were collated prior to and at the conclusion of the methods course. The exception was a moderately low, positive correlation ($r = 0.513$, $p < 0.05$) between pretest WISP scores and biological science grade average. The authors presented no interpretation for this significant result. However, given that 28 tests were performed at the 0.05 significance level, it is highly likely that one correlation coefficient might appear to be significant while this is actually not the case due to the accumulation of error resulting from repeated tests. This interpretation is plausible given the fact that no similar significant correlation was obtained between posttest WISP scores and the same variable (biological science grade average). The authors concluded that there virtually no relationship existed between prospective science teachers' understandings of the NOS and the academic variables investigated. This conclusion converged with that derived from the authors' previously reviewed study (Carey & Stauss, 1969).

The authors reported a significant difference between WISP pre- and posttest scores ($F = 8.64$, $p < 0.01$). They concluded that the participants made a significant gain in their understanding of the NOS as a result of participating in the secondary science methods course. The pre- and posttest mean WISP scores were 68.2 and 72.4, respectively. Out of 93 possible points on the WISP, the reported mean gain (+4.2 points) amounted to about 4.5 percentage points. Given that the authors did not report the corresponding standard deviations, it was difficult to assess the importance of this gain. Additionally, the authors did not comment on the practical significance of this result. Their conclusion might have had more validity if the participants were post-tested with the open-ended essay task and their generated profiles compared with those obtained from the pretest. In light of the absence of such evidence, it was difficult to assess the meaningfulness of the reported numerical gain.

The sample in the second study (Carey & Stauss, 1970) comprised all 31 practicing secondary science teachers enrolled in the science methods course at the University of Georgia during the academic year 1968-69. Most of the teachers were Fellows in the AYI at the University. The only information provided about the participants was that their undergraduate degrees were awarded by institutions in 18 states, and that their teaching experience ranged between 1 and 10 years with a mean of 5.24 years.

The participants were pre- and post-tested with the WISP. The KR-20 WISP total test, Assumptions of Science subset, and Operations of Science subset reliabilities were 0.69, 0.79, and 0.57, respectively. The corresponding posttest reliabilities were 0.64, 0.82, and 0.58, respectively. These reliability values, it should be noted, were relatively low. The Spearman-Brown formula was used to adjust the reliabilities for the WISP subset scores. The selected academic variables for this study were high school science units, college mathematics hours, college biological science hours, college physical science hours, total college science hours, college mathematics grade average, college biological science grade average, college physical science grade average, total college science grade average, and number of years of teaching experience. The values for these variables were collected for all participants prior to enrolling in the science methods course and were updated following the conclusion of the course. Sample mean values for these academic variables were reported.

Correlation coefficients were calculated between pre- and posttest WISP scores, total and subsets, and the values of the academic variables and length of teaching experience prior to and following the science methods course, respectively. Two-tailed tests were used to test whether these correlations were significantly different from zero at the 0.05 level. The concerns noted above about the previous study (Carey & Stauss, 1968) regarding repeated testing and the unit of analysis apply equally well in the case of the present study. Consequently, the reported results and associated conclusions should be viewed with caution. Finally, the ANOVA test was used to compare the pre- and posttest mean WISP scores.

Of all the academic variables collated prior to enrollment in the course, only two were significantly related ($p < 0.01$) to the pretest WISP total and Assumptions of Science subset scores. These variables were the college biological science hours (with a mean of 57.29 hours) and total college science hours (with a mean of 93.31 hours). The correlation coefficients were, however, moderately low. The largest value obtained was 0.49 that explains about 24% of the total variance in the sample. Of the updated academic variables only the college biological science grade average was significantly related to the total WISP posttest scores ($r = 0.40$, $p < 0.05$). The participants' years of teaching experience were not significantly correlated with the pre- or posttest WISP total and subsets scores. Thus, for the teachers participating in this study, there were little, if any, relations between the academic variables studied and the WISP scores. As such, the authors concluded that undergraduate science courses may not contribute to science teachers' understandings of the NOS. This conclusion was supported by the results that the authors derived from their other two studies (Carey & Stauss, 1968, 1969). Moreover, the authors noted that teaching experience may not improve teachers' conceptions of the NOS. This conclusion was consistent with the findings of Kimball (1967-68) described earlier.

The WISP posttest scores, total and subsets, were higher than the pretest scores. The gains were significantly different from zero ($F > 1$, $p < 0.01$). Moreover, the mean gains were on the order of about 11 percentage points and were in all cases greater than the variances of the corresponding pre- and posttest mean scores. Additionally, out of 93 possible points on the WISP, the posttest mean score was 78.61 indicating about 85%

agreement with the instrument's model for the NOS. However, given the fact that the participants were enrolled in other AYI courses during the course of the study, and in light of the absence of a control group, it would be difficult to attribute these gains solely to the science methods class. This was especially so given the fact that Welch and Walberg (1967-68) have reported that Fellows achieved statistically significant gains in their understandings of the NOS as a result of enrolling in AYI courses. The precaution taken by the authors, that is testing for significant correlations between the participants' WISP posttest scores and their updated academic variables that included the AYI courses for which they were simultaneously enrolled, helped to alleviate this concern. Moreover, it should be noted that the gains achieved in the present study were among the highest reported in the studies presently reviewed. This represented the first reported evidence supporting the notion that instruction in the history and philosophy of science may positively contribute to science teachers' understandings of the NOS. Consequently, as a result of their studies, Carey and Stauss (1968, 1970) concluded that "due consideration must be . . . given to the inclusion in the teacher preparation programs of courses in the history and philosophy of science" (Carey & Stauss, 1970, p. 375).

Olstad (1969) argued that science educators are increasingly advocating that science teaching at the elementary school level should emphasize "a broader understanding of the nature of science" whereby young learners are introduced to the "means by which scientific knowledge comes into being . . . that it is uncertain and changing, [and] that science is an enterprise of people" (p. 9). The present study, he continued, was based on the assumption that elementary school teachers should themselves possess a broad understanding of the nature and philosophy of science if they were expected to fulfill their envisioned role in the classroom.

The study aimed to assess prospective elementary teachers' science content knowledge and the relationship between their content knowledge and understandings of the NOS. The study also aimed to assess the effect of an elementary science methods course on the participants' understandings of the NOS.

The sample comprised all 69 prospective elementary teachers enrolled in a science methods course at the University of Washington during the autumn term, 1965-66. The study was replicated with another group of 46 prospective elementary teachers enrolled in the course during the winter term of the same year. No further information about the participants was provided.

Olstad (1969) presented an adequate description of the science methods course investigated. This represented an improvement over other studies (e.g., Carey & Stauss, 1968, 1970) where little, if any, information was provided about the science methods courses investigated. No observations of instruction, however, were conducted. The course, entitled *Science in the Elementary School*, was based on the author's assumption that the objectives and the methods employed in teaching science are inherent to one's understanding of the NOS. Thus, the course, Olstad noted, aimed to "introduce the prospective elementary school teacher to an understanding of science, both as subject matter and as processes of scientific inquiry" (p. 10). This theme was developed by reference to several specific topics which included "the nature of science, scientific 'method' and attitude, scientific models, science as a social force, [and] inductive and deductive processes" (Olstad, 1969, p.10). Moreover, the methodological implications of these topics in terms of equipment, curricular materials, and evaluation were explored. The lectures in the course were supplemented with laboratory sessions. The activities in these sessions aimed to familiarize the participants with the various aspects of process-oriented science teaching such as generating models, interpreting data, designing experiments, and inductive thinking.

The Advanced General Science Test (AGS) Form B published by the Educational Testing Service was administered at the beginning of the methods course to assess the participants' science content knowledge. The participants were also pre- and post-tested with the TOUS (Form W) (Cooley & Klopfer, 1961) to assess their understandings of the NOS. The author did not provide evidence regarding the validity of the TOUS in assessing the participants' understandings of the NOS science despite the fact that the instrument was originally validated with a sample of high school students. Moreover, the author did not calculate the reliabilities for the AGS or the TOUS for the sample in the present study. Instead, he reported the published reliabilities for these instruments which were 0.94 and 0.76, respectively. In the absence of any evidence of the instruments' validity or reliability, the findings of this study should be considered with caution.

Paired two-tailed t-tests were used to assess whether differences between mean pre- and posttest TOUS scores were significantly different from zero at the 0.05 level. The author, however, did not provide any evidence indicating that the t-test assumptions (especially the equal variance assumption) were met by the sample in this study. The same test was used to assess whether the pre- and posttest mean TOUS scores were significantly different for upper and lower achievement groups in the course. Achievement level was determined by reference to regular course examinations. The author provided no data in this regard. Finally, correlation coefficients between mean pre- and posttest TOUS scores and the AGS mean scores were calculated. The significance of these correlations was tested at the 0.05 level. No measures were taken to guard against the bias that might result from the use of repeated testing.

The substantive content knowledge of the original and replication groups were judged to be adequate. The mean scores for both groups of college students were about one standard deviation above the mean score for the ninth grade national sample (84th percentile). The author provided no justification for choosing to judge the adequacy of prospective elementary school teachers' content knowledge by reference to ninth grade students' substantive knowledge.

Analyses revealed significant gains in mean TOUS scores for the original and replication groups ($p < 0.05$). Moreover, the gains obtained by the upper achievement groups in both courses were significantly higher that those obtained by the lower achievement groups ($p < 0.01$). The author was quick to conclude that "the groups showed significant increases in their understanding of science as measured by the TOUS and thus profited significantly from instruction . . . [and] . . . the upper achievement group profited more from instruction than the lower group " (Olstad, 1969, p. 10). It should be noted, however, that with the absence of a control group, the author's strong statements about cause and effect were not warranted. Moreover, the gains achieved (+2.55 and +2.76) were on the order of 4.5 percentage points on the 60-point TOUS scale. It should also be noted that the importance of these gains could not be assessed given that standard deviations for the reported mean scores were not provided. In addition, the author did not discuss the practical significance of these gains nor did he elucidate those aspects of the

NOS in which the participants showed significant gains. The same can be said regarding the conclusion that the upper achievement groups gains were significantly higher than those of the lower achievement groups. In the case of the autumn term group, the upper achievement group mean gain was barely 1/3 percentage points greater than that of the lower achievement group (+2.40 versus +2.20). In the case of the winter term group, the difference was about 4 percentage points. Such gains would hardly seem to have any practical significance.

Moreover, there were no significant correlations between the mean pre- or posttest TOUS scores and mean AGS scores for both groups. The author thus concluded that prospective elementary teachers' understandings the NOS seemed to be independent of their science content knowledge. This conclusion was in agreement with the findings reported by Carey and Stauss (1968, 1969, 1970) and Billeh and Hasan (1975).

The author concluded that prospective elementary school teachers' understandings of the NOS could be improved by means of science methods courses designed for this purpose. However, the author, to his credit, noted that the assumption that guided the present study should not be taken for granted. Olstad (1969) noted that researchers "must find ways of testing the assumption that through this increased understanding of the procedures and processes of science comes more effective classroom science teaching" (p. 11). This was one of the earliest, though implicit, suggestions that teachers' understandings of the NOS might not directly translate into their classroom practice. Recent research studies seem to support this latter notion (e.g., Abd-El-Khalick et al., 1998; Lederman, 1995).

Lavach (1969) noted that scientists, science educators, and historians of science argue that historically oriented science teaching can enhance elementary, secondary, and college level students' understandings of the nature of the scientific enterprise. Such an approach would allow students to develop a feel for the problems that scientists face and the routes they follow in devising solutions for these problems. The author noted that research done with middle school students indicated that historically oriented science programs can improve students' conceptions of the NOS without loss in content achievement. However, Lavach continued, few attempts have been made to develop courses that utilize the historical aspects of science for science teachers. The author thus designed, organized, and conducted an inservice program in the historical development of certain physical science concepts.

The present study aimed to assess the influence of the author's historically oriented science program on practicing science teachers' understandings of science, scientists, the scientific enterprise, and the aims and methods of science. Lavach (1969) claimed that the study had a pretest-posttest control-group design. The author, however, did not pretest members of the control group. This compromised the appropriateness of the label that the author used to describe the design of the study. Also there was no indication that participants were randomly assigned to the experimental and control groups. The program served as the experimental treatment. The criterion measure was performance on the TOUS (Cooley & Klopfer, 1961) and a history of science content test.

The program participants were 26 inservice science teachers in Durham, North Carolina. The author did not indicate how or why this group of teachers was selected. He made no claims that the group was representative of any lager population of practicing science teachers. The experimental group comprised 11 science teachers. Their teaching experience ranged from 1 to 39 years with an average of 15.6 years. Two of the teachers taught life science and nine taught physical science. Two of them also taught mathematics. At the time of the study, the teachers had an average of 6.7 years of experience teaching these subjects. The 11 teachers had an average of 33.9 semester hours of undergraduate and graduate science courses. Only one teacher had formal coursework in the history of science. This information along with the undergraduate major were presented for each individual teacher in the experimental group. The author, however, did not provide any information about the 15 teachers in the control group. Yet, and with no data to support the claim, he noted that those teachers had academic and professional backgrounds similar to those of the experimental group members.

The program spanned 11 weeks. Teachers in the experimental group met for 3-hour sessions once a week. Each session consisted of a 2-hour lecture/demonstration followed by a one-hour laboratory. In the laboratory session, teachers replicated some of the experiments that were conducted by the scientist under discussion. The course focused on selected historical episodes from astronomy, chemistry, heat and thermometry, and electricity. Lavach (1969) noted that the teachers were assigned readings from a "specially written mimeographed 'text' . . . [and] . . . several historically oriented texts" (p. 167). The author, however, furnished no information about the nature or emphases of these readings. Moreover, observations of instruction in the program were not conducted. No information whatsoever was given about the control group. The nature of the control group experiences (or lack thereof) was not elucidated.

Teachers in the experimental group were pre- and post-tested with the TOUS and a non-published, 30-item history of science content test. At the conclusion of the program, those teachers also filled a 6-page course evaluation questionnaire. Teachers in the control group, however, were only post-tested with the TOUS and the history of science content test. The failure to pretest the control group impregnated the study with a variety of extraneous variables such as maturation, testing effect, and history. Any of these variables could have contributed to the gains (if any) demonstrated by the experimental group. Those gains could have otherwise been solely attributed to the experimental treatment had the author accounted for such extraneous variables by pre-testing the control group. As such, the validity of the reported results should be considered with extreme caution.

Moreover, the author did not provide evidence regarding the validity of the TOUS in assessing inservice science teachers' understandings of the NOS science despite of the fact that the instrument was originally validated with a sample of high school students. Similarly, no evidence for the validity of the history of science content test was provided. The author, however, used the KR-20 formula to calculate the instruments' reliability for the experimental group. The reported reliabilities for the TOUS and the history of science content test were 0.76 and 0.70, respectively. Additionally, the content validity of the course evaluation questionnaire was established by a group of historians of science, philosophers of science, and science educators. However, the nature of the questionnaire and the type of information it elicited from teachers in the experimental group were not explicated.

Lavach (1969) used the Fisher t-test for small sample, correlated data to compare the pre- and posttest scores of the experimental group, and the posttest scores of the experimental and control groups. The information provided was not enough to infer whether the appropriate unit of analysis, in this case being the intact group ($N = 2$), was used. As such, statistically significant results obtained should be considered suspect pending the availability of such information.

The analysis revealed a statistically significant difference between the mean pre- and posttest TOUS scores for the experimental group ($t = 4.50$, $p < 0.01$). The mean pretest score was 35.27 with a range of 26 to 44. The mean posttest score was 38.91 with a range of 30 to 49. Out of 60 possible points, the mean gain of 3.64 points amounted to an increase of 6 percentage points. The author did not comment on the practical significance of this difference. Moreover, it should be noted that the posttest mean score indicated only about 60% agreement with the model of the NOS used in the development of the TOUS. Similarly, the experimental group mean pre- and posttest scores on the history of science content test were significantly different ($t = 5.47$, $p < 0.01$). Out of 20 possible points, the mean pretest score was 9.54 while the mean posttest score was 11.73. The 2.18 average gain corresponds to about 11 percentage points. Moreover, the author reported statistically significant differences between the experimental and control group mean posttest scores on the TOUS and the history of science content test at the 0.01 level. It should be noted, however, that these two latter comparisons were not valid given that teachers in the experimental group achieved higher mean pretest scores on both instruments than those achieved by teachers in the control group on the posttest. The control group mean posttest scores on the TOUS and history of science content test were

6.6 and 30.06, respectively. The corresponding mean pretest scores for the experimental group were 9.45 and 35.27, respectively. Relative to the differences between the two groups posttest scores that achieved statistical significance, the differences between the control group mean posttest scores and the experimental group mean pretest scores would have achieved similar levels of statistical significance. These initial differences between the two groups were not taken into account when the comparisons were made. Moreover, these differences do not lend support to the author's claim regarding the equivalence of the experimental and control groups. It should be noted that throughout the study the author did not treat the control group in a manner consistent with the design of the study. Thus, all the advantages (e.g., controlling for extraneous variables, attributing any gains achieved to the experimental treatment) that could have been derived from the appropriate implementation of the study's design were jeopardized. This had severe consequences for the validity of the study's conclusions. The author, nevertheless, concluded that as a result of participating in the program, the teachers achieved significant gains in their understandings of the NOS and knowledge of the historical development of the scientific concepts discussed. The author did not elucidate the aspects of the NOS of which the teachers demonstrated better understanding.

Additionally, the author reported that the gains in teachers' understandings of the NOS and history of science were not related to their years of teaching experience, subject taught, and inservice experiences. It should be noted that relating gains in participants' understandings to certain background variables was not stated as an aim of the present study. Moreover, even though these conclusions converge with those derived from other studies (e.g., Carey & Stauss, 1970), the author presented no data of any kind to support them.

The author finally reported the results of analyzing the course evaluation questionnaires. He, however, did not provide any information on how the analysis was conducted. Of the 11 teachers in the experimental group, 10 felt that the amount of materials covered in the program was adequate and noted that their attitude toward the history of science was favorably influenced by the program. All 11 teachers also felt that they gained better understandings of the historical development of the topics discussed. Of those topics, however, astronomy was the most controversial. While the astronomy unit presented difficulties for some teachers, others reported that they achieved their greatest gains in this unit.

Finally, it should be noted that the study suffered from one additional major difficulty. The author evaluated an inservice program that he himself had designed and conducted. This might have introduced significant bias into the study and the reported conclusions. This was especially relevant given that, as noted earlier, the author failed to document several critical aspects of the study.

Billeh and Hasan (1975) argued that research on the assessment and development of science teachers' understandings of the NOS is scarce. Most of the extant literature, they continued, indicated that teachers do not posses adequate conceptions of this valued aspect of science. However, the authors advanced, the goal of improving teachers' conceptions of the scientific enterprise has not received adequate attention.

The purpose of the present study was to assess the influence of a science teaching methods course on inservice secondary science teachers' understandings of the NOS. The study also aimed to identify the variables that might contribute to such understandings. The specific null hypotheses investigated were: (a) there would be no significant increase ($\alpha = 0.05$) in science teachers' understandings of the NOS as a result of participating in a science teaching methods course, and (b) there would be no significant relation ($\alpha = 0.05$) between science teachers' gains in understandings of the NOS and their years of college science education, years of science teaching experience, science subject(s) taught, and previous professional training.

The population in the present study comprised all 186 secondary science teachers in Jordan. The teachers' ages ranged from 20 to 40 years with a median of 26 years. Their teaching experience ranged from 1 to 9 years with an average of 2.8 years. Most of the teachers taught more than one science subject. Sixty-eight percent of them were university graduates. The majority of the remaining teachers graduated from two-year teacher training colleges. Only about 12.3 percent of the teachers had previous inservice professional science training. The teachers were asked by the Jordanian Ministry of Education to attend the four-week summer training course designed and conducted by the investigators. A total of 171 teachers attended the training course and constituted the sample for the present study. They were divided into four groups according to subject matter taught (biology, chemistry, physical science, and physics). The authors did not provide evidence to show that the 15 non-participant teachers did not bias the sample. However, given the high participation rate (92% of the total population), it was safe to assume that the results of the investigation were generalizable to all secondary science teachers in Jordan.

The study had a pretest-posttest control group design. The experimental group comprised teachers in the chemistry, physical science, and physics groups. Biology teachers served as the comparison group. The authors noted that the biology, chemistry, and physics groups were comparable in terms of the teachers' university of graduation, educational background, teaching experience, and previous inservice training. However, the physical science group was different in that the majority of the teachers in this group were non-university graduates and had had substantially more inservice training opportunities. The summer training science course served as the treatment. Participants were pre- and post-tested with the *Nature of Science Test* (NOST), developed by the authors. NOST scores served as the criterion measure. Additionally, at the beginning of the science training course, the participants were administered a questionnaire that elicited data relevant to the aforementioned background and academic variables.

The science teaching methods course had three components. Teachers attended lectures/demonstrations on science teaching methods and basic science concepts covered in the Jordanian secondary school science curriculum. Teachers also participated in laboratory investigations that emphasized a guided discovery approach. Science teachers' understandings of basic science concepts were reinforced with outside readings and viewing science related films. Besides the fact that the training course spanned four weeks, the authors did not provide any information regarding the duration of the lectures/demonstrations and laboratories or the science concepts covered. Moreover, observations of instruction to insure the fidelity of the treatment were not conducted. Teachers in all four groups received all of the above components. In addition, teachers in the experimental group (chemistry, physical science, and physics teachers) received:

> Twelve 50-minute lectures in the nature of science. Theses lectures covered the following topics: What is science?; Science and common sense; science and technology; art of scientific investigation; nature of scientific knowledge (characteristics, classification, scientific theories, and models); growth and development of scientific knowledge; and sociological aspects of science. (Billeh & Hasan, 1975, p. 211)

It should be noted that this was the first reported attempt to improve science teachers' understandings of the NOS by employing formal and direct instruction about this aspect of science. There were no indications that the participants were assigned readings in the history or philosophy of science. In this regard, the authors noted that the instruction aimed to convey a more accurate view of the nature of the scientific enterprise. The lectures were not merely geared toward the content of the NOST that was used to assess participants' understandings of the NOS.

The NOST comprises 60 multiple-choice items that address four major components of the NOS: assumptions of science (8 items), products of science (22 items), processes of science (25 items), and ethics of science (5 items). The items are of two types. The first aims to assess respondents' knowledge of various aspects of the NOS. The second type of items requires respondents to make decisions that would reflect their views of the scientific enterprise. A panel of 25 scientists, science educators, and science supervisors established the content validity of the instrument. The scientists and science educators came from the American University of Beirut and the University of Jordan. The science supervisors were all Jordanians. The instrument was validated with representative samples of secondary school students in Jordan. The correlations between NOST scores and students' general and science GPAs were 0.58 and 0.60, respectively. The authors noted that the instrument discriminated significantly between secondary school science and art students in Jordan. The authors, however, did not provide any evidence to show that the instrument was valid in assessing secondary science teachers' conceptions of the NOS. The odd-even reliabilities for the NOST calculated from representative samples of secondary school students, teacher training college students, and undergraduate science majors in Jordan ranged from 0.58 to 0.82. The authors calculated the odd-even reliabilities for the pretest and posttest administrations of the NOST for teacher groups. The reliabilities ranged from 0.58 to 0.78.

To assess the influence of the science training program on participants' conceptions of the NOS, pretest and posttest mean NOST scores were calculated for the four teacher groups. The analysis of covariance (ANCOVA) was appropriately used to assess the statistical significance ($\alpha = 0.05$) of the differences in the groups mean scores. The analysis revealed that the pretest mean NOST scores for the four teacher groups were not significantly different ($F = 1.35$, $p > 0.05$). However, the posttest mean NOST scores were significantly different ($F = 5.78$, $p < 0.01$). Duncan's multiple range test revealed that the physical science and chemistry groups achieved significantly better than the biology and the physics groups. The Duncan's test, it should be noted, served to guard against the accumulation of error due to multiple tests.

Next, paired two tailed t-tests were used to assess the statistical significance of the differences between the pre- and posttest mean NOST scores for the various teacher groups. The authors, however, inappropriately used the individual teacher as the unit of analysis. The teacher groups should have been used as the unit of analysis. The mean gain scores of the chemistry (+4.15), physical science (+5.66), and physics (+2.00) groups were found to be statistically significant at the 0.0001 level. The biology group mean gain score (+1.67) did not achieve statistical significance at the 0.05 level. It should be noted that the mean gains ranged between about 3 percentage points for the physics group to about 10 percentage points for the physical science group. The authors thus concluded that the formal instruction on the NOS contributed to significant gains in teachers' understandings of the nature of the scientific enterprise. The authors, however, did not comment on the practical significance of these results. Moreover, the authors did not elucidate the participants' understandings of the NOS prior to or after the completion of the science training course. As such, it was difficult to assess the meaningfulness of the gains achieved by the teachers. Additionally, irrespective of whether the gains could be considered important or not, the posttest mean NOST scores achieved by the chemistry (36.51), physical science (36.02), and physics (33.64) groups were not high. If we take into consideration that there are 60 possible points on the NOST, these latter scores might be indicative of inadequate understandings of the NOS.

The ANCOVA was also used to assess whether the mean NOST gain scores were significantly correlated ($\alpha = 0.05$) with the background and academic variables investigated. These variables were educational qualification (university versus non-university graduates), subject taught (physics, no physics, and physics and other subjects), science teaching experience (less than or equal to 2 years versus more than 2 years), and previous inservice training. The latter variable was categorized into: no training, educational training, science training, and educational and science training. The "educational training" category included inservice training courses in assessment and evaluation, educational psychology, curriculum, teaching methods, and classroom management. The "science training" category included inservice training courses in basic secondary school science concepts. The authors noted that a critical examination of the participants' previous professional training indicated that these experiences did not include any formal instruction on the NOS. Analyses were carried out for the chemistry, physical science, and physics groups. The biology group was excluded because teachers in this group did not receive formal instruction on the NOS. No significant correlations ($\alpha = 0.05$) were found between the participants' gain scores and any of the aforementioned variables. The findings that gains in understandings of the NOS were not correlated with participants' educational qualification, years of teaching experience, and the subject(s) they teach were consistent with the findings reported by Kimball (1967-68), Lavach (1969), and Carey and Stauss (1970). Moreover, the authors noted that teaching experience might not improve teachers' conceptions of the NOS.

Summary

Consistent with their previous study (Carey & Stauss, 1969), Carey and Stauss (1968, 1970) concluded that there virtually exists no relationship between prospective and practicing science teachers' understandings of the NOS and their high school science background; college science and mathematics credits; and college science and mathematics grade averages. Similarly, Billeh and Hasan (1975) and Olstad (1969) concluded that science teachers' understandings of the NOS seem to be independent of their science content knowledge. Science teachers' conceptions of the NOS seemed also to be independent of their years of teaching experience, science subject(s) taught, and inservice professional training (Billeh & Hasan, 1975; Lavach, 1969).

In the studies reviewed in this section, the investigators employed the history and philosophy of science and/or instruction on the NOS within the context of science methods courses in their attempts to foster better understandings of the NOS among the participant teachers. All five studies reported statistically significant gains in participants' mean scores on the instruments used to assess their conceptions of the scientific enterprise. The reported gains, however, varied in their practical significance. Similarly varied were the extents to which the claims regarding the effectiveness of the various methods courses were warranted. Carey and Stauss (1968) reported a mean gain score of about 4.5 percentage points. The mean gain reported by Carey and Stauss (1970) was on the order of about 11 percentage points. More importantly, in the latter study, the reported posttest mean score indicated about 85% agreement with the model for the NOS adopted by the investigators. However, the lack of a control group and the fact that the participants were enrolled in other AYI classes during the course of the study, made it difficult to attribute these gains solely to the investigated science methods class. It should be noted, nevertheless, that the gains achieved in this study were among the highest reported in the studies reviewed in this paper.

The gains reported by Olstad (1969) were on the order of 4.5 percentage points on the 60-point TOUS scale. The importance of this gain could not be assessed given that standard deviations for the reported mean scores were not provided. Moreover, the absence of a control group from the study did not warrant the author's cause-and-effect statements about the effectiveness of the course that was used to enhance teachers' conceptions of the NOS. The gains achieved as a result of Lavach's (1969) approach that stressed the historical development of scientific concepts were on the order of about 6 percentage points. However, due to the author's failure to take full advantage of the experimental design that he used in controlling for extraneous variables, it was not possible to attribute the gains achieved to the experimental treatment employed. As a result of direct instruction on the NOS, Billeh and Hasan (1975) reported statistically significant mean gain scores that ranged between 3 and 10 percentage points. The authors thus concluded that formal instruction on the NOS contributed to significant gains in teachers' understandings of the NOS. However, the posttest mean scores achieved by the teachers in the experimental group indicated a little bit more than 50% agreement with the model for the NOS adopted by the investigators.

Finally, in all the above studies the authors did not attempt to elucidate the participant teachers' conceptions of the NOS prior to and after the completion of the investigated courses. As such, and irrespective of the magnitudes of the gains achieved, it was difficult to assess the meaningfulness of any of these gains in terms of the depth or breadth of the understandings demonstrated by the teachers.

Improving Teachers' Conceptions of the NOS within Teacher Preparation Programs

Now that research has shown that very few, if any, academic and background variables were related to science teachers' understandings of the NOS, the interest with the systematic investigation of those factors declined. Science educators turned their attention toward improving teachers' conceptions through science methods courses and various instructional packages designed for that end.

Implicit approaches.

Trembath (1972) argued that most science teaching concerned with conveying an understanding of "the relations between observation, experiment, and theory . . . is done in an incidental way and few teachers seem to directly teach the nature of hypotheses, laws and theories and the role of experiment in science" (p. 59). This statement was among the first to indicate a need for teaching the NOS explicitly. To be able to convey to their students an appropriate conception of science, the author continued, science teachers should be familiar with the NOS. Nevertheless, Trembath noted, students at Frankston Teachers' College, Victoria, have been "encouraged to develop . . . [a] narrow, inductivist conception of scientific inquiry" (p. 59). Accordingly, teachers were lead to believe that inquiry starts by observing and collecting data about the natural world. This is followed by analyzing the data and inductively deriving certain generalizations. These generalizations are then subjected to testing. The author noted that such a conception of how scientists work is oversimplified. Hypotheses are often introduced before observations and they influence what and how observations are eventually made. Moreover, the creative aspects involved in deriving generalizations from data is replaced with a rather mechanical inductive process.

In the present study, Trembath (1972) described a "small" curriculum project developed for prospective elementary school teachers at Frankston Teachers' College, Victoria, Australia. The project aimed to enhance student teachers' understandings of the ways in which hypotheses are developed and tested; the logical structure of theories and laws; and the ways in which theories and laws can be used to make different types of explanations. These broad goals were translated into 24 behavioral objectives. For example, as a result of participating in the program, prospective teachers were expected to be able to recognize, make, and test hypotheses; and to articulate the role of hypotheses, theories, and laws. Without providing any justification, the author noted that students were not presented with these behavioral objectives at the outset of the "short" program.

The program presented prospective teachers with a narrative divided into a set of "frames." The narrative put forth a certain situation. The author presented an example of a few frames from the narrative in which students are asked to isolate the cause and transmitter of an infectious disease that was spreading from one ward to another within a hospital setting. Each frame required students to read several paragraphs and provide a short answer. The answer could be a hypothesis, prediction, or inference. Students then compared their answers with those provided after each frame. If the two answers agreed, then students proceeded to the next frame. Otherwise, students were asked to re-read the frame and attempt to reconcile their answers with the suggested ones. On completing the frames, students were asked to provide a short answer that would serve as a section review. The author noted that the program took the teachers about 2 1/2 hours to complete. No further information about the program was provided. For instance, it was not clear whether the prospective teachers were debriefed on completing the set of frames or whether they were encouraged to explicitly discuss their responses to, reasoning with, or reflections on the narrative. The absence of these latter elements would render the program incompatible with the author's call for an explicit approach to teaching about the nature of scientific hypotheses, theories, and laws.

Trembath (1972) aimed to evaluate the program. However, the purpose of the study and the specific research questions were not explicated. The study had a pretest-posttest control-group design. Participants were randomly assigned to the two groups. The aforementioned program served as the treatment. The criterion measure was students' performance on an 18-item test. The participants were 48 prospective elementary school teachers in "two lecture groups" (Trembath, 1972, p. 61). No further information whatsoever about the participants was provided. Moreover, the nature of the course in which the "two lecture groups" were enrolled was not elucidated. Each of the "two lecture groups" was randomly split into halves. One half was assigned the experimental treatment (n = 24), while the other half served as the control group (n = 24). As noted earlier, it took students in the experimental group 2 1/2 hours to complete the program. Students in the control group were not required to attend lectures for the duration of the experimental treatment. They were also "asked to make no attempt to find any information about the program" (Trembath, 1972, p. 61). No observations of the instruction that members of the experimental group received were conducted.

Students were pre- and post-tested with an 18-item multiple-choice test designed for the present study. The author presented an example of one item. However, no information was provided about what objectives the test purported to measure. Moreover, no evidence for the validity or reliability of this test was provided. As such, any conclusions drawn from the present study should be viewed with extreme caution. Moreover, it should be noted that a 2 1/2 hours experimental treatment must have been weak. It would be reasonable to assume that such a treatment would not impact student teachers' understandings of the NOS, at least not in any significant manner.

The author used paired two-tailed t-tests to assess the statistical significance of the differences between the mean pretest and posttest scores. The use of ANCOVA would have been more appropriate to control for possible differences between the experimental and control groups. The analysis revealed a statistically significant difference between the pretest and posttest scores for the experimental group ($t = 5.6$, $p < 0.01$). However, Trembath (1972) appropriately noted that the experimental group mean score only increased from 7.0 to 10.7 points in a possible score of 18 points, and continued that if the instrument "was valid and reliable . . . then an even larger increase would have been desirable" (p. 62). The author concluded that the observed change in the student teachers' behavior as reflected in the posttest scores could be attributed to the program.

Further analysis of the test revealed that the participants demonstrated significant gains on some parts of the test but not on others. The author, however, did not elucidate what aspects of the program goals were not achieved. The author also did not provide a profile of the participants' conceptions of the NOS prior to or after the completion of the program.

Barufaldi, Bethel, and Lamb (1977) noted that science teachers often fail to present scientific knowledge as tentative. Rather, science is presented as a fixed body of absolute truths. Based on a very limited body of research, the authors continued, some educators assume that teachers' philosophical views of science influence their students' views. If this assumption is accepted and if the goal of helping students develop more adequate conceptions of the nature of scientific knowledge is to be realized, Barufaldi et al. advanced, then "a major *affective* goal [italics added] of science teacher education should be the enhancement of the philosophical viewpoint that science is a tentative enterprise and that scientific knowledge is not absolute" (p. 289).

It should be noted that Barufaldi et al. (1977) elected to focus on one aspect of the NOS, namely the tentativeness of scientific knowledge. Only few of the studies reviewed in the present paper adopted a similar approach. Researchers often considered a multitude of aspects related to the NOS all at once. Moreover, the authors explicitly labeled attaining an understanding of the NOS or, at least, of the tentativeness of science as an "affective" goal (as compared to a "cognitive" goal). Researchers often did not delineate the domain (cognitive versus affective) to which they believed understandings of the NOS belong. However, this categorization, whether explicitly stated or not, often had consequences for the approach that the researchers utilized in their attempts to promote understandings of the NOS. It is safe to infer that if such an understanding was categorized as belonging to the "affective" realm, then an implicit approach to teaching about the NOS was often adopted. In such an approach, the researchers manipulated certain elements of the instructional environment (e.g., Haukoos & Penick, 1983, 1985; Spears & Zollman, 1977) or involved the learners in "doing" science or science-process skills instruction that lacked *reflective* elements (e.g., Riley, 1979; Trembath, 1972) in the hope that they would develop appropriate conceptions of the NOS. If an understanding of the NOS was considered a "cognitive" goal, then researchers often adopted a more explicit approach to teaching about the NOS such as direct instruction (e.g., Billeh & Hasan, 1975) or instruction in that utilized elements from the history and philosophy of science (Jones, 1969; Ogunniyi, 1983) or both (e.g., Akindehin, 1988).

The purpose of the present study was to assess the influence of science methods courses on elementary education majors' understandings of the tentativeness of scientific knowledge. The authors reported that the study had a non-randomized, equivalent control group, pretest-posttest design. The experimental group comprised elementary education majors enrolled in three elective elementary science methods courses. Students enrolled in an elementary mathematics methods course served as the control group. The science methods courses served as the treatment. The criterion measure was participants' responses to the *Views of Science* (VS) instrument (Hillis, 1975) that was administered during the courses first and last class meetings.

The population in the present study comprised junior and senior elementary education majors at the University of Texas at Austin. The experimental group comprised 56 students enrolled in three science methods courses. Of those 12 were senior elementary education majors enrolled in a student teaching block program that consisted of practice teaching, an elementary science methods course, and a foundations of education course. Twenty-one were juniors and seniors majoring in special education and enrolled in an elementary science methods course. The remaining 23 experimental group participants were junior elementary education majors enrolled in an observation block program that consisted of field observations in an elementary classroom setting, an elementary science methods course, and an educational psychology course. The control group comprised 32 junior elementary education majors also enrolled in an observation block program that consisted of field observations in an elementary classroom setting, an elementary mathematics education course, an elementary reading methods course, and an educational psychology course. The authors did not present any demographic or background information on the participants. They, nevertheless, claimed that the four student groups belonged to the same population.

The authors conducted several statistical tests to support their claim concerning the homogeneity of the four student groups. One-way ANOVA indicated that the groups differed significantly ($p < 0.01$) in the number of college science semester hours. However, paired t-tests revealed that only special education majors had had significantly fewer semester hours of college level science. A one-way ANOVA also revealed that the four groups did not differ significantly in their mean pretest VS scores. A principal-components analysis and Varimax Rotation was also conducted to assess whether the mean group scores were significantly different with respect to the factor structure of the VS instrument. No such differences were found. These results were corroborated by multiple discriminant function analysis where the VS items served as independent variables and group membership as the dependent variable. Finally, Pearson correlation coefficients between pretest VS scores and participants' semester hours of college science were calculated. None of the correlations turned out to be significant. The authors thus concluded that the four groups were initially comparable. It should be noted, however, that the authors did not provide the specific data relating to the aforementioned tests neither in tabular nor in summary form.

The VS instrument was originally developed by Hillis (1975) to assess secondary or college physical science students' views regarding the tentative nature of scientific knowledge. The instrument comprises 40, five-point Likert-type items that are either consistent with a tentative or an absolute view of scientific claims. The VS scores range from a low of 40 to a high of 200. Two separate panels of science educators, scientists, philosophers of science, and historians of science established the face validity of the instrument. The validity of the instrument was established with four different populations: college physical science teaching assistants, college physical science students, secondary science teachers, and secondary science students. The Cronbach alpha reliabilities for these groups were 0.82, 0.81, 0.75, and 0.71, respectively. Barufaldi et al. (1977) noted that because in the present study the VS instrument was administered "to a potentially quite different population, new reliabilities were established" (p. 291). The alpha reliabilities for the three treatment groups and the control group were 0.71, 0.84, 0.80, and 0.76, respectively. The reliability for the combined group was 0.78. The authors, however, did not extend their latter argument to the validity of the instrument. Even though they recognized that the population in the present study was different from the populations used in validating the instrument, the authors did not present any evidence to support the validity of the instrument in assessing junior and senior elementary education majors' views regarding the tentative NOS.

The elementary science methods courses spanned 14 weeks. Students met once each week for 2 1/2 hours. The courses had no components that were specifically geared toward enhancing participants' views of the tentative NOS. Rather, consistent with the authors' view of the NOS as an affective outcome, an implicit approach was used. Thus, Barufaldi et al. (1977) noted, in these courses:

> Students were presented with numerous hands-on, activity-centered, inquiry-oriented science experiences . . . [and] . . . many problem-centered science activities . . . that assisted students in making reasonable responses or choices, supporting or refuting hypotheses. The uniqueness and the variety of the learning experiences in the courses provided the students with

> many opportunities to understand the tentativeness of scientific findings. (p. 291)

As such, "the authors believed that students completing a science methods course *should* have developed [italics added] a more tentative view of science because of the nature of the course" (Barufaldi et al., 1977, p. 291). The normative, "should have" tone of the authors' expectations regarding the influence of the science methods courses on students' views of science should be noted. Such a tone was indicative of a bias inherent in the present investigation. This bias is all the more relevant in case the researchers (or evaluators) were themselves instructors in these courses. The authors did not explicitly or implicitly clarify this crucial point. Moreover, instruction in the investigated courses was not observed or documented. Pending evidence to the contrary, the results of the present study should be considered with extreme caution.

Additionally, students enrolled in the science methods courses were assigned several tasks. They were supposed to present a child with a science skill-oriented learning event and describe the ensuing interaction in writing. Students were also asked to construct and present children with a "mystery box" (Barufaldi et al., 1977, p. 291) and videotape segments of the interaction with the children. The authors did not provide examples of the assigned science skill-oriented learning events nor did they explicate what a "mystery box" was. The elementary education majors were also expected to design a science skills test to assess children's mastery of science process skills (observing, inferring, hypothesizing, interpreting data, etc.). They were asked to present a small group of children with a science activity from *Science--A process Approach, Elementary Science Study, Science Curriculum Improvement Study, or BSCS (Biological Sciences Curriculum*

Study)--Elementary School Science Program. Students had to videotape 10 minutes of the latter lesson and analyze the verbal interactions relevant to learning. Finally, the students were supposed to set up, conduct, and report on a science investigation to solve a problem of their own choice.

Most of the above tasks, it should be noted, involved interaction with school children beyond what is usually possible within the context of science methods courses. The authors did not provide any information regarding the contexts within which those tasks were conducted. The participant elementary education majors enrolled in two of the science methods courses could have interacted, to varying extents, with school children because they were either student teaching or observing children in classroom settings. However, the students majoring in educational psychology had no such access to classroom children. As noted above, students were enrolled in different block courses that had student teaching, classroom observation, or no-classroom based components in addition to other educational courses. All this raised two concerns. The first related to the consistency of the treatment among the experimental group members, at least, as far as their interaction with school children was concerned. Had all the participants, like those majoring in special education, had no access to classroom children, then their experiences would have been genuinely different. Second, and more importantly, because participants simultaneously had varying experiences outside the context of the science methods course (student teaching, classroom observations, enrollment in various courses such as educational psychology, foundations, elementary reading methods, etc.) it would not be possible to solely attribute any gains in their understandings of the tentative NOS to their experiences within the science methods courses.

In analyzing the data, the authors used the two-group and three-group covariance regression models to conduct all possible pair-wise and tri-partite comparisons between the mean VS scores for the four groups, respectively. Though it was not clear from the report, it was safe to infer that only the posttest mean scores were the ones compared. Also, from the information provided, it was not clear whether the authors used the appropriate unit of analysis, in this case being the individual methods course. Moreover, given that all possible pair-wise and tri-partite comparisons were conducted, the authors did not use any measure to guard against the accumulation of error due to multiple testing. The analysis revealed no significant differences when pairs of treatment groups and all three treatment groups were compared. However, pair-wise comparisons between treatment groups and the control group as well as comparisons between pairs of treatment groups and the control group were significant at the 0.001 level. Barufaldi et al. (1977) thus concluded that "a methods course which stresses inquiry methods and procedures, emphasizing a hands-on approach integrated with individual problem solving, develops, alters, and enhances . . . preservice teachers'. . . philosophical view . . . toward the tentative nature of scientific knowledge" (p. 293).

This latter conclusion surely went beyond the limits of the present study. The authors did not limit their inference to the science methods courses investigated or the present sample. Rather, they over-generalized their results to all preservice teachers and all science methods courses. It should be noted that the results could not even be generalized to the population in the present study since the sample was "self selected" (Barufaldi, et al., 1977, p. 290). In any case, as noted earlier, it was difficult to attribute the results only to the science methods courses. Moreover, given that the authors did not report the pretest mean SV scores for the various groups, it was not possible to eliminate a possible testing effect and also it was difficult to assess the gains achieved by each group. However, if we assume that the groups did not differ on their pretest scores and that the control group mean score did not change from the pretest to the posttest, then the gains achieved could be assessed. The mean posttest VS score for the control group was 141. The mean posttest scores for the three treatment groups were 153, 149, and 148. As such, the gains achieved ranged between 3.5 and 6 percentage points. The authors did not comment on the practical significance of these gains. Moreover, given that there are 200 possible points on the VS instrument, and given that respondents can score 120 points by simply choosing the neutral responses, it was difficult to assess the extent to which the above scores reflect an understanding of the tentative nature of scientific knowledge. The authors did not explicate the participants' views prior to and after the completion of the methods courses. As such, it was difficult to assess the meaningfulness of the numerical gains demonstrated by the experimental group participants.

Riley (1979) argued that a lack of understanding of the NOS may be a major reason behind elementary school teachers' apprehension toward science. Riley continued that some science educators "suggest that this lack of understanding is the result of exposure to the products of science and little or no exposure to the processes of science" (p. 373). The author noted that there is a growing belief among science educators, though not empirically tested, that teachers' understandings of and attitudes toward science would improve as a result of first-hand, manipulative experiences and enhanced proficiency in the processes of science. This would, the author continued, entail an improved approach to science instruction where teachers place due emphasis on the process component of the elementary science curriculum. Thus, like other researchers (e.g., Barufaldi et al., 1977), the author adopted an implicit approach to teaching about the NOS through involving teachers in "doing science." Moreover, Riley assumed that teachers' conceptions of science would directly translate into their classroom practices. This latter assumption, as noted earlier, has been shown to be inaccurate (Lederman, 1992).

The study aimed to assess the influence of hands-on versus non-manipulative training in science process skills on preservice elementary teachers' knowledge of process skills, understandings of the NOS, and attitude toward science, science teaching, and method of instruction. The relationship between teachers' acquisition of science process skills and their science grade point average was also investigated.

The study had a 3 x 3 factorial design. The two independent variables were the treatment and science grade point average. The treatment had three levels: active-inquiry (hands-on), vicarious-inquiry (non-manipulative), and control. The science grade point average had three levels designated by the author as high, medium, and low. The author did not specify the cut-off limits for these latter designations. The criterion measures were teachers' scores on the *Science Process Measure for Teachers*, the TOUS, *Attitude Toward Science and Science Teaching Scales*, and *Attitude Toward Method of Instruction Inventory*.

The population in the present study comprised all student teachers enrolled in an undergraduate methods program who elected to student teach in either grade 1, 2, 3, or 4. According to the student teachers' grade point average (high, medium, or low), the population was divided into three groups. Thirty students from each group were randomly selected and assigned to one of the three treatment levels. The sample thus comprised 90 prospective elementary school teachers. No demographic or background information about the participants was provided. Random selection, however, served to alleviate concerns regarding the comparability of the three treatment groups. It should be noted, nevertheless, that Riley (1979) used "the number of science semester credits completed . . . as a covariate to equate subjects on possible influences of differing amounts of science experience" (p. 374). The three groups it seemed were, at least, not comparable in the number of science credit hours.

The procedures for the active-inquiry and vicarious-inquiry treatments were based on activities outlined in the AAAS *Guide for Inservice Instruction* (1971). The treatment in each case was presented in four, 1 1/2 hour sessions. The first session dealt with observing and classifying. The second involved activities that focused on inferring, predicting, and communicating with an emphasis on the use of graphs. The third session focused on using numbers, measuring, and the metric system. The final session dealt with using space/time relationships as well as their rate of change. The only difference between the aforementioned levels of treatment was student involvement. In the active-inquiry treatment, participants were trained in science process skills using a hands-on, manipulative approach. Participants in the vicarious-inquiry treatment group did not manipulate any materials. They were trained in science process skills using a demonstration approach. The instructor exclusively manipulated materials. Prospective elementary teachers in the control group viewed science related films for approximately the same amount of time.

To insure the fidelity of the treatments, all the active-inquiry and vicarious-inquiry sessions were videotaped and rated using the *Teaching Strategy Observation Differential*

(TSOD) (Anderson, James, & Struthers, 1974). The TSOD is an encoding matrix sheet on which the activities observed in the course of a classroom session are plotted at one-minute intervals. This observation instrument is sensitive to differences between a non-verbal, activity oriented classroom environment (active-inquiry) and a more verbal, teacher-directed classroom environment (vicarious-inquiry). Two observers rated the videotapes. Inter-rater agreement was established by consensus. The author did not calculate the inter-rater reliability. However, Riley (1979) noted that published inter-rater reliabilities for the TSOD range between 0.88 and 0.99. The author noted that the active-inquiry instructional strategy scored significantly higher than the vicarious-inquiry strategy in all four videotaped sessions and concludes that the treatments were employed as defined. The corresponding data, however, were not provided.

Four instruments were used in the present study. The preservice teachers' mastery of science process skills was measured using the *Science Process Measure for Teachers* from the AAAS *Science--A Process Approach.* The instrument's published composite Hoyt reliability was 0.89. The instrument's subsets and their corresponding published Hoyt reliabilities were: using number relationships (0.76), classification (0.68), using space/time relationships (0.71), observing (0.46), inferring (0.80), measuring (0.33), and communicating and predicting (0.80). The TOUS (Cooley & Klopfer, 1961) was used to assess participants' understandings of the NOS. The *Attitude Toward Science and Science Teaching Scales* (Moore, 1973) with respective published Hoyt reliabilities of 0.71 and 0.84 were used to assess participants' attitudes. Finally, the *Attitude Toward Method of Instruction Inventory* developed by the author was used to assess preservice teachers' attitudes toward the instructional approach employed in the study. The face validity of this latter instrument was established by a panel of experts and the Hoyt reliability calculated for the present sample was 0.93. It should be noted that except for the instrument developed by the author, the reliabilities for the sample in the present study were not calculated for the aforementioned instruments. Moreover, the author did not provide any evidence to support the validity of these instruments in assessing the respective aspects they purported to measure in the case of prospective elementary teachers. Finally, no information was provided on the type of items used in these instruments nor on their possible range of scores.

Appropriate statistical analyses were used in the present study. Three specific null hypotheses were tested in the case of each of the cognitive (knowledge of science process skills) and affective (understandings of the NOS, attitude toward science, and attitude toward science teaching) measures. (In this regard, it should be noted that Riley (1979) like Barufaldi et al. (1977) explicitly labeled understanding the NOS as an affective outcome.) The first null hypothesis posited that the active-inquiry group mean scores were equal to those of the control group, with the alternative hypothesis being that the active-inquiry group mean scores were lower than those of the control group. The second null hypothesis was that the vicarious-inquiry group mean scores were equal to those of the control group, with the alternative hypothesis being that the vicarious-inquiry group mean scores were lower than those of the control group. The third null hypothesis was that active-inquiry and vicarious-inquiry groups mean scores were equal with the alternative hypothesis being that they were different. Directional tests were only used in the case of cognitive measures and were justified by the assumption that the treatments would not tend to decrease the active and vicarious treatment groups mean scores relative to the control group scores. One tailed tests were used in testing directional hypotheses. Two-tailed tests were utilized in all other cases. The significance levels in the case of cognitive and affective measures were set *a priori* at the 0.1 and 0.05 level. Thus, the author was ready to take a greater risk in getting a type I error in the case of the cognitive measure. This reflected some doubts on the part of the researcher regarding the effectiveness of the treatment in enhancing teachers' mastery of science process skills.

The ANCOVA was appropriately used to assess whether group mean scores on the criterion variables were significantly different for treatment, science grade point average, and treatment by science grade point average interactions. The number of science semester hours completed by the prospective teachers was used as a covariate. In case significant differences were found, the Newman-Keuls multiple comparison technique was used. It should be noted that this technique is conservative and the penalty it puts on getting significant differences increases with the number of pair-wise comparisons conducted. Thus, among the studies reviewed in the present paper, Riley (1979) was among the few researchers who took appropriate measures to guard against the accumulation of error due to multiple testing. The author also used the appropriate unit of analysis (N= 3).

As far as science process skills were concerned, the analyses revealed that the active and vicarious inquiry groups scored significantly higher than the control group ($p < 0.05$). Analysis of the *Process Measure for Teachers* subsets revealed that the treatment groups scored higher on all subsets than the control group. However, the differences were only significant ($p < 0.001$) for classification and using space/time relationships. Nevertheless, the mean scores for the active-inquiry and vicarious-inquiry groups were not significantly different on all subsets. As far as science grade point average relating to the same measure was concerned, the analysis revealed that the high grade point average group scored significantly higher ($p < 0.01$) than the low group. There were significant differences ($p < 0.05$) between the high and low, and medium and low groups on inferring and using space/time relationships. Significant interactions ($p < 0.05$) were only found between treatment and science grade point average for using space/time relationships and observing. The author did not comment on the practical significance of any of these differences.

As far as attitude toward science and science teaching were concerned, the analyses revealed no significant differences between the three groups. F-values were less than the critical values for main effects (treatment and science grade point average) and interactions.

What was more important for the purpose of the present review was that there were no significant differences between the groups mean TOUS scores related to the treatments. As such, preservice teachers in the active-inquiry, vicarious inquiry, and control groups did not differ in their understandings of the NOS. The mean TOUS score for the high grade point average group was significantly higher ($p < 0.05$) than that for the low group. The author, however, did not comment on the practical significance of this difference nor did he provide mean scores for the various groups to allow an assessment of the difference.

The author thus concluded that a non-manipulative approach to training prospective elementary teachers in science process skills was as effective as hands-on manipulative instruction. Moreover, prospective elementary teachers' attitudes toward science and science instructions, and their understandings of the NOS were not significantly improved through a hands-on approach to science instruction. These results stand in sharp contrast with those of Barufaldi et al. (1977) who concluded that "doing science" can enhance prospective elementary teachers' conceptions of the NOS. Moreover, the author concluded that acquisition of science process skills and understandings of the NOS were related to elementary majors' science grade point average. This latter result was contrary to the findings reported by other researchers (e.g., Carey & Stauss, 1968, 1969, 1970; Kimball, 1967-68). However, given that mean TOUS scores were not provided in the present study, it was difficult to assess the meaningfulness of the difference in the TOUS scores between elementary education majors in the high and low grade point average groups.

Scharmann and Harris (1992) noted that the teaching of evolutionary biology can engender sensitivities and confrontation especially if students perceive the topic to be in direct conflict with their beliefs and value systems. As such, some teachers avoid teaching about evolution altogether. Others opt to teach about evolution indirectly through genetics, reproductive and mating strategies, environmental stress, ecology, etc. Even those teachers who choose to explicitly teach evolutionary theory openly express concern and anxiety about their abilities to answer ensuing student questions. The authors continued that some research studies (e.g., Scharmann, 1990) have indicated that the use of diversified instructional strategies that emphasize peer interaction and small-group discussions may help to alleviate concerns associated with teaching about evolution. Such strategies free science teachers from having to assume the role of the expert or final arbitrator on evolutionary theory. However, the successful implementation of such strategies, the authors continued, presumes that teachers have adequate understandings of the NOS and are comfortable with the theory of evolution.

Scharmann and Harris (1992) noted that some science educators advocate that specialized courses in the history and philosophy of science or direct study of the NOS can serve to improve prospective science teachers' conceptions of the NOS. Others advance that developing appropriate conceptions of the NOS should come as the indirect result of well sequenced undergraduate studies. Scharmann and Harris (1992), contrary to the primary author's earlier position on the issue (Scharmann, 1988a, 1988b, 1990), noted that developing a functional understanding of the NOS cannot be left to chance. Such an understanding should come as the result of the direct study of the NOS through a focus "on scientific theories and their developmental history" (Scharmann & Harris, 1992, p. 376). The authors continued that "although the completion of a specialized course of study does not necessarily provide a comprehensive picture, it does provide . . . an introductory perspective and foundation upon which an understanding of the nature of science can be built" (Scharmann & Harris, 1992, p. 376). As such, it seemed safe to infer that Scharmann has shifted his emphasis from an implicit to a more explicit approach in the attempt to enhance teachers' conceptions of the NOS. However, on closer examination, it turned out that this apparent shift in argument did not impact practice. Elsewhere in the report, Scharmann and Harris noted that some science educators argue that "changes in an understanding of the nature of science can be . . . enhanced through a more indirect and applied context . . . The investigators accepted [this] . . . view, and through a variety of readings and activities provided opportunities" for participants to discuss their views of the NOS (p. 379).

The data for the present study were collected at a 3-week, NSF-sponsored summer institute for inservice high school science teachers. The institute purported to (a) enhance participants' understandings of the NOS, (b) update participants' knowledge of biological and geological concepts relevant to teaching about evolution, (c) enhance participants abilities to assess and address students' misconceptions regarding evolutionary theory, (d) help participants to develop instructional units that integrate the NOS, science content, and diversified instructional strategies for teaching evolutionary biology, and (e) introduce participants to the developmental aspects related to students' conceptions about the NOS and evolutionary theory.

The present study aimed to assess participants' understandings of the NOS and their acceptance of the theory of evolution. The study also aimed to assess the effectiveness of the summer institute in improving participants' understandings of the NOS and reducing their anxieties about teaching evolution. Finally, the study aimed to assess the stability, over time, of any gains in understanding the NOS and whether the institute promoted the adoption of peer discussion for teaching evolution among participants.

The sample comprised 19 inservice secondary school science teachers, 12 male and 7 female. Participants were selected according to several criteria. These included having secondary teacher certification in biology or earth science, a degree in science education, two or more years of teaching experience, and a letter of recommendation from a district administrator. Priority was given to applicants from rural areas who assumed primary responsibilities for teaching biology and earth science. Of the 19 participants, six taught biology and two taught earth science. The remaining 11 teachers taught both subjects. No additional information about the teachers was provided. The authors, nevertheless, claimed that there were no significant correlations between the participants' age, years of teaching experience, gender, or academic degrees with any of the criterion measures. No data were provided to support this claim.

The study had a one-group pretest-posttest design. The summer institute served as the experimental treatment. A battery of four instruments was administered following instruction on the first and last days of the institute. The NOSS (Kimball, 1967-68) was used to assess participants' understanding of the "philosophical" NOS. The NOSS has 29, three-point Likert-type items with scores ranging from 0 to 87 points. Kimball reported a split-half reliability of 0.72. Additionally, an untitled 25-item, five-point, Likert-type instrument developed by Johnson and Peeples (1987) was used to assess participants' "applied" understanding of the NOS (20 items) and their acceptance of the theory of evolution (5 items). The corresponding published reliabilities for the two components were 0.78 and 0.77. The authors noted that the validity of both instruments was established by their respective developers. However, both instruments were not validated for use with inservice science teachers. The authors did not provide any evidence to support the validity of such use. Moreover, the authors did not calculate the instruments' reliabilities for the present sample. Ten, five-point Likert-type items developed by the primary author were added to the Johnson and Peeples instrument to assess participants' understandings of evolutionary content. No evidence regarding the validity or reliability of this latter component was provided. Finally, it should be noted that the authors did not delineate the notions of "philosophical" and "applied" understandings of the NOS.

The *State-Trait Anxiety Inventory* (STAI) (Spielberger, 1983) was used to assess participants' anxiety about teaching evolution. The STAI has two subscales. The S subscale measures "state" anxiety or anxiety about a specific situation (e.g., teaching evolution). This anxiety is subject to change as a result of training or educational experiences. The T subscale measures "trait" anxiety or individuals' susceptibility to anxiety. Trait anxiety is less prone to change. The authors did not provide any information on the nature of the STAI items or the range of possible scores. Finally, the *Stages of Concern* (SoC) instrument (Hall, George, & Rutherford, 1979) was used to assess participants' concern for the use of peer-discussion strategies in teaching about evolution. The SoC has 35, seven-point scale items. The scale reflects a continuum from respondents perceiving an item as being totally "irrelevant" to them to being "very true" of what they believe. The 35 items are divided into 7 subscales (each comprising five items) that represent a continuum of stages of concern from unfamiliarity to great familiarity with a certain innovation. These stages, in increasing order of concern, are awareness, informational, personal, management, consequences, collaboration, and refocusing. Each subscale or stage is represented by a standardized percentile score. In the case of both the STAI and the SoC, the authors noted that the developers have presented evidence for the reliability and validity of the instruments. No such evidence for the sample in the present study was provided.

The institute spanned 15 days. Participants met for six hours each day. During the first two weeks participants were presented with biological and geological content relevant to evolutionary theory. In addition various instructional activities and teaching approaches were taught and modeled by the authors, respectively. Teachers were explicitly required to engage in discussions about the aforementioned content and teaching strategies. The activities during the first two weeks comprised lectures, small-group discussions, field trips, and other inquiry based instructional methods.

Two themes pervaded all the aforementioned activities throughout the first two weeks of the institute. The first was an attempt to shift participants from direct teacher-centered to more indirect student-centered instructional approaches. The authors argued that by allowing students to share the responsibility for their learning, student-centered approaches might help to move them from a dualistic, right/wrong to a more global, better/worse perspective of reality. A restricted right/wrong perspective, the authors continued, might contribute to the anxiety associated with learning evolutionary theory especially in the case of students who perceive their views or values to be in direct conflict with the tenets of this theory. During the first week, the participants were also assigned readings in natural history (e.g., Gould's (1983) *Hen's teeth and horses toes*) and conducted several inquiry based investigations related to evolutionary concepts. These activities were suggested as useful for student-centered instructional approaches. In addition peer-group discussions were promoted as a useful strategy to reduce anxiety related to teaching evolution. Instead of having to assume the role of an expert on evolution, the teacher can have students in small groups explore and discuss evolutionary ideas and concepts. The teacher would then facilitate discussions and assume the positive role of resolving conflicts in case such conflicts arise. Peer-group discussions were justified for the participants by arguing that such approaches would actively and personally involve students in learning; reinforce the learning of affective instructional outcomes such as working within, identifying with, and belonging to a group; and allow the teacher to establish more opportunities for student-to-student and student-to-teacher interpersonal interactions. The second theme that pervaded the first two weeks activities was an attempt to promote participants' conceptions of the NOS through readings and discussions. As noted above, direct instruction on the NOS was not used. The final week of the institute was used to provide the participants with an opportunity to integrate what they have learned by designing instructional units on evolution utilizing the various approaches and activities presented at the institute. Participants also presented parts of the planned instructional sequences to their peers.

Given a relatively small sample size and the fact that repeated measures were taken on the same sample, the authors appropriately used the non-parametric, Wilcoxon signed rank test to assess the significance of the differences between participants' pretest and posttest mean scores on the various instruments. However, the authors did not take any measures to guard against the accumulation of error due to multiple tests. The analysis did not reveal significant differences between pretest and posttest mean NOSS scores ($Z = 0.76$, $p > 0.05$). The authors thus concluded that participants' conceptions of the "philosophical" NOS were not influenced by the institute experiences. This result, they continued, was consistent with Kimball's (1967-68) conclusion that students' conceptions of the NOS were fairly stable by the time they finish their undergraduate studies. However, statistically significant differences were obtained in the case of the Johnson and Peeples (1987) instrument ($Z = 2.74$, $p < 0.01$). The authors thus concluded that the participants' understandings of the "applied" NOS was significantly improved as result of participating in the institute. The authors, however, did not comment on the practical significance of the gain achieved by the participants. Out of 100 possible points for this instrument the pretest and posttest mean scores were 61.74 and 63.26, respectively. The mean gain (+1.52) only amounts to about 1.5 percentage points. Moreover, in the absence of a control group, it was even difficult to attribute this small gain to the treatment. Such a difference may well be explicable in terms of a possible testing effect. Additionally, as noted earlier, the authors did not define what they meant by the "applied" NOS. In this regard, they did not characterize the participants' views prior to or on completing the institute. As such, it was difficult to assess the meaningfulness of the reported gains.

The authors reported statistically significant gains in participants' acceptance of the theory of evolution ($Z = 2.93$, $p < 0.01$) and understandings of evolutionary content ($Z = 2.72$, $p < 0.01$). The corresponding mean gains in both cases amounted to about 5 percentage points. As far as the STAI was concerned, there was no significant change in participants' scores on the T subscale ($Z = -0.37$, $p > 0.05$). As such, participants' trait anxiety was not significantly reduced. This result, however, was not surprising given that trait anxiety is believed to be resistant to change as a result of educational or training experiences. The participants' state anxiety on the other hand was significantly reduced. The STAI subscale S mean score was significantly reduced ($Z = -3.51$, $p < 0.001$). The S subscale pretest and posttest mean scores were 35.58 and 28.26, respectively. Even though this decrease in mean scores (-7.32 points) seemed to be promising, it was not possible to assess its practical significance given that no information on the range of possible scores for the STAI was provided. Finally, a qualitative analysis of the SoC pretest and posttest percentile data revealed a shift from the lower levels (awareness, informational, and personal) toward higher levels of concern (consequence, collaboration, and refocusing). This shift was consistent with "a moderate consideration for the use of peer-discussion instructional format for the teaching of evolution" (Scharmann & Harris, 1992, p. 383). The authors, however, were careful to qualify this interpretation. The SoC is designed to measure long-term adoption of innovations. The observed shift may only indicate that by the end of the institute participants had a better understanding of the peer-discussion format as presented by the authors.

In order to assess the long term influence of the institute and the stability of the achieved gains, the authors conducted a follow-up workshop 8 months after the conclusion of the summer institute. Of the original 19 participants, only 9 attended the follow-up workshop. During the workshop participants discussed their reactions to pre-assigned readings and their experiences in teaching evolution during the past few months. They also engaged in peer-discussion activities. Additionally, the participants completed the same battery of instruments that was used in the summer institute. It was not clear whether the instruments were administered at the beginning or the conclusion of the workshop. This might be relevant given that the SoC was intended to measure the participants' acceptance of the peer-discussion instructional format and that they were engaged in this very instructional format during the workshop. As such, if the instruments were completed at the conclusion of the follow-up workshop, SoC scores might reflect the influence of the workshop rather than any long-term effects of the summer institute.

The authors claimed that the subgroup that attended the follow-up workshop was representative of the original sample. This conclusion was solely based on the fact that both groups had similar SoC profiles. However, it is likely that only those teachers who had positive experiences at the summer institute would attend the follow-up workshop. Given the lack of any evidence to the contrary, it was more likely than not that this sub-sample was different from the original one.

The authors noted that except for the SoC scores, participants' mean scores on all the instruments declined. None of the declines, however, achieved statistical significance. No data was provided in this regard. However, the SoC percentile scores showed an increase indicating more acceptance of the peer-discussion instructional format. However, this conclusion might be an artifact of the nature of the sub-sample that attended the workshop or, as noted above, the time of administration of the instruments. The authors were careful to note that in the absence of a control group, any conclusions of the present study should be viewed as tentative. They concluded that participants' understandings of the "applied" NOS and their acceptance of the theory of evolution were improved as a result of their experiences at the summer institute. However, the increase in participants' scores on the Johnson and Peeples (1987) instrument did not seem to be of any practical significance.

Explicit approaches.

Ogunniyi (1983) noted that science educators, in general, agree that a basic knowledge of the history and philosophy of science could enhance one's understandings of the NOS. Furthermore, teachers' conceptions of science influence their students' conceptions. If these two assumptions were accepted, Ogunniyi continued, it follows that enhancing teachers' views of the NOS is prerequisite to any effort aimed toward improving students' conceptions of the scientific enterprise. It should be noted that Ogunniyi took for granted the assumption that teachers' conceptions of the NOS "will certainly contribute to the development of valid views of science . . . among the students they will teach later on" (p. 198). This assumption has not been validated by empirical research studies (Lederman, 1992).

The present study aimed to assess the influence of a history/philosophy of science course on student teachers' conceptions of the NOS. The study had a one-group pretest-posttest design. Participants were 58 student teachers enrolled in the course. It should be noted that "no direct reference . . . [was made] . . . to the fact that the subjects were under investigation" (Ogunniyi, 1983, pp. 194-195). Only 54 participants completed both pretest and posttest. The author did not provide any information whatsoever about the student teachers. It was even not clear whether the participants were prospective elementary or secondary science teachers. The lack of such crucial information would necessarily undermine any attempt to generalize (on statistical basis) any results beyond the present sample. More importantly, it would severely limit the usefulness of the present study in terms of assessing the transferability of its conclusions to reasonably similar situations.

The NOSS (Kimball, 1967-68) and an untitled instrument developed by the author (Ogunniyi, 1982) were used to assess student teachers' conceptions of the NOS and language of science (LOS), respectively. The NOSS was administered during the first day of the course and again one week prior to its conclusion. The other instrument was administered on both occasions one week after the administration of NOSS. The NOSS has 29 items, while the other instrument has 64 items. No information was provided on the nature of the items in the Ogunniyi (1982) instrument. The published reliabilities for the NOSS and the Ogunniyi (1982) instrument were 0.72 and 0.91, respectively. The author, however, did not calculate the reliabilities for the sample in the present study.

More importantly, the author did not provide any evidence whatsoever to show that the instruments were valid in assessing student teachers' conceptions of the NOS and LOS. In this respect, it should be noted that the instrument developed by the author was validated with a group of "practicing teachers" (Ogunniyi, 1982, p. 26) and the NOSS was validated with a sample of college graduates who held degrees in the biological or physical sciences and non-science fields. The author noted that responses to the two instruments were assessed in accordance with two models derived from the work of major historians and philosophers of science such as Conant, Carnap, Hempel, and Popper. The author, however, did not explicate the aspects of the NOS or LOS model.

The investigated course was a science education course that presented student teachers with integrated topics in the history and philosophy of science. The author developed the course. Participants met once a week over the course of 16 weeks. The duration and nature of these weekly meetings were not elucidated. Ogunniyi (1983) noted that the course covered several topics including:

> Origin of scientific thought; contribution of Greek philosophers and others to the growth and development of science; significant scientific revolutions and their consequences; nature of scientific inquiry; epistemological foundations of science; science and superstition; characteristics of scientific and traditional societies; [and] scientific literacy. (p. 194)

Lectures were augmented by discussions and outside readings. Beyond this broad characterization, the author did not provide any details about the course. Moreover, no observations of instruction were conducted. Ogunniyi noted that the course aimed to enhance students' conceptions of the NOS and LOS. However, no attempts were made to gear instruction toward the statements of the aforementioned instruments. It was not clear whether the investigator was the course instructor. If this were the case, then some bias would most probably underlie the present investigation. This possible bias was all the more relevant given the lack of information on, and improper documentation of several crucial aspects of the study (e.g., delineating the population, sample characteristics and selection procedures; documenting instruction to insure that specific aspects of the two instruments were not explicitly addressed).

Two specific null hypotheses were tested. The hypotheses posited that there will be no significant differences in student teachers' conceptions of the NOS and LOS (as measured by the relevant instruments) prior to and after completing the history/philosophy of science course, respectively. ANOVA was used to compare the mean pretest and posttest scores for the NOSS and LOS instrument.

The analysis revealed statistically significant differences between participants' pretest and posttest scores on the NOSS ($F = 7.74$, $p < 0.05$) and the LOS instrument ($F = 21.54$, $p < 0.005$). Ogunniyi (1983) concluded that the student teachers showed "significant improvement in their understanding of the nature of science . . . [and] . . . the language of science after an exposure to the . . . course" (p. 197). The author, however, did not comment on the practical significance of these results. In this regard, the participants' mean pretest and posttest NOSS scores were 8.76 (with a standard deviation of 4.20) and 10.72 (with a standard deviation of 2.96), respectively. The mean gain (+1.96) amounted to about 3 percentage points. Additionally, given that there are 59 possible points on the NOSS, the mean posttest score of 10.72 does not seem to reflect adequate understandings of the NOS. On the other hand, the participants' mean pretest and posttest LOS scores were 35.50 (with a standard deviation of 3.59) and 38.48 (with a standard deviation of 3.01), respectively. The mean gain (+2.98) amounts to about 5 percentage points. Also, given that there are 64 possible points on this latter instrument, the mean posttest score of 38.48 does not seem to reflect adequate understandings of the LOS. The author did not elucidate the participants' understandings of the NOS or LOS prior to and after the conclusion of the course. As such, it was difficult to assess the meaningfulness of the reported mean gains.

The present study suffered from serious limitations. There was no evidence whatsoever to indicate that the present sample was representative of any larger population of student teachers. Such a population was not even defined. No evidence was given to support the validity of the instruments used to assess participants' conceptions of the NOS and LOS. Additionally, there were several threats to internal validity (maturation, history, instrumentation, and interaction of selection and other factors) and external validity (interaction of testing and treatment and of selection and treatment) that are inherent to a one-group pretest-posttest design. Despite all that Ogunniyi (1983) made the overarching generalization that "a science education course . . . . which includes a well integrated rudimentary knowledge of the history and philosophy of science will certainly contribute to the development of valid views of science among prospective science teachers" (p. 198). This conclusion was surely not warranted by the present study.

Akindehin (1988) argued that science teaching should emphasize the NOS, content of science, science processes, and science-related attitudes. To be able to address these various aspects of science, the author continued, science teachers should themselves develop adequate conceptions of the NOS and favorable attitudes toward science. Akindehin emphasized that achieving this latter goal "should be planned for instead of being anticipated as a side effect or secondary product of . . . traditional science content or science methods classes" (p. 73). The author thus advocated an explicit approach to improving prospective science teachers' understandings of the NOS through the development of "a special instructional package as part of the science-teacher education program" (Akindehin, 1988, p. 73). The author noted that efforts geared toward this end (e.g., Gruber, 1962; Kimball, 1967-68; Ogunniyi, 1983) have been correctional in nature. It followed that there was a need for experimental studies in order to establish the causal links between efforts to improve teachers' conceptions of science and attitudes toward science, and the achieved gains.

The present study reported on the development of an instructional package, the *Introductory Science Teacher Education* (ISTE) package, and the assessment of its influence on prospective secondary science teachers' conceptions of the NOS and attitudes toward science. The author developed the ISTE. A comprehensive review of the literature on the NOS, the history and philosophy of science, philosophy, general science, and science teaching was utilized to generate a tentative outline for the course. The outline was scrutinized by experts in curriculum development, the history and philosophy of science, philosophy, science, science education, and teacher education. The outline was accordingly modified to enhance the content validity of the package. The ISTE was designed to be delivered in weekly one-hour sessions over the course of 12 weeks. The package comprised nine units that included lectures, discussions, and laboratory sessions.

The first unit, *Forms and Fields of Knowledge*, introduces student teachers to the nature of knowledge and varying ways of knowing. The unit emphasizes that science is only one way of generating knowledge about the natural world. The second unit, *Nature* *of Science*, introduces students to various aspects of the scientific enterprise and scientific disciplines. The author did not delineate the aspects of the NOS emphasized. The third unit, *Ways of Scientists*, presents student teachers with a model of scientific inquiry. The model emphasizes aspects of scientists' work such as generating and defining problems, generating hypotheses, and experimenting. It also emphasizes the role of established theory, ethical and regulative mechanisms, logical and mathematical systems, and creativity in scientific investigation. Akindehin (1988) noted that the unit aims to "clarify the view that scientists usually approach problems in systematic ways" (p. 75). However, concerns about presenting students with a rigid view of scientific inquiry are alleviated by the fact that the aforementioned model explicitly directs students' attention to the dynamic interactions between the various aspects of inquiry. The fourth unit, *Class Discussion--Francesco Redi and the Generation of Insects*, is intended to reinforce student teachers' understandings of the various aspects of scientific inquiry. During the discussion, students map the similarities between Redi's work on refuting the notion of spontaneous generation and the various points of the model with which they were presented in the former unit. The fifth unit, *History of Science*, presents students with an overview of the state of knowledge before the Greeks. Broad developments in scientific thought are then traced all the way from the 4th up to the 20th century. The sixth unit, *Class Experiment*, provides student teachers with the opportunity to put to practice their understandings of scientific inquiry. Students are given five different experiments that require them to find answers to genuine problems in chemistry, biology, and physics. The seventh unit, *Class Discussion--Science and Superstition*, presents students with natural phenomena (e.g., the bending of potted plants toward a window) and various corresponding explanations (e.g., the plants bend because they normally grow outdoors, or because other plants on the outside were calling on them, etc.). The student teachers are then invited to discuss and compare scientific versus supernatural explanations of those phenomena. The eighth unit, *Class Discussion--The New Light*, exposes student teachers to persuasive communication in the hope of brining about a change in their attitudes toward science. For instance, student teachers discuss Edison's invention of the electric bulb and its ensuing applications. The justification behind this latter activity was not presented, nor was the concept of "persuasive communication" delineated. The final unit, *Class Discussion--The Scientist at Work*, presents students with the humane aspects of scientific work. The unit utilizes certain scientific events to specifically highlight those aspects of scientific investigation that usually do not appear in the polished and published reports. Examples of the events used in this latter unit include scientific attempts to determine the origin of life on Earth and the age of the Earth.

The study had a pretest-posttest control-group design. Participants were not randomly assigned to the experimental and control groups. The participants were all the prospective secondary science teachers enrolled in the first year of a three-year program leading to teacher certification in two teacher education colleges in Nigeria. The participants were divided into four groups. The two experimental groups, with a total of 65 student teachers, were enrolled at the Adeyemi College of Education. The two control groups, with a total of 80 student teachers, were pursuing studies at the Ondo State College of Education. The two colleges are 83 kilometers apart. This served to restrict, virtually completely, any experimental treatment diffusion. The two teacher colleges were under the supervision of the same university, the University of Ife, Nigeria. The two institutions had the same admission requirements and ran identical teacher training programs. As such, members of the control and experimental groups were expected to be comparable and to have had very similar academic experiences throughout the course of the study. These assumptions, however, were not supported by any empirical data. The author did not provide any demographic or background information about the participants whatsoever.

Two instruments were used in the present study. The NOSS (Kimball, 1967-68) was used to assess participants' conceptions of the NOS. The NOSS has 29, three-point Likert-type items with scores ranging from 0 to 59. The NOSS was validated with a sample of American college graduates who held degrees in the biological or physical sciences and non-science fields. The second instrument, the *Teacher Science-Related Attitude Scale* (TESRA), was used to assess student teachers' attitudes toward science. The author noted that the TESRA was adapted from two other instruments, the *Test of Science-Related Attitudes* (TOSRA) (Fraser, 1981) and the *Inquiry Science Teaching Strategies* (ISTS) (Lazarowitz & Lee, 1976). Both TOSRA and ISTS are five-point Likert-type instruments and were developed to measure attitudes toward science. The former was validated with Australian secondary school students while the latter was designed for science teachers. The published reliabilities for the seven TOSRA subscales and the 40 ISTS items ranged between 0.67 and 0.92. The TESRA, the instrument used in the present study, comprised six TOSRA subscale and 10 ISTS items. The range of possible scores for the TESRA was not reported. The TOSRA subscales were Social Implications of Science, Normality of Scientists, Attitude Toward Scientific Inquiry, Adoption of Scientific Attitudes, Enjoyment of Science Lessons, Leisure Interest in Science, and Inquiry Science Teaching Strategies.

The author did not calculate the instruments' reliabilities, total or subscale, for the sample in the present study. It should be noted that reporting the reliabilities for the TOSRA and ISTS provide no evidence toward the reliability of the hybrid instrument, the TESRA. The reliability and validity of this latter instrument should be independently established. Indeed, the TESRA was administered to a group of 30 Nigerian secondary school students to validate it for the Nigerian context. The Spearman-Brown split-half reliability for this group was 0.81. The author did not explain why the instrument was not validated with prospective secondary science teachers nor did he present any evidence to show that the participants were, in any respect, comparable to the sample used to validate the instrument. Moreover, the author did not make any attempt to validate the NOSS for the Nigerian context. As such, concerns about the validity and reliability of the two instruments could not be dismissed.

At the outset of study, two groups, each comprising 30 student teachers, were randomly selected from the participants at the two institutions. Student teachers in the two groups were administered the NOSS and the TESRA as a pretest. Next, students in the two experimental groups (one of which was not pre-tested) received the ISTE instructional package in addition to their regular coursework. Meanwhile, at the other teacher training college, student teachers in the two control groups were enrolled in their regular coursework. As such, the experimental and control group experiences were similar save the experimental treatment. The author delivered the ISTE package to the experimental group members. Two other lecturers assisted in the unit on classroom experiments. One week following the conclusion of the ISTE instructional package, student teachers in all groups were administered the NOSS and the TOSRA. Akindehin (1988) noted that “none of the students had advance notice of the posttests. As such they could not ‘prepare’ for the tests”(p. 78). Administering the pretest to only one of the two experimental groups would allow the author to assess the interaction between the treatment and testing.

To assess the significance of any interactions between the treatment and testing, the generated data were appropriately analyzed in accordance with a 2 x 2 factorial design. The treatment (experimental versus control) and the pretest (having taken the pretest versus not) served as the main effects (or independent variables). Student teachers’ scores on the NOSS and the TESRA served as the dependent variables. Two-way ANOVA was used in the analysis. The use of ANCOVA would have been more appropriate to control for possible differences between the groups. As far as the TESRA was concerned, the analysis revealed no statistically significant results for the pretest and the interaction effects. The author, however, remained silent about the results of this analysis in the case of the NOSS scores. As such, it was safe to infer that statistically significant results were obtained for the pretest effect or the interaction effect in the case of the NOSS. This would undermine the statistical significance of any differences obtained between pre- and posttest mean NOSS scores.

For the TESRA scores, a statistically significant difference ($p = 0.001$) was obtained for the main effect. The grand mean TESRA score was 270.84. However, given that the number of items or the range of possible scores on the TESRA were not provided, it was difficult to assess the meaning of such a score. The standard deviations from the mean for the experimental and control groups were 7.07 and -7.07, respectively. As such, the statistical significance was in the favor of the experimental group. In the case of the NOSS, a statistically significant result (p = 0.008) was obtained for the treatment effect. Out of 58 possible points on the NOSS, the grand mean score was 51.84. This mean score, it should be noted, is the highest reported NOSS score among the studies presently reviewed. The standard deviations from the mean for the experimental and control groups were 1.41 and -1.41, respectively. As such, the statistical significance was in the favor of the experimental group. It should be noted, however, that in the case of both instruments, the author did not report the mean pre-test and post-test scores. As such, it was difficult to assess the practical significance of the gains achieved by the student teachers as a result of the ISTE package. Moreover, the author did not explicate the participants' understandings of the NOS or attitudes toward science prior to and after the treatment. Such information would have been helpful in assessing the meaningfulness of the achieved gains.

Having established the absence of interaction effects in the case of the TESRA composite scores, the author proceeded to assess the significance of the differences obtained on the various subscales of the instrument. One-way ANOVA was used in this analysis since only the scores of the pre-tested participants in the experimental and control groups were used. Following the ANOVA, the step-wise discriminant analysis subprogram of the *Statistical Package for the Social Sciences* (SPSS) software was used with the treatment as a grouping variable and the TESRA subscales scores as the discriminating variables. The analysis revealed that four TESRA subscales significantly discriminated between student teachers in the experimental and control groups. These four subscales (along with the Wilke's Lambda values and significance levels) arranged in decreasing discriminatory powers were: Attitude Toward Scientific Inquiry ($\lambda = 0.94$, $p < 0.05$), Inquiry Science Teaching Strategies ($\lambda = 0.90$, $p < 0.05$), Enjoyment of Science Lessons ($\lambda = 0.86$, $p < 0.05$), and Leisure Interest in Science ($\lambda = 0.81$, $p < 0.01$).

The author thus concluded that as a result of being exposed to the ISTE package, the participant prospective secondary science teachers achieved better understandings of the NOS and developed more favorable attitudes toward science. The package was more effective than traditional science and science methods classes to which members of the control group were exposed.

Shapiro (1996) argued that students are often exposed to what Latour (1987) labeled the "face of science that knows" or science as a substantive body of knowledge. Those students, however, are less often, if ever, given opportunities to learn about the "face of science that does not yet know" or science as a complex endeavor of investigation. By the time students leave high school, most of them would have had limited experiences with the nature of investigation in science and many would have developed unfavorable attitudes toward science and science teaching. This is especially the case with many elementary education majors whose encounters with science are limited, by and large, to their school years. As such, Shapiro continued, many prospective elementary school teachers often express anxiety about and fear of teaching science. Unless teacher preparation programs, the author suggested, provide those student teachers with favorable experiences with science, they are apt to provide their students with experiences similar to their own. And even though, Shapiro noted, a number of science educators "have asserted that both teachers and learners can benefit from learning about the nature of science by working as scientists do" (p. 536) there have been only a few studies that investigated the kinds of learning that occur when students participate in independent investigations in science.

Shapiro (1996) noted that a review of the literature indicated that, in general, preservice teachers possess inadequate conceptions of the NOS. Moreover, the literature comprised many suggestions to the effect that a focus on the NOS can help improve teachers' conceptions. However, Shapiro continued, the situation seemed to be more complex than often envisioned since many studies (e.g., Aguirere, Haggerty, & Linder, 1990; Lederman & Zeidler, 1987) have indicated that some approaches to teaching about the NOS have very little or no effect on learners' conceptions. For instance, some research studies (e.g., Lederman, 1986, 1992, 1995) have indicated that learners' conceptions were not apt to change unless the NOS was explicitly addressed during instruction.

The present study reported on the changes in one prospective elementary teacher's thinking about the nature of investigation in science during her involvement in designing a study to answer a simple research question. The present case study emerged from a larger investigation that was guided by the following research questions: (a) How can changes in elementary student teachers' thinking and feelings about the nature of investigation in science be studied during their involvement in independent investigations in science? (b) What are the changes in elementary student teachers' thinking and feelings about the nature of investigation in science during their involvement in independent investigations in science? (c) What implications do these changes have for teacher preparation programs?

Data for the larger study were collected over the course of four years. More than 210 student teachers in four cohorts were involved in the study. During their science methods class, each cohort of student teachers worked on the assignment: "Inviting Investigations" (Shapiro, 1996, p. 541). The assignment was intended to help prospective teachers develop an in-depth understanding of science and scientific procedures of investigation. Over the course of about 7-weeks devoted to the assignment, student teachers were asked to pose a simple genuine problem, generate a research question, and then design a systematic procedure to answer their question. The author and other research assistants helped the student teachers in defining their problems and refining their research questions. They encouraged the students to think about relevant variables and how to define and control them during the study. Throughout the assignment, student teachers kept journals of the various stages of their investigations. After the completion of the project, the students designed a display where they summarized their study and shared their findings with peers and visiting children from neighboring schools.

During the first three years of the study, a research tool, the repertory grid, was developed and refined. Details on the development of this tool were not provided. Jan, the student teacher chosen for the case study presently reported, was selected from the fourth year cohort. This cohort had 38 students, 34 female and 4 male, enrolled in an elementary science methods class "for generalist teachers in a North American teacher education program based in a university faculty of education" (Shapiro, 1996, p. 542). Four of the participants were majoring in science education and 12 had university degrees prior to joining the bachelor teacher preparation program. About 90% of the participants indicated that they had no similar experiences with independent investigations in science during high school years. No additional information was provided about the participants.

The study was qualitative in nature. The repertory grid and individual interviews served as the main sources of data. Twenty-one (out of the 38) participants completed the repertory grid at the beginning of the science methods class and again after the conclusion of the investigation. During the second administration of the grid, the participants were not provided with their original grids. Participants were interviewed following the second administration of the grid. The interviews focused on the changes that students made in their grids. Six researchers assisted the author in conducting the interviews. The author did not comment on the nature of the interview or the measures, if any, that were taken to insure consistency among the interviewers. Several other data sources were employed in the study. A survey was used to gather information about the participants' backgrounds, interests, and attitudes toward teaching science. The nature of the survey or the elicited information were not explicated. At the beginning of the class the student teachers were also asked to provide a written statement about their definition of science. This task was also completed at the conclusion of the methods class where students were asked to indicate whether and how their definitions of science have changed as a result of participating in the investigation. Other sources of data included notes made by the researcher throughout the study, project displays, and the complete records of the student teachers' notes, journals, and reflections that they made throughout the investigations.

The repertory grid had two dimensions. The first comprised personal constructs and the second comprised elements related to conducting scientific investigations. The personal constructs were "essentially linguistic categorization systems which allow insights into the ways individuals organize thinking about events and phenomena" (Shapiro, 1996, p. 542). In the present study participants were provided with 15 constructs along one dimension of the grid. The constructs were developed from responses elicited during individual interviews with the student teachers of the cohort enrolled in the science methods class during the third year of the study. No details were provided about the process of developing these constructs. The constructs were related to scientific investigation and each represented a continuum between two opposite poles. A list of the 15 constructs is provided in Table 1.

The constructs were used to provide descriptive ratings for 12 elements along the second dimension of the grid. Like the constructs, participants were provided with these elements. The author noted that the elements represent typical experiences encountered in the course of conducting a scientific investigation. These elements were: a problem or topic of interest is selected for investigation; the topic is developed into a testable question; factors and variables which may affect the outcome of the investigation are identified and defined; an idea about how the investigation will turn out is developed; materials and equipment needed to conduct the investigation are collected; observations are collected and recorded to answer the problem question; improvements must be made to the original design of the investigation; an unusual or an unexpected result is produced; the investigation does not run smoothly; the results of the investigation are recorded; conclusions are drawn from the results of the investigation; the findings and conclusions are organized for public presentation (Shapiro, 1996, p. 543). These elements, it should be noted, represented a somewhat rational and systematic approach to scientific investigation.

For each element, the student teachers completed a grid or chart rating the elements on each of the 15 personal constructs. The ratings were given along a five-point scale that ran between the opposite poles of each construct. An example of a grid completed by Jan for the first element, "a problem or topic of interest is selected for investigation," after the conclusion of her project is provided in Table 1. The author did not explicate an *a priori* model for the nature of investigation in science against which student teachers' ratings were judged. The author merely aimed to describe changes in student teachers' thinking about the nature of scientific investigations in relation to the personal constructs.

As noted above, student teachers completed repertory grids after the conclusion of their independent investigations. Next, they were individually interviewed. The interviews aimed to generate insights about changes in student teachers' thinking about the nature of scientific investigations. Pronounced movements on the grids became focal points for discussion during the interviews. A pronounced movement was defined as a change of two or more squares toward one pole or the other of a certain construct. All interviews were audio-taped and transcribed for analysis. The interviews were analyzed in conjunction with other materials generated during the study. Changes in student teachers' thinking were coded and organized into categories. These categories were eventually organized into themes of change about the nature of investigations in science as a result of involvement in independent inquiries. The author, one research consultant, and two graduate students conducted the analysis. It was not clear whether or to what extent the other six researchers who assisted the author in conducting the interviews or the assistants who helped the student teachers in their investigations were involved in the analysis of the data. Having interacted with the participants during their investigative experiences,

Table 1.

Jan's Post-Investigation Repertory Grid: Personal Constructs Versus Element #1: A Problem or Topic of Interest Is Selected for Investigation

	1	2	3	4	5	
1. Creating my own ideas	x					1. Just following directions
2. Challenging, problematic, troublesome		x				2. Easy, simple
3. Shaping the investigation			x			3. Conducting the investigation
4. Having some idea beforehand about the project outcome			x			4. Having no idea what will result from the study
5. Using the imagination-spontaneous ideas	x					5. Recipe-like prescriptive work
6. Frustrating experience					x	6. Satisfying experience
7. Creating new knowledge	x					7. Discovering what exists--the way things are
8. Doing real science	x					8. Doing things unrelated to science
9. Personally meaningful, interesting	x					9. Not particularly meaningful or interesting
10. Rational, logical activity		x				10. Affective--feelings and emotions involved
11. Experience with the phenomena			x			11. Observing objectively
12. Theoretical work				x		12. Practical work
13. Using the "scientific method" to solve the problem				x		13. Not using any particular method
14. Important work in science		x				14. Less important work in science
15. Process oriented		x				15. Product oriented

From "A case study of change in elementary student teacher thinking during an independent investigation in science: Learning about the 'face of science that does not yet know,'" by B. L. Shapiro, 1996, Science Education, 80(5), p. 545.

those individuals would have contributed multiple and probably valuable insights and perspectives into the data analysis process.

Twelve change themes were identified. These were changes in: ideas about the nature of the steps and procedures of investigation in science; thinking about what science is; ideas about the complexity of investigation in science; thinking about the value of establishing an hypothesis, clarifying variables, and factors affecting the outcome of the study; thinking about the importance of thinking logically while moving through the project; thinking about the importance of personal commitment to a project, seeing it through to its conclusion; the importance of a personal participation in the investigation experience, rather than a mindless following of steps; views about self as successful science learner; views about the importance of sharing knowledge with a community, seeing science as a means of sharing knowledge with others; ideas about the importance of taking a critical perspective on the knowledge claims of research studies, a realization of the power to manipulate results; an appreciation for finding the unexpected; and ideas about the usefulness of independent investigations as a learning approach in the elementary science classroom.

In the present study, the author only reported in detail on three change themes that were evident in the case of one prospective elementary teacher, Jan. Jan was chosen to provide a detailed case study account of the quality of change in student teacher thinking that occurred during participation in the independent investigation. Jan was in her final year of the teacher preparation program. Her academic performance was average to above average. At the beginning of the science methods class, Jan indicated a lack of confidence in her ability to teach science to elementary students. Jan, along with her partner, Laura, were chosen for several reasons. First, they were representative of other members in the sample because of the lack of confidence in their understandings of science. Second, both Jan and Laura were not majoring in science education. Finally, both student teachers had difficulties conducting their investigation and were willing to discuss those difficulties with the investigator. Following is a description of the three change themes that were characteristic of shifts in Jan's thinking about the nature of investigation in science. The data presented to support these change theme were Jan's pre- and post-project repertory grids for the elements: a problem or topic of interest in selected for investigation; the topic is developed into testable topics; and factors and variables which may affect the outcome of the investigation are identified and defined.

The first change theme was in Jan's ideas about the nature of the steps and procedures of investigation in science. The author noted that most students had major difficulties in selecting a research question. Jan and Laura initially came up with the question: "Where do fruits ripen best?" They suggested placing six different fruits in six different locations around their homes to determine where would a fruit ripen best. After the student teachers sat through a lecture/discussion on the issue of clarifying the change or variable condition being studied, Jan and Laura approached the author. They were now aware of the difficulty of determining whether the results they would obtain would be due to the conditions of the various locations, the stage of ripening of the different fruits, or the ripening pattern characteristic of each fruit. Following their discussions with the author and in light of the fact that Laura knew a lot about bananas, Jan and Laura re-framed their question to: "Where do bananas ripen best?" On further discussion, the student teachers felt that they should only focus on those factors that might contribute to the ripening of the bananas, so the question was refined into: "Under what conditions do bananas ripen best?" Next, Jan and Laura realized that they had to decide what they meant by "best." So the question was re-phrased again and finally put as: "Under what conditions do bananas ripen most quickly?" Similarly, Shapiro (1996) indicated, Jan and Laura found themselves rethinking and refining their approaches and procedures at virtually every stage of the investigation. The repertory grid analysis and interview data indicated that Jan made some major shifts in her thinking about problem selection. For instance, she made a complete reversal from thinking about problem selection as a frustrating experience to being a satisfying one. Her attitude toward the investigation changed from it merely being an assignment to be done to being a meaningful and worthwhile experience. Jan pointed out that she came to appreciate the necessity of refining a research question along several dimensions that she came to value a rational approach to the issue. Moreover, Jan indicated that she often thought of doing science as being synonymous with following rules and checklists. After participating in the investigation, she came to appreciate the role of original thinking and imagination in devising ways to come up with answers to a research question.

The second change theme was in Jan's thinking about what science is. At the beginning of the methods class, Jan included four elements in her definition of science. She indicated that science is a body of information that has been tested and re-tested that it now achieved the status of facts. Jan also indicated that science pervades everyday life through our use of technology. Jan considered scientific investigation to be an endless endeavor that involves the study of frequently occurring, everyday situations. After the completion of the investigation, Jan was asked to comment on her original statements about science. She noted that she came to view science as less of a mere collection of facts and more of a process of inquiry. She indicated that even though she still believed that science is part of everyday life and that scientific investigation will never end, she did not view science as synonymous with technology any more. Science, she explicated, is about observing and studying the world. She also indicated that her experience helped her to appreciate the complexity of inquiring into everyday occurrences and the difficulty of drawing conclusions from the generated data.

The third change theme was in Jan's ideas about the usefulness of independent investigations as a learning approach in the elementary science classroom. By the end of the investigation, Jan came to believe that investigations would provide students with enjoyable and worthwhile experiences. Finally, Jan shifted from an objectivist view of science to one that emphasized the role of researchers in creating new knowledge. This was reflected in her increased sense of ownership of, and satisfaction with the investigative project.

However, it should be noted that Shapiro (1996) did not explicate the areas in which Jan showed little or no change in her thinking about the nature of investigation in science. Thus, the reported case study represents an unbalanced treatment of the issue. In this regard, a misconception about the nature of the use of evidence in scientific investigations was evident in one of Jan's quotes. The author did not comment on this apparent misconception. In the context of relying the excitement of falling on something unexpected during the course of an investigation, Jan noted "an hypothesis can be proven correct or incorrect but there is other information to be found along the way" (Shapiro, 1996, p. 553). Jan seems to have not grasped the notion that hypotheses cannot be "proven" in science in the absolute sense of the word. Rather, evidence is brought about to add support to or otherwise decrease the confidence in the validity of a certain hypothesis.

As far as all the participants in the present study were concerned, the author noted that the major change for most of them was the development of an appreciation for the complexity of the process of designing and conducting an investigation. The participants also emphasized the value of talking to one another and to the instructor and research assistants about their projects. They indicated that sharing ideas about encountered difficulties with other students and seeking the instructor's guidance did much to alleviate frustrations and make the investigation a more successful experience. This, the author noted, represented a shift toward thinking of science as a collaborative enterprise. The participants also indicated that their attitudes toward science were, in general, favorably influenced as a result of participating in the investigation. By virtue of their engagement in the process of formulating questions, collecting data, drawing conclusions, designing displays, presenting their projects to peers and school children, and reflecting on and arguing their case the participants indicated that they developed more confidence in their abilities to work and think scientifically. Another finding that the author noted in passing was that students who had a stronger background in science made fewer changes in their thinking about the nature of scientific investigation as compared to non-majors such as Jan. The author did not articulate this latter finding or discuss its consequences.

A noteworthy feature of the present study was the explication of the student teacher conceptions of the nature of investigations in science prior to and after her involvement in the project. This represented a major departure from the studies in the present review where teachers' conceptions of the NOS and changes in those conceptions were merely presented as numerical values and mean gain scores, respectively. Virtually no attempts were undertaken to elucidate the participants views' about the scientific enterprise and the changes in those views brought about by the various treatments and/or experiences. As such, in most cases it was difficult to assess the meaningfulness of the reported "gains" in teachers' conceptions of the NOS.

Probably the most important features of the present study were its emphasis on reflection and its explicitness. Shapiro (1996) noted that students were often encouraged to reflect on their experiences in discussions as well as in writing. Moreover, the author emphasized the reflective nature of the interviews that allowed student teachers (and researcher) to have insights into changes in their thinking about science. This was possible due to two reasons. The first was the participants' involvement in the independent investigations. The student teachers were able to refer to specific examples when reflecting on and delineating how their experiences affected their thinking about the NOS. The second reason was the fact that student teachers were provided with the constructs and elements that were utilized to help them reflect on specific aspects of the investigations. This represented an explicit aspect of the approach used in the present study to enhance participants' views of the NOS. In this respect Shapiro noted that "the use of personal constructs allowed reflection on features of changes in thinking that were not immediately apparent to students" (p. 554). This feature of the study, the fact that participants were provided with the constructs and elements, might be argued against and for. On the one hand, those who value an implicit approach to teaching about the NOS may argue that these constructs, and eventually the emerging change themes, were imposed on the student teachers. Students' experiences were thus compartmentalized into the conceptual boxes with which they were provided. Advocates of an implicit approach may argue that what really counts are those changes that students have inductively derived from their experiences. On the other hand, advocates of an explicit approach to teaching about the NOS may argue in favor of providing students with the personal constructs and elements. These constructs represent a conceptual framework that would guide students in their thinking *about* what they were doing, and bringing to their attention features of the nature of scientific investigation that they were not aware of or could have not come to realize had this issue been left to chance. As such, the provided constructs served as an explicit tool to guide student thinking and reflection about their experiences.

The issue of explicitness set aside, the value of reflection as a tool to enhance student teachers' conceptions of various aspects of teaching and learning receives support from the empirical literature. Several studies, for instance, have shown the effectiveness of reflection in improving student teachers' conceptions of their subject matter and helping them to develop more integrated views of their disciplines (e.g., Gess-Newsome & Lederman, 1992, 1995; Lederman, Gess-Newsome, & Latz, 1994; Lederman & Latz, 1995).

Finally, even though Shapiro (1996) noted that "changes in thinking were highly personal" (p. 554), she did not make explicit the point that the results of the present study were limited by the idiosyncrasy of the changes in teachers' thinking and the possible uniqueness of the reported case study. Indeed the author noted that students with strong science backgrounds did not demonstrate shifts similar to ones noted in Jan's case. As such, the present study remained silent regarding the improvement of secondary science teachers' conceptions of the NOS given that those teachers usually have strong backgrounds in their respective disciplines.

Summary

Trembath (1972) assessed the influence of a 2 1/2 hour program on student teachers' conceptions of the nature of scientific hypotheses, theories, and laws. The program presented the participants with a multi-frame situation that required them to pose hypotheses, interpret data, and infer explanations. The data analysis revealed a statistically significant gain in the participants scores. However, Trembath appropriately noted that the gain had minimal practical significance given that the student teachers' mean posttest score indicated a little more than 50% agreement with the model of the NOS adopted by the author.

Barufaldi et al. (1977) assessed the influence of science methods courses on elementary education majors' understandings of the tentativeness of scientific knowledge. The courses presented students with hands-on, activity-centered, inquiry-oriented science experiences that were aimed to assist students in making decisions related to supporting or refuting hypotheses. Data analysis revealed that the treatment groups achieved significant gains in their understanding of the tentative NOS. The authors concluded that a science methods course that emphasized inquiry methods, and hands-on experiences integrated with individual problem solving enhanced preservice teachers' understanding of the NOS. However, given that mean pretest and posttest scores were not provided, it was difficult to assess the extent to which the treatment was successful. Based on several assumptions that gave the authors the benefit of a doubt, the gains were estimated to be in the range of 3 to 6 percentage points.

The findings of Barufaldi et al. (1977), however, were not corroborated by a similar study conducted by Riley (1979). Riley assessed the influence of hands-on (active inquiry), non-manipulative (vicarious inquiry), and no training in science process skills on preservice elementary teachers' understandings of the NOS. The analysis revealed that preservice teachers in the active inquiry, vicarious inquiry, and control groups did not differ in their understandings of the NOS as measured by the TOUS.

Scharmann and Harris (1992) assessed the effectiveness of a summer institute in improving inservice secondary science teachers' understandings of the NOS. Even though the authors argued for a somewhat explicit approach to foster better understandings of the NOS, there were no indications that explicit elements were employed. The institute spanned 15 days. Participants met for six hours each day. They were presented with biological and geological content relevant to evolutionary theory in addition to various instructional activities and teaching approaches The activities comprised lectures, small-group discussions, field trips, and inquiry-based instructional methods. Data analysis revealed no significant differences between pretest and posttest mean NOSS scores. However, statistically significant differences were obtained in the case of the Johnson and Peeples (1987) instrument. The authors thus concluded that while participants' conceptions of the "philosophical" NOS were not influenced by the institute experiences, their understandings of the "applied" NOS were significantly improved. However, the mean gain achieved by the participants amounted to a mere 1.5 percentage points. Such a gain could not possibly have any practical significance. The authors, it should be added, did not define what they meant by the "applied" NOS.

Ogunniyi (1983) assessed the influence of a history/philosophy of science course on student teachers' conceptions of the NOS. The course addressed the origins and development of scientific thought, the nature of scientific inquiry, and the epistemological foundations of science. Data analysis revealed statistically significant differences between participants' pretest and posttest NOSS scores. However, the mean gain achieved by the participants amounted to about 3 percentage points. More importantly, the posttest mean NOSS score indicated less than 20% agreement with the model for the NOS adopted by the developers of the instrument.

Akindehin (1988) reported on the development of an instructional package, the *Introductory Science Teacher Education* package (ISTE), and the assessment of its influence on prospective secondary science teachers' conceptions of the NOS. The ISTE was delivered in 12, one-hour sessions. The package comprised direct instruction on the nature of scientific knowledge and its development, the history of science, and a model of scientific inquiry. Participants were also involved in a variety of other activities. Statistically significant gains were obtained in participants' mean NOSS scores. Out of 58 possible points on the NOSS, the posttest mean score was 51.84. This mean score was the highest reported mean NOSS score among the studies reviewed in the present paper. However, the author did not report the mean pretest and posttest NOSS scores. As such, it was difficult to assess the impact of the ISTE package.

Shapiro (1996) reported on the changes in one prospective elementary teacher's thinking about the nature of investigation in science in relation to a set of provided personal constructs as a result of the student teacher's involvement in designing a study to a answer a simple research question. The prospective teacher, Jan, demonstrated changes in her thinking about the nature of the steps and procedures of investigation in science. Jan indicated that she often thought of doing science as being synonymous with following rules and checklists. After participating in the investigation, she came to appreciate the role of original thinking and imagination in devising ways to come up with answers to a research question. Jan also came to view science as less of a mere collection of facts and more of a process of inquiry. Finally, Jan shifted from an objectivist view of science to one that emphasized the role of researchers in creating new knowledge. The emphasis on reflection and explicitness were the most important features of this study. Jan was often encouraged to reflect on her experiences during the investigation. Discussions with the investigator during individual interviews also helped Jan to have insights into changes in her thinking about science. The personal constructs with which Jan was provided represented an explicit framework that guided her thinking about scientific investigations.

Another noteworthy feature of Shapiro's (1996) study was the explication of the student teacher's conceptions of the NOS prior to and after her involvement in the project. This represented a major departure from the studies in the present review where teachers' conceptions of the NOS and changes in those conceptions were merely presented as numerical values and mean gain scores, respectively. The investigators in the studies reviewed in this section, both those who adopted an implicit approach (Barufaldi et al., 1977; Riley, 1979; Scharmann & Harris, 1992; Trembath, 1972) and an explicit approach (Akindehin, 1988; Ogunniyi, 1983) did not explicate the participants' understandings of the NOS prior to and after the completion of the various treatments.

Such information would have been helpful in assessing the meaningfulness of the reported gains.

Improving Undergraduates' Conceptions of the NOS within Science Content Courses

Concurrent with the efforts to influence science teachers' conceptions of the NOS through science methods courses and other instructional packages were efforts to improve undergraduate, non-science majors' conceptions of the scientific enterprise within the context of science content courses. These latter efforts were relevant to the present review because many candidates for teacher education programs, particularly at the elementary level, come from the population of undergraduate non-majors. Of the five studies reviewed in this section only one adopted an explicit approach to teaching about the NOS through instruction on the history and philosophy of science, and the interactions between science and society. The remaining four studies employed an implicit approach whereby elements in the instructional environment were manipulated in the hope of fostering among students better conceptions of the scientific enterprise.

Implicit approaches.

Spears and Zollman (1977) argued that laboratory teaching is an integral part of college science instruction. Laboratories, in general, aim to enhance students' understandings of the process and content of science. The authors continued that instructional strategies used in laboratories could be divided into two general categories.

The first is "structured," emphasizes verification, and provides students with explicit procedures. The second approach is "unstructured," stresses inquiry or discovery, and even though it specifies objectives, it assigns students the task of devising their own procedures and methodologies. Spears and Zollman noted that educators embrace varying views about the effectiveness of these approaches in enhancing students' understandings of the process of science. Bruner, for instance, argued that students can only come to understand the nature of scientific inquiry if they engage in scientific inquiry themselves. The authors continued that Gagne, on the other hand, assigned structured activities a greater role in developing students' understandings of the process of science. Additionally, Spears and Zollman noted that:

> The intellectual model of Piaget also leads one to hypothesize that some structure must be provided for students. If the student cannot apply formal operations to his study of physics, he cannot be expected to devise and understand the process of science, a formal operational procedure. (p. 34)

This latter theoretical argument was poorly articulated. The authors did not justify the manner in which they came to link "structure," formal operational thinking in manipulating scientific concepts, and understanding the process of science through conducting laboratory activities. Their argument equated scientific inquiry or "the process of science" with a sequence of formal and logical operations. The validity of this argument, however, was questionable. The authors noted that virtually no studies compared the effectiveness of the aforementioned laboratory strategies in enhancing students' understandings of the process of science.

The present study was concerned with the instructional structure of laboratory activities. The authors aimed to assess whether engagement in some degree of scientific inquiry influences students' understanding of the process of science. The authors noted that in the present study the "structured" laboratory did not use a strictly traditional, "cook book" approach. Students were encouraged to think about the procedures with which they were provided.

The study had a pretest-posttest two-treatment design. Students were randomly assigned to the four lecture sections and associated laboratory sections of a physics course offered at Kansas State University during the spring semester, 1973. The two laboratory approaches investigated were not specified in the course listings. It was not clear, however, whether the two experimental treatments were randomly assigned to these sections. The type of laboratory activity, structured versus unstructured, served as the independent variable. Students' performance on the SPI (Welch & Pella, 1967-68) was the dependent variable. Participants were pre- and post-tested in the lecture sections during the first and last week of classes, respectively. To account for students' past experiences, information about their major, years in college, and course lecture and laboratory grades were collected and used as control variables. The mean values of these variables for the two experimental groups were not reported. An additional variable was the type of lecture presentation in each of the four sections of the course. To guard against any possible bias, the lecturers were not allowed to see the SPI prior to or during the study. However, the authors felt that the mode of presenting the lecture might impinge on students' SPI scores. As such, this variable was included in the study. No information, however, regarding how this variable was operationally defined or included in the analyses was provided.

The independent variable represented two types of laboratory involvement. Both types asked students to investigate physical principles discussed in the lectures, presented students with a problem, and informed them about the available equipment. Beyond this point the two approaches differed in a major way. In the "structured" laboratory, students were provided with explicit procedures with which they attempted to verify the physical principle concerned. Students in the "unstructured" laboratory, however, were free to investigate the problem in whichever way they deemed appropriate. They made their own decisions regarding what data to collect, how to collect these data, how to treat the data, and how to interpret and present their results. The experiments were written such that they conformed to the design of the structured and unstructured activities. In both laboratories students were expected "to collect data and draw conclusions or inferences from the data in a manner consistent with . . . knowledge of students in the concrete operational stage" (Spears & Zollman, 1977, p. 35). The authors, however, did not provide additional information on the criteria that were used to judge whether students were performing at that developmental stage. More importantly, the authors did not conduct any observations of the instruction in either laboratory environment to insure the fidelity of the treatment.

The SPI Form D was used to assess students' understanding of the process of science. This form of the instrument has 135 agree/disagree type statements. The instrument's KR reliability calculated for the total sample of 171 non-science major students in the present study was 0.86. The authors did not report whether the KR-20 or

KR-21 formula was used. The authors noted that the validity of the instrument has been established with populations that ranged from high school students to professional scientists and, as such, was suitable for use with college students. It should be noted, however, that the instrument was not specifically validated with non-science college majors. The instrument measures understandings of four elements of the scientific enterprise: Assumptions, Activities, Nature of Outcomes, and Ethics and Goals. The SPI total and component scores were obtained in the present study. The authors, based on a personal communication with the developer of the instrument (Wayne Welch), noted that factor analysis has shown that the SPI total score can be used to assess understandings of the process of science. No further information in this regard was provided.

The population comprised all 171 students enrolled in the four section of the physics course. The students were non-science majors. Most of them were majoring in elementary education, business administration, home economics, and the social sciences. Ninety-six percent of the participants were freshmen and sophomores. Spears and Zollman (1977) noted that "prior departmental studies show that over 90% of these students completed high school biology, but only 58% and 23% reported having completed high school chemistry and high school physics, respectively" (p. 36). The authors, however, did not reference these earlier studies nor did they provide any demographic or academic background information about the sample. Spears and Zollman continued that because some students missed either the pretest or posttest or did not fill the administered SPI, data from only about 50% of the original sample were used in the final analysis. The authors, however, did not take any measures to check whether the remaining sample was not biased by this high attrition. No data was provided to indicate that respondents were a representative sample of the original population. Moreover, the authors did not report the SPI reliability for the remaining sample.

ANCOVA was appropriately used to analyze the data. The authors, however, did not provide any evidence to show that the assumptions of this statistical model were met by the sample in the present study. A separate analysis for each of the SPI subsets was performed. The pretest score, laboratory grade, and lecturer were kept as covariates because they were found to contribute substantially to the posttest scores. Finally, the adjusted posttest scores for the two groups were compared.

Analyses indicated that there were no statistically significant differences ($\alpha = 0.05$) between the adjusted scores of the two groups on the Assumptions, Nature of Outcomes, and Ethics and Goals components of the SPI. There was a significant difference ($F = 4.7$, $p < 0.05$) in the mean scores on the Activities component. The mean score of students in the "structured" laboratory (46.3) was higher than that of students in the "unstructured" laboratory (45.0). The difference, however, could not have amounted to more than 2.5 percentage points. Even though the authors did not discuss the practical significance of this result, the observed difference was very small to be of any practical importance. The authors, however, concluded that students in the "structured" laboratory achieved better understandings of the process of science.

Spears and Zollman (1977) argued that structured laboratories presented students with examples of how scientists work and thus facilitated the development of their formal operational thinking skills. However, because of their weak background in physics, the authors continued, students in the unstructured laboratory did not derive the same benefits. These students mostly performed at the concrete operational level. They, Spears and Zollman noted, seldom engaged in the activities of scientists (i.e., observing, hypothesizing, developing models, predicting, and testing predictions). As noted above, the authors seemed to base their arguments on a model of science that endorses the existence of a single "scientific method." Moreover, the authors presented no evidence whatsoever to support the above interpretation of their results. The authors finally concluded that non-science majors can benefit more from structured laboratory experiences. These experiences could help them to develop the desired understandings of the processes of science.

What is more important for the purposes of the present review, was that compared to students in the structured laboratory group, students in the unstructured group did not demonstrate better understandings of the NOS as measured by the SPI. Doing science, either within a structured, traditional environment (Carey & Stauss, 1968) or within the more advocated inquiry or discovery approach, did not seem to improve college students' understandings of the NOS. Thus, the results of the present study lent support to the conclusions of Kimball (1967-68).

Haukoos and Penick (1983) investigated the effects of classroom climate on learning science process skills and content achievement in a college level science class. The authors replicated their study two years later (Haukoos & Penick, 1985). They noted that science educators have been mainly occupied with developing curricular materials and devising or modifying instructional strategies in their attempts to improve science education. Classroom climate, "the dynamic interaction of all elements operating in the classroom," however, has been largely overlooked (Haukoos & Penick, 1983, p. 629). Classroom climate, the authors continued, is partially related to the amount of intellectual freedom that students enjoy within the classroom. This freedom derives from the extent to which instruction is directive or non-directive. Haukoos and Penick (1983) noted that:

> Direct verbal behavior of the teacher—lecturing, giving directions, reciting facts, criticizing, or praising—tends to minimize the variety of possible student responses. Indirect behavior—eliciting student statements, listening and accepting students ideas—increases the freedom of students and encourages them to exhibit a variety of responses. (pp. 630-631)

The authors cited research studies that reported significant gains in the development of students' inquiry skills and science process skills (formulating hypotheses, recording and analyzing data, etc.) as a result of participating in non-restrictive classrooms. The above argument, it should be noted, was based on the assumption that students learn about science and the nature of scientific inquiry implicitly through certain aspects related to the classroom environment. In this case, these aspects derived from the extent to which the teacher used direct verbal behaviors. Haukoos and Penick continued that research focusing the effects of classroom climate has mainly been concerned with elementary and secondary classrooms. Thus, the purpose of the two presently reviewed studies was to extend this line of research into post-secondary teaching and to investigate the effects of classroom climate on community college students' learning of science process skills and content achievement.

The two studies had a pretest-posttest two-treatment design. The classroom climate served as the independent variable. The groups received two experimental treatments. The first was a Discovery Classroom Climate (DCC) and the second a Nondiscovery Classroom Climate (NDCC). The dependent variables were students' mean scores on the SPI Form D (Welch & Pella, 1967-68) and the Biology Achievement Test (BAT). In both studies, participants were enrolled in a comprehensive, two-year community college. The subjects in the first study (Haukoos & Penick, 1983) were 78 students enrolled in four intact sections of an introductory college biology course entitled “Principles of Biological Science.” Three of the sections spanned 10 weeks, whereas the fourth was an accelerated five weeks class. The experimental treatments were randomly assigned to the four sections. The five-week class received the DCC treatment. No further information whatsoever was provided about the participants. In the second study (Haukoos & Penick, 1985), the participants were 61 students enrolled in two intact sections of the same course. Of the 23 students enrolled in the NDCC section and the 38 enrolled in the DCC section, 52% and 61% were female, respectively. The mean age was 24.6 and 22.0 for the NDCC and DCC sections, respectively. These demographic data were the only information provided about the participants.

Throughout the duration of the course, students in both groups received instruction on the same content. The lecture/discussion sessions followed the same text materials and were accompanied by 35-mm photographic slides. In the laboratory portion of the course, students carried out the same experiments using the same materials. The only difference between the two treatments was the classroom climate. This climate was determined by the behavior of the instructor; the extent to which the instructor used direct or indirect verbal behaviors. During laboratory sessions, students in the NDCC group were exactly told how to manipulate materials. Their results were either accepted or rejected by the instructor. Students in the DCC laboratory were alternatively encouraged to select and explore their own questions, and to manipulate the available materials in whichever ways they deemed fit in answering their questions. The instructor kept explicit directions and judgments to a minimum. In this regard, it seemed that the laboratory environments were similar to the "structured" and "unstructured," or traditional and inquiry based treatments that were employed by Spears and Zollman (1977). In the lecture/discussion sessions, students in the NDCC were presented with the content in a manner "that conveyed the impression that science was complete and final, and seldom did the students question it" (Haukoos & Penick, 1983, p. 631). With the DCC group, the instructor assumed a low profile, elicited student questions, and encouraged discussion of the lecture material and projected slides. All student responses and interpretations were accepted and were not judged as right or wrong.

In both studies, the primary author served as the instructor for all sections in the course. This was intended to minimize the number of intervening variables by limiting variations in delivering the treatments. To insure the fidelity of the treatments, student-teacher interactions were audio-taped and analyzed. Audio-taping was made on daily basis. In the second study, Haukoos and Penick (1985) reported that ten-minute interactions following laboratory sessions were randomly selected for analysis. The duration of the analyzed sample interactions in the first study (Haukoos & Penick, 1983) was not reported. The Science Laboratory Interaction Categories (SLIC) (Shymansky & Penick, 1979) was used to analyze these data. No information regarding the validity or reliability of this instrument was provided. Student-teacher interactions were coded into the categories of the SLIC and were then compared to established DCC and NDCC criteria. The DCC criteria included teacher behaviors such as asking thought provoking questions and accepting student ideas. Asking factual questions and providing negative or positive feedback were among the criteria for NDCC verbal behaviors. Next, the percentage of total class time spent on each of the coded behaviors was calculated and used to produce a Learning Condition Index (LCI) for each treatment. The LCI values range from 0 which indicates that teacher behavior places no restrictions on students, to 1 which indicates that students are completely restricted by the teacher's behaviors. Ten LCI values were reported for each section in the course. In the first study, the average LCI values for the NDCC and DCC classes were 0.64 and 0.06, respectively. The corresponding LCI values reported in the second study were 0.63 and 0.07. It was not clear who analyzed the student-teacher interactions, or whether the coding was checked by more than one researcher.

Students were pre- and post-tested with the SPI Form D (Welch & Pella, 1967-68). This instrument, comprising 135 agree/disagree type statements, was used to assess students' understandings of the nature of scientific processes. The KR reliability for the sample in the first study (Haukoos & Penick, 1983) was 0.86. The authors did not report whether the KR-20 or KR-21 formula was used. The SPI reliability for the second study (Haukoos & Penick, 1985) was not reported. In both studies, no evidence regarding the validity of the instrument in assessing community college students' knowledge of the processes of science was provided. The Biology Achievement Test (BAT) was used to assess students' content achievement. The BAT was administered as a posttest only. This test was developed by the Office of Testing in the community college where the studies were conducted. Haukoos and Penick (1983) noted that "neither formal validity of the test questions nor reliability of the test was measured" (p. 632).

The ANCOVA was appropriately used to determine whether the mean SPI scores for the DCC and NDCC treatments were significantly different ($\alpha = 0.05$). The authors did not specify whether covariates other than the pretest scores were used in the analysis. The ANOVA was used to test for significant differences between the mean BAT scores. Although the use of this test was appropriate given that students were not pre-tested with the BAT, it did not allow the authors to account for differences in students' content achievement prior to enrolling in the course. In both tests, the authors properly used the intact class as the unit of analysis. Haukoos and Penick (1983, 1985), however, did not provide evidence that the assumptions of these statistical models were met by the samples investigated. Finally, in case the ANOVA or ANCOVA revealed statistically significant differences, the Duncan's multiple range test was used to determine where do these differences exist. This latter test, it should be noted, is conservative and served to guard against the accumulation of error due to multiple tests.

Haukoos and Penick (1983) reported no statistically significant differences among the DCC and NDCC groups BAT scores. The authors thus concluded that both treatments were equally effective in fostering content achievement. What is more, students in the five-week DCC class achieved equally well on the BAT as students in the ten-week NDCC and DCC classes. The authors noted that the literature was ambivalent regarding the effects of the discovery classroom climate on student content achievement. While some studies reported significant gains in students' content achievement in discovery climates, others noted that students in non-discovery climates often demonstrate better content achievement. The authors attributed the results of the present study to the motivation of students in both groups to complete the course with a passing grade.

Haukoos and Penick (1983) found that the ten-week DCC group had a significantly higher mean SPI score than the NDCC and the five-week DCC groups. The reported difference was on the order of about 8 percentage points. However, given the authors did not report the standard deviations for the mean SPI scores, it was difficult to judge the practical significance of this difference. The authors also did not elucidate the aspects of the nature of scientific inquiry of which students in the DCC group achieved better understandings. The authors concluded that, given enough time, classroom climate can influence students' learning of science processes.

The authors also noted that if science processes were not emphasized through use, students may loose their knowledge of these processes. The authors based this latter conclusion on the fact that the pretest mean SPI scores for the NDCC groups were higher than their posttest scores. Contrary to that students in both DCC classes had higher posttest than pretest mean SPI scores. The authors, however, provided no evidence to show that these differences were statistically significant. Moreover, these gains and losses were on the order of 1.5 percentage points. Finally, it should be noted that the authors did not confine their conclusions to the sample in the present study even though no evidence was provided to show that this sample is representative of any larger population.

In their second study, Haukoos and Penick (1985) were not able to replicate the results of the first study concerning the effects of classroom climate on learning science processes. Analyses revealed no statistically significant differences, at any acceptable level, between the DCC and NDCC groups mean SPI and BAT scores. Since both studies showed that the two groups did not differ on their content achievement, the authors concluded that criticisms of discovery classrooms concerning the less emphasis placed on covering content were not justified. Again the authors generalized their findings beyond the samples in the two studies.

On the other hand, the authors recoursed to several factors to explain why students in the DCC class did not demonstrate better understandings of the processes of scientific inquiry as compared to students in the NDCC class. The authors noted that in the replication study, the instructor might have developed subtle ways to render the classroom climate in both treatments less distinct. They also suggested that although the SLIC recorded specific teacher behaviors, it did not do equally well with documenting behavior patterns. As such, certain behavior patterns that might have been characteristically different in the two studies may account for the observed result. Moreover, the authors noted that they were "not able to truly match students in the original study with those in the replication. Students *may* [italics added] have been older, brighter, more motivated, or different in other ways" (Haukoos & Penick, 1985, p. 166). It should be noted that the authors did not limit the conclusions of their first study to the sample investigated. They made a rather sweeping generalization. Now that the expected results were not obtained, possible effects due to the participants' characteristics were invoked. The authors did not provide any data or conduct any systematic analysis to support any of these speculative interpretations. And even though Haukoos and Penick noted that "we have two choices; we can question the new data or we can question the old" (p. 165), they decided to only question the new study. They did not choose even to speculate about another, probably more plausible, interpretation: Namely, that classroom climate might not be related to developing students' understandings of the nature of scientific inquiry. The fact that the authors did not even consider this alternative interpretation indicated an inherent bias in favor of the DCC treatment. Given the fact that the initial results were not replicated and that the authors insisted that some factor other than the treatment was responsible for the new results, serious doubts could be raised about the results obtained in their initial study. Consequently, these studies did not seem to lend support to the assumption that college students can learn *about* science implicitly through factors related to the classroom climate that specifically derive from the teacher verbal behaviors.

Scharmann (1990) noted that the teaching of evolutionary biology can engender sensitivities and confrontation especially if students perceive the topic to be in direct conflict with their beliefs and value systems. As such, some instructors avoid teaching about evolution altogether. However, given that evolutionary theory is a major unifying theme within biology, instructors eventually find themselves teaching about it through genetics, reproductive and mating strategies, environmental stress, ecology, etc. The author, argued, that the problem resides less with evolution and more with a lack of understanding of the NOS and particularly of the nature scientific theories.

Scharmann (1990) adopted a Kuhnian view of paradigms and paradigm shifts. According to Kuhn (1970) and other philosophers, Scharmann noted that the validity of a scientific theory depends, among other things, on certain criteria such as its internal consistency, predictive power, fruitfulness, and the availability of corroborative lines of evidence. However, at any time the relative importance and interpretation of these criteria derive from within a contemporary working paradigm. A change in this paradigm, thus, engenders a change in the validity of a certain scientific theory. The theory may be modified or altogether replaced with an alternative one that, according to the new paradigm, performs better on the aforementioned criteria. As such, inherent to an understanding of scientific theories is a recognition of their tentative nature.

Moreover, the author continued, even though empirical evidence supporting the claims of a certain scientific theory is necessary for establishing its validity, not all the tenets put forth by a theory can be empirically tested, nor do they need to be. This notion, however, seems to be problematic to many students, especially those who "may not possess a high degree of tolerance for ambiguity . . . [and] . . . exhibit dualistic perceptions . . . viewing an issue from a discrete 'right-wrong' rather than a more global 'better-worse' perspective" (Scharmann, 1990, p. 92). In the specific case of evolutionary theory, Scharmann advanced, some science educators argue that the use of a diversified instructional strategy could help students to overcome such difficulties. Within one such strategy advanced by Nelson (1986) students were first introduced to basic evolutionary concepts and then encouraged to discuss those concepts among themselves. Next, students were given opportunities and guidance to resolve any misconceptions about or difficulties with evolutionary theory that arose as a result of these discussions.

The author argued that several factors contributed to the effectiveness of this diversified strategy. First, during their discussions, students use logical, empirical, historical, and sociological criteria to challenge and judge the validity of the ideas of evolutionary theory. However, it was not clear from Scharmann's discussion whether students' knowledge of these criteria within the context of evolutionary theory was assumed or whether students received explicit instruction about these aspects. Second, a diversified instructional strategy "allows students individually and in groups to examine a controversy from a variety of perspectives to achieve a more comprehensive understanding of the nature of science and evolutionary theory" (Scharmann, 1990, p. 92). Again, it is not clear whether these perspectives were the students' own or those of different scientific, social, or religious groups. If the latter was the case, it was not clear how students would develop their knowledge of a variety of such perspectives. Third, through discussion and confronting the ensuing controversies, a diversified instructional strategy was expected to *convey* to students the notion that science is not a static body of established facts, but a rather dynamic enterprise. Students were expected to view science as a way of generating knowledge, and that this knowledge is, at best, tentative. Fourth, students would come to understand that not all tenets of a scientific theory are supported by empirical evidence, but that inferences, predictions, applications, and explanations derived from the theory are consistent with such evidence. Finally, students were expected to view evolutionary theory as less conflicting with their own value systems. Given that Scharmann did not elucidate an explicit role for the instructor in guiding students toward these desired understandings of the NOS, nor in equipping them with the conceptual tools (logical and historical criteria for evaluating theories, etc.) necessary to achieve such understandings, it was safe to assume that students were expected to implicitly learn all these aspects about the NOS just by participating in the discussions.

The purpose of the present study was to assess the effect of a diversified instructional strategy on freshmen college students' understandings of the nature of evolutionary/scientific theory. Scharmann (1990) hypothesized that compared to students presented with evolutionary theory through the traditional lecture approach, those exposed to a diversified instructional strategy would overcome their misconceptions and achieve better understandings of evolutionary/scientific theory. The study targeted several misconceptions. These included the belief that religious students have to reject evolutionary theory; that science is objective and free of religious and philosophical assumptions; that scientific knowledge is established and non-changing; and that a single inherent uncertainty would lead to the rejection of a scientific theory.

The study had a non-equivalent control-group design. The diversified instructional strategy served as the experimental treatment. Participants were pre- and post-tested with an instrument that measured their understandings of the NOS, acceptance of evolutionary theory, and their knowledge of evolutionary concepts. Participants were all 30 students enrolled in two sections of a three-week, summer session, general biology course for non-majors. The instructors of the two sections agreed to participate in the study. The experimental group comprised 13 students and the control group 17 students. It was not clear whether the treatment was randomly assigned to one of the groups. Scharmann (1990) claimed that the two intact groups were "judged not to be different in age, gender, year in school, interest in science, . . . socioeconomic status [and] backgrounds" (p. 93). The author, however, did not provide any data whatsoever to support this claim nor did he explicate how the comparability of the two groups was established.

The course convened six days a week. The daily 2 1/2 hour lectures were followed by two-hours of laboratory work. Evolutionary biology served as an underlying theme in the entire course. The two instructors agreed to follow the same outline throughout their classes. The course started with a unit on the nervous system. During the second half of the first week evolutionary theory was presented. Students received a total of 10 hours of lectures and explored the applications of evolutionary biology during four hours of laboratory work. Students were then presented with several units including ones on taxonomy, reproductive biology, and coevolution of plants and animals.

Following two introductory lectures and one laboratory session on evolution, the author was introduced to the experimental group. The author implemented the diversified instructional strategy over the course of one instructional day (4 1/2 hours). No observations of instruction were conducted. Students were first given 30 minutes to individually respond in writing to a set of four questions concerning the evolution/creation controversy. The questions asked the students to explain how they felt about the theory of evolution and about creation origins, whether they perceived the two notions to be in conflict, and whether they believed that science teachers should present creationist ideas in addition to evolutionary theory in their classrooms. Next, students were randomly assigned to discussion groups of 3-5 students. They were asked to share their responses to the above questions and then respond to a set of four new questions. The first three questions of this new set asked each group to provide reasons that would support teaching only evolution in science classes, teaching creation origins in addition to evolution, and teaching neither evolution nor creation origins. The fourth question asked the students to examine the set of reasons they provided in response to the first three questions and then to decide whether one was more compelling than the others. Students also had to explain why that set of reasons was more convincing. Ninety minutes were allocated for this phase of the treatment. During this time, the author monitored the progress of the discussions but did not interfere in any. He only reminded students that the aim of the discussion was not to get the group to adopt the views of a certain individual nor to reject an individual's views. The aim was for students to attempt to resolve their conflicting ideas regarding the issue discussed and possibly reach consensus within their group. For the next 30 minutes spokespersons shared their groups concerns, differences, and points of agreement with the whole class. The presentations were followed by a 30-minute break during which the author attempted to integrate the groups views in preparation for the next phase. After the break, the author led a 90-minute interactive lecture/discussion. This phase aimed to resolve any misconceptions that arose as a result of the group discussions and were evident in their presentations. Finally, students were given the opportunity to reflect on the discussion activity. During the last 30 minutes of the instructional day they were asked to re-examine their responses to the questions given at the outset of the treatment. Students were asked to write whether, how, and why their feelings about evolution and creation have changed as a result of participating in the discussions. The control group, Scharmann (1990) noted "received the same content information; however, the mode of instruction was a more traditional lecture approach" (p. 94). It was not clear whether the author himself presented the control group with this "content information," the nature of which was not explicated. It also should be noted that there were no indications that the experimental group received instruction about the empirical, logical, historical, and sociological criteria for establishing the validity of theories. As noted earlier, the author referred to these criteria when presenting the rationale behind the expected effectiveness of a diversified instructional strategy in enhancing students' conceptions of the NOS. Moreover, no information was provided about participants' misconceptions regarding the nature of evolutionary/scientific theory or the nature of the criteria that the students consulted in adjudicating between the various ideas that ensued as a result of their discussions.

Participants were pre- and post-tested at the outset and conclusion of the course, respectively. The author used an untitled instrument developed by Johnson and Peeples

(1987). The instrument had 25 five-point, Likert-type items. Scores thus ranged from 25 to 125 points. Twenty items were intended to measure students' understanding of the nature and methods of science, and the remaining five measured their acceptance of the theory of evolution. The author noted that the validity of the instrument was established with a group of undergraduate students and was thus judged to be appropriate for use in the present study. It was not clear, however, that the instrument was specifically validated with freshmen, non-major students comparable to those participating in the present study. Scharmann (1990) noted that the published reliabilities for the two components of the instrument were 0.78 and 0.77, respectively. The author, however, did not calculate these reliabilities for the sample in the present study. In addition to this instrument, 10 multiple-choice items written by the investigator were administered to measure students' knowledge of evolutionary theory. The author furnished no information about the validity and reliability of this content test.

Since the control group pretest scores were not normally distributed, the author appropriately used the non-parametric, Mann-Whitney U-test to compare the between-group pre- and posttest scores. The Wilcoxon test for repeated measures was properly used to compare the within-group pre- and posttest scores. However, the author did not provide the information necessary to judge whether the proper unit of analysis, being in this case the intact class, was used (N = 2). As such, the significance of any results are suspect pending the availability of such information.

The analysis revealed no significant differences between the pretest scores of the experimental and control groups. As such, the two groups were judged to be equivalent prior to the experimental treatment on their understanding of the NOS, attitude toward evolution, and knowledge of evolutionary content. However, as noted earlier, the author did not provide any data to support his claim that the two groups were similarly equivalent on other demographic and background variables. Anyone of these variables could have influenced the outcome of the experimental treatment. The posttest scores on evolutionary content knowledge were not significantly different. However, the posttest scores of the two groups were significantly different ($U = 1.75$, $p < 0.05$) when it came to understanding the NOS and attitude toward evolution. The author, however, did not report the pre- and posttest mean scores and standard deviations for the two groups. As such, it was not possible to estimate the gains achieved by the experimental group or to check whether such gains can potentially have any practical significance beyond the reported statistical one.

The within-group comparisons using the Wilcoxon test for repeated measures revealed that the content knowledge pretest and posttest scores were not significantly different for both groups. Students in both classes did not achieve statistically significant gains in their knowledge of evolutionary concepts as a result of enrolling in the course. The author thus concluded that non-major science students did not seem to be interested in learning about specific evolutionary content. The analysis, however, revealed a significant difference between the pretest and posttest scores for both the experimental group ($Z = 2.98$, $p < 0.001$) and the control group ($Z = 2.33$, $p < 0.01$) on the NOS and attitude toward evolution tests. Students in both groups achieved statistically significant gains in their understandings of the NOS and their acceptance of evolutionary theory. The author, however, did not provide the mean scores for both groups on any of the tests or test components. As such, it was not possible to assess or compare the gains achieved by the experimental and control groups. The author concluded that both classes provided students with opportunities to grow in their understandings of the NOS but that the diversified instructional strategy was superior in this respect. However, given the lack of data to support this claim and the fact that both groups demonstrated gains in their understandings of the NOS, the effectiveness of the treatment should be considered with extreme caution. The gains achieved by both the experimental and control groups may have been the result of a testing effect especially in light of the fact that only three weeks separated the administration of the pre- and posttests.

Scharmann finally noted that "if scientific theory is presented using historical and sociological criteria in addition to logical and empirical criteria, student misconceptions can be addressed in a systematic . . . manner" (p. 98). However, as noted earlier, there were no indications that participants were presented with any of these criteria. Given that these criteria were used to judge the validity of evolutionary theory, the author did not provide any information on when the criteria were presented. Moreover, no descriptions were provided of these criteria, how they were presented, and in which ways they were utilized in the discussions. In this regard, the discussions seem to have been more of a sharing of student ideas and feelings about the evolution/creation issue than an attempt to resolve their misconceptions. This was evident in the author's short summary of student reflections at the conclusion of the experimental treatment. In what the author labeled a "strictly qualitative sense," students as a "consequence of participating in the discussion . . . had reasons to support why they felt a certain way about the issue . . . [and] . . . described a feeling of relief to find that they were not alone in their confusion regarding conflicting claims or value positions" (Scharmann, 1990, p. 98). No other evidence was provided to support the claim that students demonstrated growth in their understandings the nature of scientific/evolutionary theory. Moreover, in addition to the fact that the claim regarding the success of the treatment in overcoming student misconceptions was not supported by any evidence, the claim seems to be an unlikely outcome given that students did not achieve better understandings of the content proper of evolutionary theory.

Explicit approaches.

As a result of interest in enhancing the achievement of general education objectives by non-science majors at the University of Tulsa, a general education, physical science course was developed. Jones (1969) aimed to evaluate whether students enrolled in this general physical science course achieved better understandings of science and scientists as compared to students enrolled in professionally oriented courses. Three professional courses offered in the College of Engineering and Physical Sciences at the University of Tulsa were chosen for comparison. These were general chemistry, general physics, and engineering physics.

Each of the four investigated courses spanned two semesters. The courses, however, varied in the number of class periods and laboratory hours. The general education physical science and engineering physics courses had two lecture periods per week each, while the general chemistry and general physics courses had three lecture periods each. The general chemistry course had four laboratory periods, the engineering physics course had three, while each of the general education physical science and general physics courses offered two laboratory periods per week. Each of the professional courses was concerned with a particular scientific discipline, the general education physical science course included topics from astronomy, physics, chemistry, and geology. The professional courses focused mainly on the facts, vocabulary, discoveries, and quantitative procedures of the disciplines concerned, as well as on problem solving within those disciplines. The general education physical science course was concerned with some facts and principles from the four aforementioned disciplines but placed greater emphasis on historical development, philosophy of science, and science-related societal issues. The author noted that the instructional activities and emphases in the four courses were not documented. Jones (1969), however, claimed to have elicited the instructors' objectives for the various courses. These objectives, however, were not reported.

The study employed a non-randomized, pretest-posttest control-group design. The total sample comprised 155 students. The TOUS (Cooley & Klopfer, 1961) served as the criterion measure and the adjusted mean scores of the two groups were compared. The analysis of covariance (ANCOVA) was used to establish whether the difference between the mean scores of the two groups was significant at the 0.05 level. The specific null hypothesis tested was:

> There is no difference in the mean score of the experimental group on the Test on Understanding Science and the mean score on that test of students in the control group, when measures of the effects of initial performance on the criterion, predicted college achievement, and actual achievement in a college course are statistically controlled. (Jones, 1969, p. 47)

The 87 students enrolled in the general education physical science course served as the experimental group. Students enrolled in the three professional courses (55 students) served as the control (or more accurately the comparison) group. The author provided no demographic or background information about the participants. Such information is crucially needed to establish the comparability of the experimental and comparison groups. However, the use of ANCOVA alleviated concerns in this regard. The ANCOVA allows the researcher to make the two groups equal on one or more control variables. In the present study the control variables were the pretest TOUS scores, predicted college achievement, and students' actual achievement in the various courses. Jones (1969), however, did not provide evidence to show that the assumptions of ANCOVA, especially the homogeneity of regression, were met by the sample in the study (Gall, Borg, & Gall, 1996).

The TOUS (Cooley & Klopfer, 1961) was used to assess participants' understandings of the NOS. Jones (1969), however, did not provide any evidence regarding the validity of the instrument, originally validated for use with high school students, in assessing college students' understandings of the NOS. Moreover, evidence for the reliability of the instrument for the group in the present study was not provided.

The ANCOVA revealed that there was a significant difference between the mean TOUS scores for the experimental and control groups ($F = 5.38$, $p < 0.05$). The null hypothesis was thus rejected. Next, the adjusted TOUS mean scores were compared. The mean gain score for the experimental group was +5.79 points, whereas that for the comparison group was -0.45. Thus, the difference in the gain scores of the two groups was 6.25 points which amounts to a substantial increase of about 11 percentage points. The author, however, did not discuss the practical significance of this result nor did she elucidate the aspects of the NOS of which students in the experimental group demonstrated better understanding.

Jones (1969) concluded that the general education, physical science course was more effective in enhancing students' understandings of the NOS than the professionally oriented courses. The author was careful to limit her conclusion to the sample in the present study and to the confines of the experimental design used. Jones suggested that the general education, physical science course at the University of Tulsa be recommended for all non-science majors to meet their physical science requirement course. Jones also recommended that the historical and philosophical components of the course, as well as materials and activities geared toward enhancing students' understandings of the NOS be retained or increased. The present study lent support to Kimball's (1967-68) conclusion that college students' understandings of the NOS can be enhanced by studying historical and philosophical aspects of science.

Summary

Jones (1969) compared the relative effects of professionally oriented science courses and a general education physical science course on undergraduate, non-majors' conceptions of the NOS. Contrary to the professional courses, the general science course emphasized the historical development of scientific concepts, the philosophy of science, and science-related societal issues. The author reported statistically significant gains in the experimental group mean TOUS score. The gain was on the order of 11 percentage points.

Spears and Zollman (1977) investigated the influence of "unstructured" versus "structured" laboratory environments on non-majors' conceptions of the NOS as measured by the SPI. The analysis revealed no statistically significant differences between the scores of the two groups on the Assumptions, Nature of Outcomes, and Ethics and Goals components of the SPI. There was a statistically significant difference in the mean scores on the Activities component. The difference, however, amounted to a mere 2.5 percentage points. In general, students in the unstructured laboratory group did not achieve better understandings of the NOS. Doing science within an inquiry environment did not seem to improve participant students' conceptions of the NOS.

Haukoos and Penick (1983, 1985) investigated the influence of Discovery Classroom Climate (DCC) versus Nondiscovery Classroom Climate (NDCC) on non-majors' conceptions of the NOS. The two environments differed in the extent to which the instructor used direct or indirect verbal behaviors. The underlying assumption was that by manipulating certain aspects of the classroom environment, the researchers can help students learn about the nature of scientific inquiry. Haukoos and Penick (1983) reported that one DCC group had a significantly higher mean SPI score than the NDCC groups. The reported difference was on the order of eight percentage points. The authors, however, were not able to replicate this finding in a second study (Haukoos & Penick, 1985). There were no statistically significant differences between the DCC and NDCC groups mean SPI scores in the second study. The authors insisted that some factor other than the treatment was to blame for this latter result. A bias in favor of the DCC treatment was thus apparent. This bias raised serious doubts about the results of the initial study.

Scharmann (1990) assessed the relative effects of traditional and diversified instructional strategies on freshmen college students' understandings of the nature of evolutionary/scientific theory. The author implemented the diversified instructional strategy over the course of one instructional day (4 1/2 hours). Even though the treatment invited students to reflect on their conceptions of evolutionary theory, there were no indications that other explicit instructional elements were employed. The author noted that the experimental group posttest score was significantly higher from that of the control group, but he did not report the corresponding pre- and posttest mean scores and standard deviations. Thus, it was not possible to estimate the gain achieved by the experimental group nor to assess its practical significance. More doubts about the effectiveness of the treatment came from the fact students in both experimental and control groups achieved statistically significant gains in their understandings of the NOS. A possible testing effect could have been responsible for the observed gains.

In general, it was difficult to establish that the use of implicit approaches within the context of science content course were effective in improving students' conceptions of the NOS. At best, the achieved gains were relatively small to be of any practical significance. Nevertheless, in all the above studies, including the one that employed an explicit approach and reported relatively important gains, the authors did not elucidate the aspects of the NOS of which the participants demonstrated better understanding. Thus, it was not possible to assess the meaningfulness of the reported numerical gains.

Conclusions, Discussion and Critical Appraisal

First, the studies reviewed in the present section indicated that teachers' conceptions of the NOS were independent of virtually all the investigated variables. These variables included teachers' high school and college science content knowledge, science achievement, and academic achievement (Billeh & Hasan, 1975; Carey & Stauss, 1968, 1969, 1970; Olstad, 1969; Scharmann, 1988a, 1988b; Wood, 1972). Teachers' conceptions of the NOS were also not related to other cognitive variables such as logical thinking ability, quantitative aptitude, and verbal aptitude (Scharmann, 1988a, 1988b); social-personal variables such as locus of control orientation (Scharmann, 1988b); and personal attributes such as sex (Wood, 1972). Conceptions of the NOS were likewise independent of the teaching level (elementary versus secondary) (Wood, 1972), science subject taught, inservice professional training (Billeh & Hasan, 1975; Lavach, 1969), field-based teaching experiences (Scharmann, 1988b), and years of teaching experience (Billeh & Hasan, 1975; Kimball, 1967-68; Lavach, 1969).

Learning science content in undergraduate courses and inservice institutes, it seemed, did not contribute to science teachers' understandings of the NOS. Similarly, "doing science" either through participation in the activities of science in undergraduate science courses or through professional practice, did not seem to enhance prospective or practicing science teachers' conceptions of the NOS (Carey & Stauss, 1968, 1970; Kimball, 1967-68). Thus was the need for researchers to use alternative approaches to address potential, prospective, and practicing science teachers' understandings of the NOS.

Before assessing the "success" of these attempts, we will examine the assumptions inherent to the alternative approaches used in the reviewed studies. These approaches, as previously noted, could be categorized under two general labels; implicit and explicit. On the one hand, researchers who adopted an implicit approach utilized science process skills instruction and/or scientific inquiry activities (Barufaldi et al., 1977; Riley, 1979; Trembath, 1972) or manipulated certain aspects of the learning environment in their attempts to enhance teachers' conceptions of the NOS. Aspects of the learning environment that were manipulated included the extent to which researchers used structured activities (Spears & Zollman, 1977) and direct verbal behaviors during instruction and/or laboratory sessions (Haukoos & Penick, 1983, 1985). Other researchers optimized student-student interactions through the use of peer discussions (Scharmann, 1990; Scharmann & Harris, 1992). On the other hand, researchers that adopted an explicit approach in their attempts to improve science teachers' conceptions of the NOS utilized elements from the history and philosophy of science and/or direct instruction on the NOS (Akindehin, 1988; Billeh & Hasan, 1975; Carey & Stauss, 1968, 1970; Jones, 1969; Lavach, 1969; Ogunniyi, 1983).

Implicit and explicit approaches: A closer look at underlying assumptions.

Before turning to address this issue, an important point should be clarified. It cannot be over-emphasized that the above delineation should not be taken to mean that implicit and explicit approaches differ in terms of "kind." That is, not every instructional sequence in the history (or philosophy) of science is an explicit attempt to enhance learners' conceptions of the NOS, nor is every science process-skills instructional sequence or scientific inquiry activity an implicit approach to achieve that end. In this respect, Russell (1981) notes 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 in science" (p. 56). As such, an instructional sequence in the history of science (HOS) could be labeled as an implicit approach if it were devoid of any discussion of one or more aspects of the NOS. Similarly, involving learners in scientific inquiry can be more of an explicit approach if the learners were provided with opportunities to reflect on their experiences from within a conceptual framework that explicates some aspects of the NOS.

Shapiro (1996), for instance, involved prospective elementary teachers in independent "scientific investigations." In this sense, those student teachers were "doing science." Such an approach has been previously labeled as implicit. Shapiro, however, provided the prospective teachers with personal constructs to help them reflect on specific aspects of their investigations. Some of these constructs, we have seen, were concerned with certain aspects of the NOS. Among the aspects that were emphasized was the role of imagination in science (using the imagination—spontaneous ideas versus recipe-like prescriptive work), the role of subjectivity in science (experience with the phenomena versus observing objectively), the nature of scientific constructs and entities (creating new knowledge versus discovering what exists--the way things are), and the lack of a single method for doing science (using the "scientific method" to solve the problem versus not using any particular method). These constructs represented a conceptual framework or an explicit tool that guided students in their thinking about and reflection on what they were doing. These constructs, as Shapiro noted, brought to the student teachers' attention features of the NOS that they were not aware of or could have not come to realize had this aim been left to chance.

The basic difference between implicit and explicit approaches, it follows, was not a matter of the "kind" of activities used to promote understandings of the NOS. The difference lied in the extent to which learners were provided (or helped to come to grips) with the conceptual tools, in this case aspects of the NOS, that would enable them to think about and reflect on the activities in which they are engaged. This difference derived from the assumptions underlying the two approaches. First, advocates of an implicit approach assumed that learning about the NOS would result as a "by-product" of the learners' engagement in science-based activities. They expected science teachers to learn about the NOS as a consequence of instruction in science process-skills and/or involvement in inquiry-based activities, or as a result of changes in the learning environment despite the absence of any direct reference to the NOS. For instance, Barufaldi et al. (1977) noted that "students presented with numerous hands-on, activity-centered, inquiry-oriented science experiences . . . should have developed a more tentative view of science" (p. 291). There were no indications that these activities were followed by any discussions of the notion that scientific knowledge is not certain. Indeed, participant student teachers were not even made conscious of the researchers' aim to foster among them an understanding of the tentativeness of science. Similarly, under the implicit approach changes in the learning environment were believed to engender among learners better understandings of the NOS. For instance, Haukoos and Penick (1983) noted that if "the instructor assumed a low profile by sitting at student eye level and stimulated discussion of the . . . materials with questions designed to elicit student ideas" then learners would develop an understanding of the notion that scientific knowledge is not complete or absolute (p. 631). Again, the researchers did not attempt to make students aware of the fact that scientific knowledge is tentative. They assumed that the instructors' verbal behaviors would convey the latter notion to the learners.

Contrary to what was assumed under the implicit approach, advocates of an explicit approach argued that the goal of enhancing science teachers' conceptions of the NOS "should be planned for instead of being anticipated as a side effect or secondary product of . . . science content or science methods classes" (Akindehin, 1988, p. 73). They advanced that certain aspects of the NOS should be made explicit in any attempt aimed toward fostering adequate conceptions of the NOS. For instance, Billeh and Hasan (1975) presented inservice secondary science teachers with 12 lectures that dealt with, among other things, the nature of scientific investigations, the nature of scientific knowledge (characteristics, classification, and scientific theories and models), and the sociological aspects of science. Others used instruction in the history and philosophy of science to achieve better understandings of the scientific enterprise (e.g., Jones, 1969; Ogunniyi, 1983). Still others used a combination of these elements. For instance, in addition to instruction on the NOS, Akindehin (1988) used Francesco Redi's work on refuting the notion of the spontaneous generation of insects to illustrate to preservice science teachers aspects of a dynamic model of scientific investigation with which they were presented. Moreover, inquiry-based activities were sometimes used in addition to the aforementioned elements to enhance teachers' conceptions of the NOS (e.g., Akindehin, 1988; Olstad, 1969).

The aforementioned differences between implicit and explicit approaches seemed to be rooted in yet another assumption. This second assumption may help to clarify why advocates of an implicit approach expected learners to develop certain understandings of the NOS by participating in science-based activities, learning science-process skills, or, for instance, as a result of the instructor assuming a low profile during instruction when all of these approaches lack any reflective elements or direct reference to the NOS. Advocates of an implicit approach, it seemed, assumed learning about the NOS to be an "affective" goal. Barufaldi et al. (1977) and Riley (1979) explicitly labeled attaining an understanding of the NOS as an "affective" learning outcome. As such, conceptions of the NOS were thought of as "attitudes" or "dispositions" toward science. Consequently, attainment of better conceptions of the NOS would, as would favorable attitudes toward science, be facilitated through successful experiences in "doing science." By comparison, those researchers who used an explicit approach seemed to consider developing an understanding of the NOS to be a "cognitive" learning outcome. And even though none of the latter researchers made explicit use of the label, it was rather plausible to infer this from the very fact that they presented science teachers with lectures that specifically addressed clearly delineated aspects of the NOS (e.g., Akindehin, 1988; Billeh & Hasan, 1975; Carey & Stauss, 1968, 1970; Olstad, 1969). To sum up, two interrelated assumptions seemed to underlie the implicit approach. The first depicted attaining an understanding of the NOS to be an affective learning outcome. This assumption entailed a second one; the assumption that learning about the NOS would result as a by-product of "doing science."

The assumptions underlying the implicit approach harbored some naive views about the NOS. Under this approach it was assumed that aspects of the NOS can be *directly read* from the records of the scientific enterprise and its practices. In a sense, a one-to-one correspondence was assumed between the practice of science and the NOS. As such, one could *discover* aspects of the NOS by going through the motions of science. However, the "NOS enterprise," if you will, is a reflective enterprise. The varying images of science that have been constructed throughout the history of the scientific enterprise are, by and large, the result of the collective endeavors of historians of science, philosophers of science, sociologists of science, scientists turned historians or philosophers, and reflective scientists. Within a certain time frame, the various aspects that are taken to be representative of the scientific enterprise reflect the collective attempts of those individuals to *reconstruct* the history and activities of science in an attempt to understand its workings. The endeavor to delineate various aspects of the NOS is not a matter of merely reading the "book of science" or going through its motions, but rather a matter of putting questions to that book and reflecting on that practice. Kuhn (1970) notes that a shift in the kind of questions that historians asked of the records of science has completely transformed the way we view science. As such, it follows that even though any attempt to foster better understandings of the NOS among science teachers should be framed within the context of the content and activities of science, these attempts, nevertheless, should be explicit and reflective. It is essential that teachers be provided with conceptual frameworks that would help them to construct better understandings of certain aspects of the NOS. These conceptual frameworks, as previously noted, are the product of a purposeful and elaborate endeavor by a collective of individuals who examine the scientific enterprise. It is unlikely that prospective or practicing science teachers would be able to construct such elaborate conceptual frameworks through their relatively limited experiences with, and reflection on, the various dimensions of the scientific enterprise.

The underlying assumptions of the implicit approach seemed to have compromised its effectiveness in enhancing science teachers' understandings of the NOS. Since if we deferred, for the moment, a critical appraisal of the success of the various approaches (implicit and explicit) and examined the reviewed studies on the basis of the statistical models that were employed and the numerical gains that were reported, we could conclude that an explicit approach was generally more effective in fostering appropriate conceptions of the NOS among prospective and practicing science teachers. This conclusion is based on the fact that, on the one hand, all eight studies that employed an explicit approach reported statistically significant gains in participant science teachers' conceptions of the NOS as measured by the respective instruments in use (Akindehin, 1988; Billeh & Hasan, 1975; Carey & Stauss, 1968, 1970; Jones, 1969; Lavach, 1969; Ogunniyi, 1983; Olstad, 1969). On the other hand, of the eight studies that employed an implicit approach, four reported no statistically significant gains in participants' understandings of the NOS as measured by virtually the same instruments (Haukoos & Penick, 1985; Riley, 1979; Scharmann & Harris, 1992; Spears & Zollman, 1977). Moreover, the results in a fifth study (Scharmann, 1990) were ambiguous.

Nevertheless, a *critical* appraisal of the effectiveness of the various attempts undertaken to enhance science teachers' conceptions of the NOS was central to the present study. This appraisal should, as noted earlier, be undertaken from the standpoint that the teachers' resultant understandings of the NOS would adequately meet the condition deemed necessary to enable those teachers to convey appropriate conceptions of the scientific enterprise to their students.

Success of the attempts in meeting the necessary condition.

Before addressing this issue it might be useful to delineate the knowledge base needed to teach the NOS to K-12 students. In the following argument, attaining an understanding of the NOS was taken to be a *cognitive* learning outcome.

Generally, mastery of two components is deemed necessary for one to be able to effectively teach a certain topic. The first is knowledge of the content of the target topic. In the case of the NOS, this component would correspond to knowledge of the various aspects of the NOS. The second component is knowledge of pedagogy. This component refers to knowledge of generic pedagogical principles, the characteristics of the learners, and classroom management skills. However, a third component has been gaining increased recognition as pivotal to effective teaching. This component is pedagogical content knowledge (PCK) (Shulman, 1986, 1987; Wilson et al., 1987). Applied to teaching about the NOS, PCK would include, in addition to an adequate understanding of the various aspects of the NOS, knowledge of a wide range of related examples, activities, illustrations, explanations, demonstrations, and historical episodes. These components would enable the teacher to organize, represent, and present the topic for instruction in a manner that makes the target aspects of the NOS accessible to K-12 students. Moreover, knowledge of alternative ways of representing aspects of the NOS would enable the teacher to adapt those aspects to the diverse interests and abilities of learners.

It is against this knowledge that one is tempted to appraise the success of the attempts undertaken to enhance science teachers' understandings of the NOS. However, such an appraisal may be unrealistic given that PCK usually develops as a result of extensive and extended experiences in teaching a certain topic. Alternatively, what needs to be emphasized is that teaching about the NOS requires science teachers to have *more* than a rudimentary or superficial knowledge and understanding of various aspects of the NOS. Those teachers should be able to comfortably discourse about the NOS (Robinson, 1969), lead discussions regarding various aspects of the NOS, design science-based activities that would help students to comprehend those aspects, and contextualize their teaching about the NOS with some examples or "stories" from the HOS. For instance, it is not enough for teachers to "know" that scientific knowledge is socially and culturally embedded. They should be able to use examples and/or simplified case histories from scientific practice to substantiate this claim and make it accessible and understandable to students.

Appraised against the above background, it was safe to conclude that, in general, the aforementioned studies were *not successful* in fostering among science teachers understandings of the NOS that would enable them to effectively teach this valued aspect of science. This conclusion was based on three common features of the studies. The first related to the practical significance of the gross numerical gains reported in the various studies. If we grant that teachers' scores on the various instruments that purported to measure their conceptions of the NOS were faithful representations of those teachers' views of science, and if we put aside all the concerns regarding the warrant of many of the reported gains that were discussed at length in the reviews and again in the corresponding summary sections, we still come to the conclusion that the statistically significant gains reported were mostly too small to be of any practical significance.

Haukoos and Penick (1985) and Riley (1979) reported no statistically significant gains in participants' scores on the instruments used to assess their conceptions of the NOS. Scharmann and Harris (1992) reported no significant gains in participants' scores on the NOSS. They, nevertheless, obtained statistically significant gains on another instrument (Johnson & Peeples, 1987). However, the mean gain achieved by the participants on this latter instrument amounted to a mere 1.5 percentage points. No significant gains were achieved by participants in the Spears and Zollman (1977) study on three of the four components of the SPI. The authors, however, reported a gain that amounted to 2.5 percentage points on the Activities component of that instrument. Data analysis in the Ogunniyi (1983) study revealed a statistically significant gain that amounted to about 3 percentage points on the NOSS. Barufaldi et al. (1977), based on several assumptions that gave the authors the benefit of a doubt, obtained an average gain of about 4 percentage points on the VS instrument that assessed teachers' understandings of the tentative NOS. Carey and Stauss (1968) and Olstad (1969) reported mean gain scores of about 4.5 percentage points on the TOUS. The gain achieved in Lavach's (1969) study was on the order of about 6 percentage points. Finally, Haukoos and Penick (1983) obtained a significant gain on the order of 8 percentage points on the SPI. However, their result was severely compromised by the fact that the authors were not able to replicate the finding in their second study (Haukoos & Penick, 1985).

A second feature that characterized many studies was that irrespective of the gains achieved, the participants' post-treatment scores indicated, at best, limited understandings of the NOS. For instance, the posttest mean NOSS scores achieved by teachers in the Ogunniyi (1983) study indicated less than 20% agreement with the model for the NOS adopted by the developers of the instrument. Billeh and Hasan (1975), as a result of direct instruction on the NOS, reported statistically significant mean gain scores on the order of 10 percentage points. However, the posttest mean scores achieved by the teachers in the experimental group indicated a little bit more than 50% agreement with the model for the NOST. Similarly, even though the gains reported by Trembath (1972) amounted to about 18 percentage points, the participants' mean posttest scores indicated a little more than 50% agreement with the model of the NOS adopted by the author.

Only in two of the reviewed studies did participants achieve gains that might start to count as practically significant. Carey and Stauss (1970) and Jones (1969) reported statistically significant gains that were on the order of about 11 percentage points. More importantly, the participants' posttest scores indicated about 85% and 73% agreement with the models for the NOS that underlie the WISP and the TOUS, respectively. Finally, the posttest mean NOSS scores reported by Akindehin (1988) indicated more than 90% agreement with the model for the NOS adopted by the author. However, given that Akindehin did not report the mean pretest and posttest NOSS scores, it was difficult to assess the impact of the ISTE package that he used in the study.

Finally, a third feature of the studies made it even more difficult to ascertain the impact of the various treatments used. With the exception of Shapiro (1996), the investigators in all of the reviewed studies did not elucidate the participant teachers' conceptions of the NOS prior to and after the completion of the investigated courses or instructional packages. As such, irrespective of the magnitudes of the gains achieved or the correspondence between the participants' views and the models for the NOS employed in those studies, it was difficult to assess the meaningfulness of the gains demonstrated by the teachers and the depth or breadth of their understandings of the NOS. None of the studies, for instance, asked the teachers to elaborate or explain their views of science, support those views with examples, or design and present activities that might be effective in conveying certain ideas about the NOS to students. Thus, it can be concluded that the condition necessary for enabling teachers to effectively convey to students appropriate views of the NOS (i.e., helping teachers to develop such views themselves), has *not* been sufficiently met.

A Role for HOS in Improving Teachers' Conceptions of the 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 inappropriate views of the scientific enterprise (Gess-Newsome & Lederman, 1993; Lederman & Latz, 1995; Nordland & Devito, 1974; Stofflett & Stoddart, 1994). Science teacher education programs should continue their attempts to promote among prospective teachers more adequate conceptions of the NOS. However, there is a limit to what can be done within the context of teacher education programs. The relative ineffectiveness of the attempts to enhance science teachers' conceptions of the NOS should not be surprising given that the durations of the treatments were very short.

In most of the attempts, these treatments were framed within the context of science methods courses or inservice programs and typically lasted a few hours (e.g., Scharmann, 1990; Trembath, 1972) or a few days (e.g., Akindehin, 1988; Billeh & Hasan, 1975). 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 in science methods courses or inservice programs to dealing with the NOS. It is highly unlikely that prospective and practicing teachers' views of the scientific enterprise, views that have developed over the course of at least 14 years of high school and college science, can be effectively changed, updated, or elaborated during a few hours, days or weeks for that matter.

The relatively limited time that can be dedicated within teacher education programs (or courses) to improve science teachers' conceptions of the NOS is understandable given that the agendas of those programs are already extensive and overly long. During their years in teacher education, prospective teachers enroll in courses designed to familiarize them with areas related to educational psychology, foundations of education, pedagogy, classroom management, instructional design, teaching methods, evaluation, current reforms in teaching and learning, the recent educational research literature relevant to teaching and learning, and school policies and laws. Over and above that, prospective teachers spend roughly one third of their final year in teacher preparation programs student-teaching in public schools.

As such, the efforts to enhance prospective teachers' conceptions of the scientific endeavor undertaken within science teacher education programs need to be augmented with relevant coursework in other disciplinary departments (Bork, 1967; Brush, 1969; Matthews, 1994). *Intuitively*, coursework in the philosophy and history of science, disciplines that respectively deal with the epistemology of scientific knowledge and its development, serve as primary candidates. Indeed, many science educators have argued that coursework in the history and/or philosophy of science can serve to improve science teachers' conceptions of the NOS (Abimbola, 1983; Brush, 1969, 1989; Bybee, Powell, Ellis, Giese, Parisi, & Singleton, 1991; Duschl, 1989; King, 1991; Klopfer & Watson, 1957; Matthews, 1994; O'Brien & Korth, 1991; Robinson, 1969; Rutherford, 1964; Scheffler, 1973).

The notion that HOS can be used to "explain the meaning of science, its function, its methods, its logical, psychological and social implications" (Sarton, 1952, p. 59) is not new. During the past 70 years, science educators (e.g., Conant, 1947; Duschl, 1990; Haywood, 1927; Klopfer, 1964, 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 appropriate conceptions of the scientific enterprise.

However, despite the longevity of these arguments, and to the best of our knowledge, there is *not* one single empirical study in the science education literature that examined the influence of college level HOS courses on learners' conceptions of the NOS. Recommendations for the inclusion of HOS courses 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 of the scientific enterprise (Russell, 1981) and inferred a potentially useful role for HOS courses in improving prospective teachers' conceptions of the NOS.

Some may argue, and understandably so, that what has been stated earlier about 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' conceptions of the NOS, it may be plausible to infer that HOS can also have a similarly positive influence on learners' conceptions of the scientific enterprise. The plausibility of such an inference hinges, however, on the extent to which the attempts to include HOS in science teaching were successful in improving students' understandings of the NOS. The question that follows, then, is to what extent were those attempts successful in enhancing learners' conceptions of the scientific enterprise?

The HOS in Science Teaching

Attempts to incorporate the HOS in science teaching were relatively few (Bybee et al., 1991). Some of those attempts sought to improve students' attitudes toward science—an affective outcome; others sought to enhance students' understandings of the NOS—a more cognitive outcome (Russell, 1981).

In the late 1940s, James B. Conant introduced the *Harvard Case Histories in Experimental Science* (Conant, 1957) into the general education courses in science at Harvard University. Conant (1947, 1951) argued that non-science majors can understand the methods of science by examining the historical development of scientific ideas. Leopold Klopfer extended Conant's ideas and developed the *History of Science Cases for High Schools* (HOSC) (Klopfer & Watson, 1957). These case studies were shorter than their collegiate predecessors and more complete with narratives, marginal notes, discussion questions, and experiments and problems for students to work out. Each case study emphasized one or more aspects of the NOS (Klopfer & Watson, 1957). In addition to student materials, the HOSC provided teachers with ample resources. These resources included guides, supplementary readings, teaching kits, supplies for doing the suggested experiments, and unit tests (Klopfer & Cooley, 1963). Klopfer (1969) argued that high school science teachers "may confidently use the history of science in their instruction to illuminate some of the essential aspects of the scientific enterprise" (p. 90). During the 1960s, the *Project Physics Course* was developed at Harvard University (Rutherford et al., 1970). Brush (1969) argued that *Project Physics* was the first major curriculum development effort to include substantial attention to the HOS at the high school level. The course emphasized the human side of the scientific enterprise and aimed to foster among students better attitudes toward, and understandings about science (Welch, 1973; Welch & Walberg, 1972). The "History of Modern Science" program developed by Stephen Brush (1984) at Harvard University was a more recent attempt to include the HOS in science teaching.

The Impact of Including HOS in Science Teaching on Learners' Conceptions of the NOS

If the attempts to incorporate HOS in science teaching were relatively few (Bybee et al., 1991), then the efforts to assess the influence of such attempts on students' conceptions of the NOS were fewer. A comprehensive search of the literature resulted in only four relevant empirical studies.

Klopfer and Cooley (1963) argued that despite of taking one or more science courses, high school students typically did not attain adequate conceptions of the NOS. The authors attributed this state of affairs to a lack of instructional procedures specifically designed to help students attain better understandings of science and scientists. Klopfer and Cooley continued that the HOSC materials (Klopfer & Watson, 1957), that form the core of the HOSC Instruction Method, were intended to achieve this end. The historical case studies were designed to be used within regular high school biology, chemistry, or physics courses.

The present study aimed to answer two questions. The first was whether students who studied under the HOSC Instruction Method as part of their regular science courses achieved better understandings of the NOS as compared to students who did not. The second question was whether students who studied under the HOSC Instruction Method achieved as much understandings of science content as students who did not.

The study had a randomized, pretest-posttest control-group design. The HOSC Instruction Method served as the experimental treatment. The TOUS, Form X (Cooley & Klopfer, 1961) served as the criterion measure for understanding the NOS. The TOUS has three subscales that aim to measure students' understandings of the scientific enterprise, scientists, and the methods and aims of science, respectively. The criterion measure for science content knowledge was student achievement on the Cooperative Biology Test, From Y; the Cooperative Chemistry Test, Form Z; or the Cooperative Physics Test; Form Z; all published by Educational Testing Service.

The study was organized at Harvard University as the "HOSC Instruction Project." Seven Regional Centers directed by science education professors were established to coordinate the administration of the various instruments. The authors wrote 255 personal letters to science teachers throughout the United States soliciting their participation during the 1960-61 school year. The authors did not explain how or why were these teachers chosen to be part of the original pool of potential participants. A total of 108 teachers agreed to participate in the study. The participating classes were randomly assigned to either the experimental or the control group.

The authors claimed that the participating classes were widely distributed geographically and were representative of various types of high schools in the United States (public and private, rural and urban, and small, mid-sized, and large). The teachers were of the two sexes and had wide ranging teaching experiences. No data, however, were presented to support any of these claims. Moreover, no information was provided about the participant classes, teachers, or students. Such data and information would be necessary to support any claims regarding the generalizability of the results of the present study to any larger population.

The authors believed that the type of science course (biology, chemistry, or physics) and the teacher's understandings of the NOS might influence the effectiveness of the HOSC Instruction Method. Thus, on the one hand, the sample was stratified according to the type of course. The experimental group, with a total of 53 classes, consisted of 19 biology, 19 chemistry, and 15 physics classes. The control group, with a total of 55 classes, consisted of 22 biology, 20 chemistry, and 13 physics classes. On the other hand, teachers' understandings of the NOS were dichotomized as high or low. This categorization, as noted below, was used as a covariate in analyzing the data. Teachers' conceptions of the NOS were assessed using "a specially prepared questionnaire"

(Klopfer & Cooley, 1963, p. 34) that yielded three scores, corresponding to the TOUS three subscales, as well as a composite score. No information whatsoever was provided about the teacher questionnaire. The use of a questionnaire other than the criterion instrument (the TOUS) to assess teachers' views of the NOS coupled with, as the authors noted, taking every effort to make sure that the participating teachers would not see the TOUS, was apparently undertaken to ensure that teachers would not teach to the test.

An additional variable that the authors believed would affect the posttest TOUS scores was students' scholastic aptitude. This variable was assessed using the Otis Quick Scoring Mental Ability Tests: Gamma Test, Form Am, published by the World Book Company. It is noteworthy that the authors did not provide any evidence regarding the validity or reliability in the case of *all* the aforementioned instruments and tests. Reliability coefficients usually provided by the instrument developers were not reported nor were such coefficients calculated for the sample in the present study.

During the months of September and October, 1960, the TOUS and the Otis Mental Ability Test were administered by personnel from nearby colleges and universities to a total of 2,808 students in the experimental and control groups. The experimental period ran from the middle of October, 1960 to the middle of March, 1961. During this period teachers in the experimental group taught two units using the HOSC Instruction Method. The HOSC units and instruction times were chosen by the participating teachers to fit their individual courses. In general, the teachers reported that each HOSC unit was covered in two weeks (11 instructional periods). Thus, the duration of the experimental treatment was approximately four weeks. During this time, teachers in the control group taught their regular science courses.

Two posttests were administered to the 105 classes (out of the initial 108 participating classes) that remained in the study. The first posttest, the TOUS, was administered during the month of March, 1961 to a total of 2,615 students in the control and experimental groups. The TOUS was mostly administered by outside personnel save the case of 35 classes where the participating teachers administered the instrument. The second posttest, the Cooperative Test in either biology, chemistry, or physics, was administered during the month of April, 1961 to a total of 2,590 students (1,069 students in biology, 945 in chemistry, and 576 in physics). All answer sheets were returned to Harvard University for scoring.

The authors noted that additional information and comments were gathered from the teachers using three questionnaires. However, no information was provided regarding the nature of these questionnaires or the information they aimed to solicit. A few visits were also made by the authors and directors of Regional Centers to some experimental classes. The nature of these visits and their purpose were not elaborated.

Appropriate statistical procedures and unit of analysis (class means rather than individual student scores) were used in analyzing the data. Two series of analyses were used to answer the questions of interest. The first series, the "main analyses," aimed to assess whether students in the experimental group achieved more gains in their understandings of the NOS as measured by the TOUS. These analyses were conducted with data from 100 classes out of the 108 participating classes. The authors reported that, out of the eight classes that were not included in the final analyses, two experimental classes did not use the HOSC Instruction Method, three (one experimental and two control) withdrew from the study before the posttest administrations, and three (two experimental and one control) did not provide all the necessary data. No tests were conducted, and no information was provided to assess whether these eight classes had any commonalties. As such, it was not possible to judge whether the noted attrition was due to random rather than systematic reasons.

Four main analyses, based on the TOUS total scores and the three subscale scores, were conducted. In each case, the null hypothesis posited no difference between the mean TOUS total or subscale scores for students in the experimental and control groups. Three-way ANCOVA with covariance adjustments for pretest TOUS scores and scholastic aptitude scores was used in these analyses. Three main effects were investigated: the method effect (whether students were instructed using the HOSC Instruction Method or not), the teacher rating effect (whether the teacher was rated high or low on his/her understandings of the NOS), and the science course effect (whether the course investigated was in biology, chemistry, or physics). To meet the condition of proportionality among the cells in the design used in the analysis, the authors discarded some of the classes in the available sample. The classes that were included in any one set of analysis were randomly selected from the available classes in each cell. The authors provided detailed descriptions of the numbers and ratios of classes that were used in the analyses corresponding to the TOUS total and subscale scores. In each case, the breakdown of the classes according to the effect investigated were also reported.

The second series of analyses, the "subject test analyses," aimed to assess whether, compared to students in the control group, HOSC students achieved similar gains in their understandings of science content as measured by the Cooperative Test in either biology, chemistry, or physics. Data from 101 classes were used in this set of analyses. The one class that was added to this series of analyses, as compared to the main analyses, provided enough data for analysis of subject matter achievement. A total of three analyses were conducted, one for each subject matter. In each case, the null hypothesis tested posited no significant differences in science content achievement between students in the experimental and control groups. The only effect investigated was the method effect, that is, whether a certain class was instructed using the HOSC Instruction Method or not. One way ANCOVA with covariance adjustment for scholastic aptitude was used to compare the standardized mean Cooperative test scores for students in the experimental group with those for students in the control group. In the "subject test analyses," a computer program that generates the value of Wilke's lambda, a generalization of the univariate analysis of variance, was used. Conversions from Wilks's lambda to the F distribution can be readily made.

In the case of the TOUS total score, the analysis revealed a significant main effect for method of instruction ($p < 0.0005$). Other main effects as well as interactions between the main effects did not achieve significance levels. An examination of the non-adjusted mean TOUS total scores indicated that the experimental group achieved a significant ($p \ll 0.001$) mean gain of 5.09 points (about 9 percentage points). The control group achieved a likewise significant gain ($p < 0.001$) on the TOUS total score. This gain, however, was smaller than that achieved by the experimental group (2.10 points, or about 3.5 percentage points). The differences between the experimental and control groups were smaller when adjusted mean scores, in which initial differences in student understandings of the NOS (pretest TOUS scores) and scholastic aptitude (Otis Test scores) were accounted for, were considered. Students who studied under the HOSC Instruction

Method scored, on the average, 2.95 points (5 percentage points) higher than students in the control group. It should be noted that the experimental group mean TOUS total score was 36.76. Out of 60 possible points on the TOUS, this score indicates only about 60% agreement with the model for the NOS underlying the TOUS.

As far as the TOUS subscale 1 (Scientific Enterprise) score was concerned, the analysis also indicated a significant main effect for method of instruction ($p < 0.0005$). None of the other main effects or interactions achieved significance levels. An examination of the non-adjusted mean TOUS subscale 1 scores indicated that the experimental group achieved a significant ($p < 0.005$) mean gain of 2.1 points out of 20 possible points (about 10 percentage points). The control group also achieved a significant gain ($p < 0.005$) on the same subscale. This gain, however, was smaller than that achieved by the experimental group (0.70 points, or about 3.5 percentage points). The adjusted mean score for students who studied under the HOSC Instruction Method was 1.35 points (7 percentage points) higher than that achieved by students in the control group.

Similar results were obtained with the TOUS subscale 2 (Scientists) scores. The analysis indicated a significant main effect for method of instruction ($p < 0.05$). None of the other main effects or interactions achieved significance levels. An examination of the non-adjusted mean TOUS subscale 2 scores indicated that the experimental group achieved a significant ($p < 0.001$) mean gain of 1 point (about 5 percentage points). The control group achieved a likewise significant gain ($p < 0.001$). This gain, however, was smaller than that achieved by the experimental group (0.68 points, or about 3.6 percentage points). The adjusted mean score for students instructed by the HOSC

Instruction Method was 0.36 points (2 percentage points) higher than that of students in the control group.

As far as the TOUS subscale 3 (The Aims and Methods of Science) score was concerned, the analysis again indicated a significant main effect for method of instruction ($p < 0.0005$). None of the other main effects or interactions achieved significance levels. An examination of the non-adjusted mean TOUS subscale 2 scores indicated that the experimental group achieved a significant ($p < 0.001$) mean gain of 1.8 point (about 9 percentage points). The control group also achieved a significant gain ($p < 0.001$) on the same subscale. This gain, however, was smaller than that achieved by the experimental group (0.692 points, or about 4.6 percentage points). The adjusted mean score for students who studied under the HOSC Instruction Method was 0.87 points (4.3 percentage points) higher than that obtained by students in the control group.

Based on these results, Klopfer and Cooley (1963) concluded that the HOSC Instruction Method was superior in promoting better understandings of the NOS among high school students. In particular, the HOSC Method was more effective in promoting understandings about the scientific enterprise and the methods and aims of science than in enhancing students' understandings of scientists.

Moreover, in the case of the TOUS total and subscale scores, the observed differences were only attributed to the "method of instruction" effect. The lack of significant variations due to the teacher effect was described by the authors as "surprising." Coupled with the lack of a significant interaction between the instruction method and teachers' initial understandings of the NOS, the absence of a main teacher effect indicated that the effectiveness of the HOSC Instruction Method was independent of the teachers' understanding. As such, when initial differences in student understandings of the NOS and scholastic aptitude were controlled for, the HOSC Instruction Method helped students to attain better conceptions of the NOS regardless of whether the teacher was rated high or low on his/her understandings of the NOS.

The similar absence of a teacher effect, and lack of interaction between instruction method and teacher rating on understandings the NOS in the case of the control group, however, was perplexing to the authors. Klopfer and Cooley (1963) expected teachers who rated high in their initial understanding of the NOS to foster better conceptions of the NOS among their students. Such an expectation is based, no doubt, on the assumption that teachers' views directly translate into their teaching practices. However, in line of the recent research on the translation of teachers' views of the NOS into classroom practice (Abd-El-Khalick et al., 1998; Brickhouse & Bodner, 1992; Duschl & Wright, 1989; Hodson, 1993; Lantz & Kass, 1987; Lederman, 1995), this result should not be surprising at all. This line of research has shown that there seems to be a host of factors that mediate the translation of teachers' conceptions of the NOS into their classroom practice.

The absence of a main effect due to the type of course, coupled with the lack of a significant interaction between method of instruction and type of course, indicated that the effectiveness of the HOSC Instruction Method was independent of the type of course. The authors thus concluded that students studying under the HOSC Instruction Method were expected to achieve gains in their understandings of the NOS, as measured by the TOUS, irrespective of whether they were taking a course in biology, physics, or chemistry.

As far as subject matter achievement was concerned, analysis of the mean Cooperative Biology Test scores indicated a significant difference ($F = 5.60$, $p < 0.05$) favoring the control group. Students in the control group achieved an adjusted Cooperative Biology Test mean score of 58.95 (with a standard deviation of 6.38) while students in the experimental group achieved a score of 56.51 (with a standard deviation of 6.13). This difference amounted to a maximum of about 4 percentage points. However, in the case of both the Cooperative Chemistry and Physics Test scores, no significant differences were found between the control and experimental groups (F values were 0.87 and 0.68, respectively). The authors thus concluded that when the HOSC Instruction method was used, a small loss in biology content achievement was noted. No such loss of achievement was observed in the case of chemistry and physics content knowledge. The authors continued that the results of the subject test analyses indicated that the usual objections raised against the use of materials such as the HOSC can no longer be justified. Such objections usually advanced that valuable content achievement is necessarily compromised when HOSC and similar materials were used in the science classroom.

Klopfer and Cooley (1963) concluded that the present study clearly indicated that the HOSC Instruction Method was effective in enhancing students' conceptions of the NOS when used in biology, chemistry, or physics courses. The authors continued that their conclusion was especially warranted given the experimental nature of the study, the relatively large sample size, and the high levels of significance achieved. The authors also noted that the HOSC materials can be used without fear of compromising subject matter achievement or extended time commitments given that the gains reported in the present study were achieved over the relatively short duration of four weeks. In general, the results of the present study lent support to the notion that incorporating the HOS in science teaching can enhance students' understandings of the NOS.

Yager and Wick (1966) aimed to assess the influence of three emphases in teaching eighth grade general biology on students' conceptions of the NOS and critical thinking. The general biology course adopted a molecular approach and incorporated laboratory experiences to a high degree. The teaching emphases investigated were a "textbook and laboratory" (TL) approach, a "multi-reference laboratory" (MRL) approach, and a "multi-reference laboratory and idea" (MRLI) approach. The study was conducted at the University of Iowa Laboratory School during the 1962 and 1963 school years. It should be noted that several aspects of the study, especially those regarding participants, design, and procedures, were not clearly delineated in the report. As such, descriptions of these aspects had to be reconstructed from various parts of the report.

The study had a randomized, pretest-posttest comparison group design. The aforementioned three teaching emphases served as the experimental treatments. Students' performance on the TOUS (Cooley & Klopfer, 1961), the *Watson-Glaser Critical Thinking Appraisal* (Watson & Glaser, 1961), and the *Nelson Biology Test* (Nelson, 1952) served as the criterion measures. The authors did not provide any evidence regarding the validity of these instruments in assessing eighth graders' conceptions of the NOS, critical thinking abilities, and understandings of biological concepts, respectively. In this regard, it should be noted that the TOUS was originally developed and validated for use with high school (rather than middle school) students. Moreover, the authors did not provide any information regarding the reliability of the instruments in use. Reliability coefficients usually provided by the instrument developers were not reported nor were such coefficients calculated for the sample in the present study. All this may cast some doubt on the results of the presently reviewed study.

Seventy students were randomly assigned to three sections of the investigated eighth grade biology course. No further information whatsoever was provided about the students. The students were informed that they were part of an investigation. However, they were not made aware of the purpose, procedures, or outcomes of the investigation. The authors argued that the Hawthorne effect was minimized by the fact that students were not aware of their group status and that student involvement in research studies at the laboratory school was a regular occurrence. The students were administered all three aforementioned instruments as pre- and posttests during the first and last weeks of the study, respectively.

Three teachers taught the various sections. They were described as better than average, highly committed, and personally interested in the results of the study. The teachers had similar backgrounds with an average of five years of teaching experience, 50 graduate-level biology semester hours, and training in the history and philosophy of science. No additional information were provided about the teachers. The three teachers worked as a team and were periodically shifted from one section to another. As such, they taught units under the three emphases in use. This procedure, the authors noted, was undertaken to minimize the teacher effect on the outcomes of the study.

Students in all three groups studied the same units and were presented with the same biological concepts and theories. The teaching emphases, however, were varied among the groups. Students who studied under the TL approach exclusively used the paperback editions of the BSCS Blue Version materials (BSCS, 1961). No other textbooks, references, or investigations were used. The approach emphasized mastery of biological concepts through inquiry-based laboratory activities. Moreover, under the TL approach, the teachers intentionally avoided discussions related to "differences in opinion, interpretations, and reports of new findings" (Yager & Wick, 1966, p. 16). In addition to the materials used by the TL group, the MRL group used a variety of textbooks, references, handouts, and excerpts from original works. Under this approach, every effort was taken to avoid identifying activities or instructional sequences with a certain textbook, reference, or laboratory manual. Laboratory guides were accordingly prepared as separate handouts. While the TL students were not involved in modifying laboratory activities, students in the MRL group often added to, or modified laboratory procedures. When a certain concept or theory was presented, the teachers accorded attention to a variety of related views provided by modern writers. However, there was no mention or discussion of the history of the presented scientific ideas or of the controversies associated with their development. Under the third approach, the MRLI approach, students had experiences that were identical to those of the MRL students with the additional dimension of HOS. The teachers made a concerted effort to highlight the original contributions of scientists toward the development of the ideas discussed, and how these ideas changed over time to assume their present dynamic form. The possibility of these ideas changing in the future was also emphasized. Moreover, attention was accorded to the cultural conditions associated with the various ideas presented and the multitude of ways in which similar ideas were viewed and interpreted in different cultures throughout their historical development. As such the tentativeness and cultural embeddedness of scientific knowledge were explicitly discussed.

The authors used the individual student as the unit of analysis. This use was appropriate given that participating students were randomly assigned to the three treatment groups. ANCOVA was appropriately used to analyze the data. Participants' pretest TOUS, *Watson-Glaser Critical Appraisal*, and *Nelson Biology Test* scores were used as covariates in the analyses. When ANCOVA indicated the presence of statistically significant differences between the groups, two-tailed t-tests were used to decide where the differences existed. All possible pair-wise group comparisons were conducted to achieve this end. The authors, however, did not take any measures to guard against the accumulation of error that would result from multiple testing.

Nonetheless, the authors, to their credit, made sure that the assumptions underlying the ANCOVA were met by the data. First, the homogeneity of variance assumption was tested using the Bartlett's test. In all cases, the results were non-significant indicating that this assumption was met. Second, the regression of posttest scores on pretest scores for the TOUS, *Watson-Glaser Critical Appraisal*, and *Nelson Biology Test* were the same for all three treatment groups. In each case, the result was non-significant (F-values were 1.24, 2.62, and 0.095, respectively) and, thus, the homogeneity of regression assumption was satisfied. Third, the authors tested whether the regressions in all three cases were linear. In each case, the hypothesis that pre- and post-test scores were related in a linear fashion was not rejected (F values were not provided).

The hypothesis that there was no difference between the treatment groups mean TOUS scores was rejected at the 0.01 significance level (F = 4.95). Pair-wise comparisons indicated that the MRLI adjusted mean TOUS score (37.16) was significantly higher than that of the MRL group (36.39) which in turn was higher than that of the TL group (27.65). It should be noted that the MRLI and MRL groups adjusted mean scores were substantially higher than that of the TL group (about 16 percentage points higher). However, the adjusted mean TOUS score for the MRLI group was only about one percentage point greater than that of the MRL group. Given that the historical dimension was the only difference between the MRL and MRLI group treatments, it followed that HOS seemed to have had only a minimal effect of students' conceptions of the NOS. Finally, out of 60 possible points on the TOUS, the highest average, that achieved by the MRLI group, corresponds only to about 60% agreement with the model for the NOS underlying the TOUS.

Similarly, the hypothesis that there was no difference between the treatment groups mean scores on the *Watson-Glaser Test* of critical thinking was rejected at the 0.01 significance level (F = 4.95). Pair-wise comparisons indicated that the MRLI group adjusted mean score was higher than that of the MRL and TL groups (the mean scores were 54.92, 53.00, and 41.09, respectively). Again, it should be noted that the MRLI and MRL group adjusted mean scores were very close, and substantially higher than the TL group.

As far as the *Nelson Biology Test* adjusted mean scores were concerned, the null hypothesis could not be rejected (F = 0.0015). As such, no pair-wise comparisons were conducted. The authors concluded that all three treatment groups did not differ in their mastery of the biological concepts presented in the course. It should be noted that in the case of all three criterion instruments, pretest scores and standard deviations were not reported. As such, it was not possible to asses the practical significance of the gains that were achieved as a result of the MRL and MRLI treatments. The authors did not discuss the practical significance of any of their findings.

The authors concluded that the investigated emphases in teaching had varying impacts on students' conceptions of the scientific endeavor and critical thinking. Compared to the use of a single textbook-laboratory approach, the multi-reference approaches (MRL and MRLI) were superior in developing students' understandings of the NOS and critical thinking ability. This was achieved without compromising content knowledge achievement.

The authors also noted that the MRLI approach, with the added HOS dimension, was superior to both the TL and MRL approaches. This conclusion can only be justified when comparing the MRLI and the TL approaches. The results of the present study, however, do not lend support to the conclusion that the MRLI approach was "superior" to the MRL approach. As noted earlier, the mean posttest TOUS and *Watson-Glaser* test scores were almost identical for students in the MRL and MRLI groups. In both cases, the mean MRLI group scores were only about one percentage point greater than those of the MRL group. While such differences may have been statistically significant, they surely lack any practical significance. As such, it could be concluded that HOS, the only difference between the MRL and MRLI treatments, seemed to have contributed little to students' understandings of the NOS.

The authors were careful to acknowledge the central role of teachers in advancing students' understandings in the classroom. Yager and Wick (1966), and rightly so, questioned whether the results of the present study could be generalized, given that the participant teachers had special training in the history and philosophy of science and advanced training in biology. The authors noted that the significant role of the teacher in ensuring the success of various emphases in teaching in the science classroom should not be overlooked.

Welch and Walberg (1972) noted that the developers of *Harvard Project Physics* course were concerned with the decrease in the number of students who elected high school physics. The course was designed to attract students who were not bound for careers in science, mathematics, or technology. The most distinctive aspect of the course, Welch and Walberg continued, was its humanistic orientation; an attempt to show the relationship between ideas in physics and social and technological developments. More importantly, for the purpose of the present review, *Project Physics* course was the first major curriculum development effort to include substantial attention to the HOS at the high school level (Brush, 1969).

The present study was conducted during the final year of *Project Physics* course development. At the time of the study, the course was being used by about 80,000 students in all 50 states. The study aimed to assess the influence of *Project Physics* course on the classroom learning environment and a variety of cognitive and affective student outcomes. The cognitive outcomes included student understandings of the nature and processes of science, and their content achievement. The affective outcomes included student interest in, and attitudes toward science, physics, and physics subject matter, as well as their satisfaction with *Project Physics* course.

The study had a randomized, pretest-posttest control-group design. *Project Physics* course served as the experimental treatment. Student performance on a variety of instruments served as the criterion measure. The TOUS (Cooley & Klopfer, 1961) and the SPI (Welch & Pella, 1967-68) were used to assess student understandings of the NOS. The "Physics Achievement Test" (Winter & Welch, 1967) and student course grades were used to measure content knowledge achievement. The "Pupil Activity Inventory" (Cooley & Reed, 1961), the "Semantic Differential Test" (Geis, 1969), and *Physical Science Interest Measure* (Halpern, 1965) were used to assess student interest in, and attitudes toward science, physics, and physics subject matter, respectively. The social climate of the classroom was assessed using the "Learning Environment Inventory" (Walberg & Anderson, 1968). Course satisfaction was measured using a questionnaire developed by the first author (Welch, 1969). Additionally, two unpublished questionnaires were used to assess student perceptions of physics and reactions to the course. It is noteworthy that the authors did not provide any evidence regarding the validity of *all* of the above instruments and tests. The authors, however, computed the reliability (KR-21 or Cronbach Alpha) coefficients for the sample in the present study for all the instruments. These reliability coefficients were relatively high. It should be noted that the present review will only focus on the results concerning measures of understanding the NOS. The results for all other measures will be briefly summarized.

The authors attempted to generate a national random sample of physics teachers. A list of the names and addresses of 16,911 physics teachers was obtained from NSTA. According to NSTA, the list was complied from responses obtained from 81% of all secondary science teachers in the United States. This initial list was reduced to 16,702 names due to geographical considerations that related to anticipated travel expenses. The names on this latter list were assigned ordinal numbers. A table of random numbers was then used to generate a list of 136 teacher-names. Letters explaining the nature of the study and associated responsibilities, and soliciting participation were mailed to these 136 teachers. A total of 124 teachers replied. Of those, 72 accepted to participate in the study and 52 declined.

A variety of reasons were noted by the teachers who were unable to participate in the study. These reasons included prior commitments, such as continuation of college studies or summer jobs; lack of interest; and other miscellaneous reasons, such as changing jobs, travel-related health problems, expecting a baby, etc. T-tests were used to analyze the letters returned by non-acceptors for systematic trends. The analysis revealed that, compared to non-acceptors, teachers who agreed to participate in the study tended to come from large high schools where the Physical Science Study Committee (PSSC) physics course was being taught. The authors thus concluded that the results of the present study may be generalized to large high schools where previous innovations have been accepted. Welch and Walberg (1972), however, noted that any generalization should take into account the limitations related to selecting the sample, such as listing by NSTA and refusals.

A table of random numbers was used to assign the 72 acceptors to the experimental (46 teachers) and control (24 teachers) groups. Due to illnesses and transfers, the final sample ended up being 53 physics teachers, 34 experimental and 19 control. No information whatsoever was provided about the participant teachers.

Teachers in the experimental group attended a six-week training session at Harvard University and taught *Project Physics* course during the 1967-68 school year. Because of the possibility of the Hawthorne effect, teachers in the control group were also brought to

Harvard University for two days. They were entertained by professors in the physics department and made aware of the significance of their participation in the study. Teachers in the control group taught their regular physics courses during the time of the study. Teachers in both experimental and control groups administered pre-, mid, and posttests to their students. Travel expenses, stipends, and course materials were provided by *Project Physics*.

Due to the relatively large number of instruments used in the present study, a system of randomized data collection was used. This system, whereby in the same session a random half of the class is administered one instrument while the other half is administered another, allowed the authors to maximize the number of instruments that can be administered during a given class session. Tests were arranged by the researchers before they were sent to participating teachers. Within their classrooms, teachers were asked to hand the first test to the first student in a certain raw, the second test to the student in the next raw, and so on. As such, in one session, mean scores were obtained on two different instruments, and individual scores on each instrument were obtained for half the students in the class.

The "Learning Environment Inventory" (Walberg & Anderson, 1968) was administered in December. All other criterion instruments were administered as pre-, mid, and posttests using the randomized data collection technique. In addition, the Henmon and Nelson (1960) IQ Test was administered in December. The achieved IQ scores were used to assign students to three ability groups: low, middle, and high. The authors noted that IQ was a variable of interest because *Project Physics* course was designed to appeal to a broader range of student abilities.

The authors appropriately used the posttest teacher-mean, or the average scores of all students taught by the same teacher, as the unit of analysis. Since the cell sizes corresponding to the three IQ ability levels were unequal, the authors appropriately used a nonorthogonal ANOVA to analyze the data. Using IQ as a variable in the analysis allowed the authors to tests for course and IQ interactions. Moreover, since main effects are usually confounded in nonorthogonal analyses, the authors decided to examine the IQ main effect first, the course main effect second, and the interaction between course effect and IQ third, in that order. This procedure made possible an un-confounded test for the course main effect that was of primary interest in the present study. It should be noted that the authors did not provide any evidence to indicate that the assumptions underlying the statistical tests in use were met by the data in the present study.

In the case of each criterion measure, the null hypothesis was that the difference between the experimental and control groups mean scores were non-significant. In case ANOVA indicated a statistically significant difference (statistical significance was set at the 0.1 level), two-tailed F-tests for differences in means were used to determine the direction and relative size of the course effect. Again the significance level for the F-tests was set at the 0.1 level. Two main reasons were advanced by the authors to justify their use of this relatively non-conservative significance level which entailed a greater chance of committing a type I error. First, the authors argued, a two-tailed 0.1 test is equivalent to a one-tailed 0.5 test that could be used in the present study because of the directionality of the hypotheses tested. Second, they continued, the "results were to be used for applied decision making" (Welch & Walberg, 1972, p. 377).

Data analyses indicated significant course effects on some “affective” measures. *Project Physics* students scored approximately one standard deviation higher than students in other physics courses on the “Course Satisfaction” measure. As far as the social climate of the classroom was concerned, *Project Physics* students perceived their classes to have more diversity, and to be more egalitarian and less difficult. By comparison, students in the control group found their classes to have favoritism and to be more difficult. Moreover, as compared to students in the control group, *Project Physics* students thought that physics was more understandable and enjoyable. *Project Physics* students also found the historical approach to be interesting, and rated physics as more historical, philosophical, social, humanitarian, less mathematical, and applied than students in other courses.

There were no significant course effects on the Semantic Differential measures that included scales such as perceiving laboratory work to be interesting, and learning about science, physics, and the universe to be interesting. However, there was a significant interaction between the Semantic Differential measures and IQ. For the middle IQ groups, *Project Physics* students responded more favorably to the aforementioned scales. This was reversed in the case of the low IQ groups. Students in other courses related more favorably to the above measures than *Project Physics* students. Finally, there were no differences on the Semantic Differential measures between students in the high IQ groups.

More importantly, for the purposes of the present review, no significant differences were found between *Project Physics* students and students in the regular physics courses on any of the “cognitive” measures. In particular, compared to students in the control group, students in the experimental group did not achieve better mean scores on the TOUS and SPI. Thus, as measured by these latter instruments, *Project Physics* students did not achieve better understandings of the NOS. Given that substantial attention was accorded to the HOS in *Project Physics* course, the results of the present study did not lend support to the notion that HOS contributes to students' understandings of the NOS. These results were described by the authors as "disappointing" (Welch & Walberg, 1972, p. 377).

Solomon, Duveen, Scot, and McCarthy (1992) noted that the present study was motivated by the National Curriculum for England and Wales reference to the nature and history of science. The latter document noted that students should develop understandings of the tentative nature of scientific ideas and their relationship to the social and cultural contexts within which they were developed. However, the authors continued, the requirement to teach the HOS in England was made despite the lack of adequate classroom resources, and empirical research on students' conceptions of the NOS and the effects of an historical approach on students' understandings of science.

Solomon et al. (1992) continued that a large number of science educators champion an historical approach to science teaching. Those educators often argue that incorporating the HOS in science teaching would result in better understandings of scientific concepts and their social relevance, enhanced student motivation, and more favorable public attitudes toward science. However, the authors noted, such arguments were usually theoretical in nature. Little empirical research has been done to support the recommendations often advanced for including the HOS in science teaching. As such, the purpose of the present study was to document how learning science through HOS might influence students' understandings of the NOS and scientific concepts.

The authors noted that Kuhn's ideas regarding the difficulties associated with attempting to understand outdated modes of explanation figured in selecting classroom materials for the present investigation. As such, the HOS selections used in the study were chosen for their ease of comprehension, fit with the content being taught in the investigated classrooms, and relevance to understanding certain aspects of the NOS that students were shown to lack. These materials were prepared and pilot-tested by the primary author but were still in draft form at the time of the study. The materials were later published as *Exploring the Nature of Science* (Solomon, 1991).

The historical materials used comprised 13 units that matched the topics emphasized in the National Curriculum for England and Wales. The authors described the first unit, "Mountains on the Moon." This unit traced the development of telescopes and Galileo's observations of shadows on the moon. The unit then explored Galileo's inference as to the presence of mountains on the moon—a planet previously thought to be a perfect heavenly body, and his attempts to calculate the height of these mountain from the observed shadows. After reading the story, the students worked in pairs to develop posters in which they explained the content of the reading. The whole class then built a model of the moon and its "mountains," shined a light on the model, and carried their own investigations in which they attempted to relate the length of the shadows and the inclination of the light with the height of the modeled "mountains." The authors noted that even though not all 13 units had the exact same structure, each historical narrative was followed by an activity. The purpose of these activities was to get students to think about the text and extract from it as much information as possible.

It should be noted that many crucial aspects of the present study, including descriptions of the sample, the instruments in use, and procedures, were absent from the report. This was particularly the case with the data collection and analysis procedures about which the authors provided virtually no information. As a result, the general warrant of the conclusions of the present study was compromised.

In pilot work done prior to the study, the authors, based on the work of Citro (1990), constructed and administered a multiple-choice questionnaire on the NOS to 400 students. No information whatsoever was provided about the students in this pilot sample. Similarly, no information was provided about the student conceptions of the NOS that the questionnaire purported to assess. The authors noted that their awareness of the fact that students may give different, and sometimes contradictory, answers based on the domain of knowledge that questionnaire items tap into, led them to "amend" the questionnaire after analyzing the data. The amended questionnaire was used as a pre- and post-test in the present investigation.

The authors, however, did not explain how or on what basis this "amendment" was made. Given what the authors seemed to know about student responses to paper-and-pencil instruments, the appropriate procedure would have been to follow up the questionnaire administration with individual interviews with the respondents, or with a sample of the respondents. Any amendments based on follow-up interview data would have added to the validity of the questionnaire in use. As vague as the description of this phase of the study was, the authors did not provide any information regarding the validity of their questionnaire. Likewise, no information was provided to support the questionnaire reliability. This latter aspect was particularly crucial given that the authors noted that the questionnaire "was to provide ancillary *quantitative* data for evaluating the classroom research [italics added]" (Solomon et al., 1992, p. 412). The authors did note that based on this pilot work, the misconceptions of the NOS that they expected students to have were a naive form of empiricism, different and usually inappropriate meanings for the word "theory," a naive view of history, and a two-way (right/wrong) value system.

The present study was undertaken in five classrooms located in three schools that represented different geographical areas. In addition to the teachers, the participants were 94 students. As can be inferred from the results section, the student ages ranged between 11 and 14 years. The authors did not provide any information about the participating teachers, classes, or students. The investigation ran the length of one school year.

The authors noted that the present study drew on three research traditions. The first was action research where the participating teachers worked alongside with the researcher(s). (The number of researchers, as opposed to collaborating teachers, was not clear from the report.) The second was that of intervention studies where a new innovation was introduced and researcher(s) monitored students' and teachers' progress by repeated interviews. The frequency and nature of these interviews as well as the kind of data collected were not elaborated. The third tradition was that of experimental research "where impartial observation and measurement were designed to probe and explain the progress of the pupil understanding" (Solomon, 1992, p. 413). It was rather perplexing how these three very different research traditions with varying epistemological and methodological commitments were used in the one and same study. For instance, it was not explicated how it was possible for the authors to make "impartial" observations (whatever that may mean) while being actively involved in the classroom. In the absence of crucial details regarding the ways in which changes in student (and teacher) views were documented, the claimed methodological variety could hardly be defended.

The authors did admit that using all three research approaches resulted in some constraints. They noted that working alongside the teachers precluded any judgments of their actions. Working from an intervention-study perspective, the authors were concerned with interviewing the students at the end of lessons rather than, as is usually the case with action research, helping them to develop better understanding.

Participating teachers chose and taught 6 out of the 13 units available in *Exploring the Nature of Science* (Solomon, 1991). Two additional units were specifically designed to meet the needs of one teacher. Solomon et al. (1992) noted that despite the variety of teaching "there was a strong theoretical coherence in our research" (p. 413). The authors noted that continuous communication with the teachers, the teachers' own enthusiasm, and the researcher(s)' experience made this variety a source of richness rather than one of incoherence. The authors, nonetheless, did not provide any details about the nature of the teacher-researcher or teacher-teacher communication, or about the shared aspects of teaching that made it possible to maintain a coherence of vision and practice in teaching the various units by different teachers. The instructional strategies used and aspects of the NOS emphasized were not explicated. As such, it was not possible to know whether, after the historical narrative was presented, students were helped to make their own conclusions about science or whether (and to what extent) they were guided by the teachers to develop certain understandings about the NOS.

The results from analyzing interview data were reported first. The authors did not describe the participants' views as a whole. They rather provided examples from individual student responses. Regarding expectations and theory, prior to the course, an 11-year-old boy, Leo, firmly held the position that scientists had no expectations about the results of their experiments. Leo also thought that theories were synonymous with facts. Two other female students were ambivalent about these issues and expressed more fluid views. In general, the authors noted that students had little knowledge about scientists, were unfamiliar with the word "theory," and were not able to provide examples of scientific theories.

After the course, several students maintained their initial images of scientists. However, students now referred to real scientists and real experiments. Leo, who initially thought that theories were facts, *seemed* to be moving toward the notion of theories as ideas. However, when probed further, he fell back to the idea that a theory *is* a fact.

Following a unit on Peter Medawar's theory of the body's immune reaction that was told in the form of a cartoon strip, 12 and 13-year-old students were asked to write about their understandings of Medawar's explanation. Later discussions showed that some of the students developed more sophisticated ideas about hypotheses, theories, and experiments. The authors provided some quotations in this regard but did not explain the context in which these quotes revealed progress in students' views of theories and experiments.

Regarding views on historical settings, the authors noted that most of the students dismissed past theories as a sort of "wrong" knowledge. The students suggested the lack of knowledge, logic, or technology as reasons for the "failures" of such theories. The students did not show any empathy for past ideas. In one unit, students performed simple experiments modeled after work by Needham, Pasteur, and Puchect. In these experiments, students took the roles of scientists. Many students found it extremely difficult to role-play a certain scientist especially when they knew that the scientist was "wrong." Students were unable to appreciate the social conditions and contemporary thinking that led scientists to develop certain ideas and make certain decisions. The authors expressed their "discomfort" with these student views. These results, however, should not have been surprising given that the authors made explicit reference to Kuhn's notion of incommensurability when developing their theoretical perspective.

Next, the authors presented the results from analyzing four of the NOS questionnaire items. It was not clear whether the questionnaire had only four items or whether these were selected for the purpose of reporting certain results. The four questions asked students why they thought scientists do experiments, whether scientists usually know what to expect before they perform their experiments, what a scientific theory is, and why different groups of scientists sometimes hold different theories. The analysis of student responses, reported in the form of a bar graph for all 94 participating students, revealed certain trends. First, almost half of the students moved from thinking that the purpose of experiments was to make discoveries toward seeing experiments as attempts to generate explanations. Second, at the conclusion of the course, the number of students who thought that scientists know what they expect would happen in an experiment almost doubled (from 24 to about 48 students). However, almost one-half of all the students (40 students) still believed that scientist do not know what to expect when they perform an experiment. Third, compared to about 30 students who thought theories to be synonymous with facts prior to instruction, only a few still expressed that view at the conclusion of the course. Others now believed that a theory is an idea or an explanation. Finally, regarding why scientists subscribe to different theories, most of the students noted, prior to instruction, that scientists usually look at the results of their experiments in different ways. There was no change in students' views regarding this issue at the conclusion of the study.

The authors concluded that the historical units used in the present study made valuable contributions to students' understandings of the NOS. This was especially the case with the shift that students made toward viewing experiments as attempts at explanation that carry expectations about what may happen.

The teachers in the present study believed that their students learned some science concepts better when they examined them in historical and controversial situations. The authors noted that this improvement might be due to a Hawthorne effect that was a result of the teachers' enthusiasm and the extra classroom help they provided to their students. It should be noted that because many aspects of the study were poorly documented, it was not possible to judge whether the improved student understandings were a result of HOS instruction or of direct and explicit instruction on the NOS provided by the participating teachers. The authors noted that helping students to focus on the evidence that was used to support a theory over another produced more "durable learning" (Solomon et al., 1992, p. 419) as compared to teaching accepted theory. The authors, however, did not provide any data to support this latter conclusion.

Finally, the authors noted that they had evidence that an historical approach made conceptual change in student ideas easier. The authors, however, did not disclose the supporting evidence. Moreover, this conclusion seemed to run counter to the authors' remarks about the difficulties that students faced in empathizing with scientists' ideas in other historical settings.

Summary and Conclusion

Klopfer and Cooley (1963) reported that HOSC students exhibited significant gains in their understandings of the scientific enterprise, as measured by the TOUS, after a four week treatment period. Students' post-test results indicated about 60% agreement with the model for the NOS adopted by the investigators. Similar gains in understanding the NOS were reported by Yager and Wick (1966) when high school students were instructed using an approach that emphasized the historical development of scientific concepts. In contrast to the Klopfer and Cooley study, however, the study by Yager and Wick failed to provide support to the notion that incorporating the HOS in science teaching contributed to enhanced student understandings of the NOS. This was the case given that, in the Yager and Wick study, similar gains in understandings of the NOS were achieved by students who studied under a multi-reference laboratory approach that did not include any reference to the HOS.

The Welch and Walberg (1972) study that matched Klopfer and Cooley's (1963) study in its experimental design and relatively large samples size, came to cast doubt on the effectiveness of the historical approach in improving students' conceptions of the scientific enterprise. In this study of a randomly selected, national sample of 52 science classes, Welch and Walberg found that *Project Physics* students made no statistically significant gains in their understandings of the NOS as compared to high school students enrolled in traditional physics courses. These findings were particularly important given that *Project Physics* course was the first major curriculum development effort to include substantial attention to the HOS at the high school level. The course was only successful in enhancing students' attitudes on measures such as course satisfaction, diversity, difficulty level, and learning environment (Welch, 1973).

Solomon et al. (1992) reported that middle school students taught about the NOS through history showed progress in their understandings of some aspects of the scientific endeavor. However, given the aforementioned poor documentation of several aspects of the study, it was not possible to tell whether the reported improvement in student views of the NOS was due to incorporating the HOS in science teaching or the result of direct instruction on some aspects of the NOS.

It follows that the evidence concerning the effectiveness of the historical approach in enhancing learners' conceptions of the NOS remains, at best, inconclusive. "It appears that historical material *does not ensure* improved understanding of science [italics in original]" (Russell, 1981, p. 61). As such, recommendations to include HOS courses in the preparation of science teachers based on inferences derived from using HOS in science teaching do not seem to be grounded in any firm empirical literature.

In this regard, interestingly enough, discussions about the effectiveness of the historical approach by its originators and reviewers brings back to light the earlier discussion about implicit and explicit approaches to improving learners' conceptions of the NOS. Klopfer (1969) noted that for the historical approach to be effective in enhancing learners' conceptions of science, "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). To sum up, it seems that HOS of itself may not suffice to improve learners' views of science. Aspects of the NOS that are deemed important for students to understand need to be given *explicit* attention.

Chapter III

Method

Purpose

The purpose of the present study was to assess the influence of history of science (HOS) courses on college students' conceptions of the nature of science (NOS). The study also aimed to examine whether students, including student teachers, who entered HOS courses with a conceptual framework consistent with current conceptions of the scientific enterprise were more likely to achieve, if any, more elaborate and enriched understandings of the NOS. Additionally, the study aimed to assess what aspects, if any, of the investigated courses tended to render the courses more effective in influencing students' conceptions. Such aspects included: course objectives; instructor priorities, such as the commitment to enhance learners' conceptions of the NOS; teaching approach, such as explicit attention to the NOS or striving to help students develop alternate ways of approaching HOS; and classroom dynamics, such as large, lecture-oriented versus small, discussion-oriented courses. The research questions that guided the present investigation were:

1. Do HOS courses influence college students' conceptions of the 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 NOS more likely to achieve, if any, more adequate and enriched understandings of the NOS?

3. To what extent, if any, do various course aspects (e.g., course objectives, instructor priorities, teaching approach, and classroom dynamics) influence students' conceptions of the NOS?

Participants

Participants in the present investigation comprised two groups. The first included all 169 undergraduate and graduate students enrolled in three HOS courses offered during Fall term in a mid-sized state university on the West Coast. The second group consisted of all 15 preservice secondary science teachers enrolled in a fifth-year Master of Arts in Teaching (MAT) teacher preparation 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 of special interest for the purposes of the present study consisted of the 10 preservice MAT students enrolled in one of the HOS courses chosen for investigation.

A questionnaire (Appendix A) was used to gather biographical and background data about the participants. These data included gender, age, and education with a special focus on the participants' HOS, philosophy of science, and science backgrounds, and other relevant experiences in science. In this regard it should be noted that the questionnaire grouped coursework in the various scientific disciplines and sub-disciplines under four categories: agricultural, biological, geological and space, and physical sciences. This categorization was adapted from the catalog of the university at which this investigation was conducted. These four categories were used to characterize the participants' majors and science backgrounds. These data were used to generate profiles of the participants.

Context of the Study: The Investigated Courses

The courses chosen for investigation were three out of the four HOS courses offered during Fall term. Students can enroll in the courses for undergraduate or graduate credit. Both undergraduate and graduate students attend the same class meetings and are required to complete the same kind of assignments, such as short quizzes, exams, and/or term papers. Graduate students, however, are required to produce elaborate exams and longer term papers that reflect a more in-depth understanding of the material presented in the courses.

The first course is entitled "Studies in Scientific Controversy" (3 credit hours). This course will be referred to hereafter as the "Controversy" course. The 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" (3 credit hours), 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. This course will be referred to hereafter as the "Survey" course. The third course is entitled "Evolution and Modern Biology" (3 credit hours). This course will be referred to hereafter as the "Evolution" course. The 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 instructor of the fourth HOS course offered during Fall term was newly hired. As such, he was not available on campus when the initial contacts with the HOS faculty were made to seek their approval and make necessary arrangements for the inclusion of their courses in the present investigation. As such, the fourth course was not included in the present investigation. Thus, the above three courses were chosen for investigation on the basis of feasibility and the fact that they exhibited a range of characteristics relevant to the purposes of the present study. The courses had different objectives. Also, by virtue of student enrollment, the courses exhibited different classroom dynamics. The Controversy course was a small size discussion-oriented course. Eighteen students were enrolled in this course (after drop/add and withdrawals). The Survey and Evolution courses were mid-sized (45 students) and large (116 students) courses, respectively. The latter courses were both lecture-oriented. Moreover, the courses were taught by three different HOS faculty and, thus, were likely to reflect a range of historical and teaching approaches.

The science methods/practicum course (Science Methods/Practicum II, 3 credit hours), in which the preservice teachers were enrolled during the time of the study, was the second course in a sequence that started in the Summer term when the student teachers joined the MAT program. The first course in the sequence (Science Methods/Practicum I, 3 credit hours) focused, among other things, on the NOS. Over the course of eight instructional hours, student teachers were explicitly taught several aspects of the NOS using activities and demonstrations. Preservice teachers directly experienced or discussed approximately 15 different NOS activities. Descriptions of these activities can be found elsewhere (Lederman & Abd-El-Khalick, 1998). The specific aspects of the NOS discussed in the course were identical to those emphasized in the present study. These aspects were that scientific knowledge is tentative (subject to change), empirically-based (based on and/or derived from observations of the natural world), subjective (theory-laden), necessarily involves human inference, imagination, and creativity (involves the invention of explanation), and is socially and culturally embedded. Two additional important aspects that were emphasized were the distinction between observations and inferences, and the functions of, and relationships between, scientific theories and laws.

The Science Methods/Practicum II course (referred to hereafter as the "Methods" course) focused on classroom management, instructional planning, traditional and alternative assessment, and models of teaching with particular attention to cooperative learning and grouping, project-based learning, and field trips and informal settings. As a culminating assignment for the course, each student teacher developed an instructional unit complete with a rationale, goals, comprehensive instructional plans, and a variety of resource materials that emphasize the teaching approach in use. The instructional plans included objectives, instructional activities and sequences, and assessment and evaluation instruments.

Procedure

Data collection was continuous and spanned the entire Fall term during which participants were enrolled in the investigated courses. 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 the 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. These profiles included course objectives, instructor priorities, planned assignments, teaching approach with an emphasis on documenting explicit attention given to various aspects of the NOS, and classroom dynamics.

At the beginning of Fall term, all participants in their respective courses received a handout that explained the general intent of the study, the types of data that were going to be collected, and what students were expected to do (Appendix B). Students were informed that they were expected to complete an open-ended questionnaire that asked them about their views of the NOS. This questionnaire was to be completed twice, once at the beginning of the term and once toward the end. Students were also informed that some of them would be randomly chosen and contacted for a follow-up interview. The researcher emphasized that participation in the interview was voluntary. Informed consent was secured by having students who agreed to be interviewed sign a form designed for this purpose (Appendix C).

At the beginning of Fall term, all participants in their respective courses were administered an open-ended questionnaire intended to assess their conceptions of the NOS. During the last week of classes, all participants were administered the questionnaire again. Provisions were made so that students enrolled in more than one of the investigated courses completed the questionnaires only once. Table 2 presents the number and percentage of participants in each course who completed the pre-instruction questionnaire, the post-instruction questionnaire and those who completed both questionnaires. It should be noted that all preservice teachers and practically all participants enrolled in the Survey course (98%) completed both questionnaires. Moreover, the response rates for the Evolution course (82%) and the Controversy course (83%) were relatively high.

Table 2
Response Rates to the NOS Questionnaire

Completed Questionnaires	Survey (N = 45)		Evolution (N = 116)		Controversy (N = 18)		Methods (N = 15)	
	n	P	n	P	n	P	n	P
Pre-instruction	45	100	104	90	18	100	15	100
Post-instruction	44	98	100	86	15	83	15	100
Both	44	98	95	82	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.

Data were available for 11 of the 21 participants in the Evolution course who did not complete both questionnaires. Almost all 11 participants, five male and six female, were seniors (90%). Only one participant (10%) was a junior. The 11 participants' mean and median age was 24 and 23 years respectively. Nine of the participants (82%) majored in the biological sciences, one (9%) in general science, and one (9%) in the agricultural sciences. An examination of the fourth column in Table 7 on page 287 indicates that this profile is not appreciably different in any respect from that for all participants enrolled in the Evolution course.

Data were available for all three participants, two male and one female, in the Controversy course who did not complete both questionnaires. One of the participants (33%) was a junior, one (33%) was a senior and one (33%) was a graduate student. The three participants' mean and median age was 24 and 27 years respectively. One of the participants (33%) majored in the biological sciences, one (33%) in general science, and one (33%) in the history of science. An examination of the fifth column in Table 7 on page 287 indicates that this profile is not appreciably different from that for all participants enrolled in the Controversy course.

Table 3 presents the HOS, philosophy of science, and science backgrounds for participants who did not complete both questionnaires in the Evolution and Controversy courses. An examination of Table 3 indicates that non-respondents' science, and history and philosophy of science backgrounds did not differ from those of all participants in both courses. It follows that in the Evolution and Controversy courses non-respondents did not differ in any systematic manner from respondents to the NOS questionnaires.

Table 3
HOS, Philosophy of Science, and Science Backgrounds for Participants Who Did Not Complete Both NOS Questionnaires

	Evolution				Controversy			
	N = 104		n = 11		N = 18		n = 3	
Courses	M	Mdn	M	Mdn	M	Mdn	M	Mdn
History of science	0.7	0	0.3	0	3.2	0	8	0
Philosophy of science	0.33	0	0.33	0	0.7	0	1	0
Undergraduate science								
Agricultural sciences	1.5	0	5	0	0.6	0	0	0
Biological sciences	37	30.5	43	40	29	19	23	29
Geo/space sciences	4	1.5	2	3	5	0	0	0
Physical sciences	32	30	29	24	18	15	12	16
Total	75	68.5	80	76	53	50	35	50

Note. M = mean number of credits and Mdn = median number of credits.

As noted earlier, the NOS questionnaire was used in conjunction with follow-up semi-structured interviews. The purpose of the interviews was to clarify participants' responses to the NOS questionnaire and generate in-depth profiles of their views. These interviews were conducted with a sample of the participants. A random sample 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. To generate this sample, lists of participants' names were collected from all three HOS courses. The names in each list were assigned sequential numbers. Using a table of random numbers, a random sample of 45% of the participants enrolled in each course was chosen. Participants in this random sample were assigned sequential numbers, and then the sample was split into two sub-samples. The first sub-sample comprised participants with odd numbers and the second sub-sample comprised those with even numbers.

Students chosen for interviewing were initially contacted through electronic mail to elicit their participation. Follow-up contacts were conducted during class meetings in the various courses. Almost all of the contacted participants (96%) agreed to participate and actually showed up for the interviews. Students in the first sub-sample were interviewed within the first two weeks of the term. Students in the second sub-sample were interviewed 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 two weeks of the term.

A total of 78 participants were interviewed. The interviews typically lasted between 30 minutes and one hour. All interviews were audio-taped and transcribed for analysis. Table 4 presents the number and percentage of participants who were interviewed in each course. It should be noted that the total number of interviews, as presented in Table 4 (87 interviews), is larger than the actual number (78 interviews) because nine of the interviewed preservice teachers were enrolled in both the Methods and Evolution courses.

Moreover, at the beginning of the term, the HOS instructors were interviewed about their respective courses. The researcher also sat through the HOS courses. All sessions were audio-tape recorded. The researcher kept field notes of the sessions with a particular emphasis on documenting instances when one or more aspects of the NOS were emphasized in the observed lectures and/or discussions. Classroom segments corresponding to these latter instances were transcribed for analysis.

Table 4
The Number and Percentage of Interviewees in the Investigated Courses

	Survey (N = 45)		Evolution (N = 116)		Controversy (N = 18)		Methods (N = 15)	
Interviews	n	P	n	P	n	P	n	P
Pre-instruction	9	20	23	20	5	28	8	53
Post-instruction	10	22	22	19	5	28	5	33
Total	19	42	45	39	10	56	13	86

Instruments

Two instruments were used in the present study: An open-ended questionnaire and semi-structured interviews.

Assessing Participants' Conceptions of the NOS

An open-ended questionnaire (Appendix D), in conjunction with follow-up interviews, was used to assess participants' conceptions of the NOS. This approach was undertaken with the intent of avoiding the problems inherent in the use of standardized, forced-choice instruments that have been traditionally employed to assess learners' views of the scientific enterprise.

During the past 40 years, more than 20 paper-and-pencil instruments have been developed to assess learners' views of the NOS (Lederman et al., 1998). The TOUS (Cooley & Klopfer, 1961), SPI (Welch & Pella, 1967-68), NOSS (Kimball, 1967-68), and NOST (Billeh & Hasan, 1975) are examples of such instruments. Most of these instruments were standardized and utilized forced-choice items, such as true/false or Likert-type items. Many criticisms have been leveled against the use of such instruments to assess students' conceptions of the NOS.

One major criticism was related to an assumption characteristic of almost all paper-and-pencil instruments. This assumption was that respondents perceive and interpret items on an instrument in a manner similar to that of the instrument developers. Aikenhead, Ryan, and Desautels (1989) noted that standardized instruments that have been used to assess students' views of the NOS were all based on this problematic assumption. They argued that ambiguities result from assuming that students understand a certain statement in the same manner that the researchers or instrument developers would, and agree or disagree to that statement for reasons that coincide with those of the researchers or instrument developers. Such ambiguities, Aikenhead et al. continued, seriously threaten the validity of the instruments in use.

Another major criticism, raised by Lederman et al. (1998), was that the aforementioned instruments usually reflected their developers' views and biases related to the NOS. Being mostly of the forced-choice type, the instruments ended up imposing the researchers'/developers' own views on the respondents. Additionally, responses to instrument items were usually designed with various philosophical stances in mind. As such, irrespective of the choices the respondents made, they often ended up being stamped with labels that indicated that they firmly held coherent, consistent philosophic stances such as inductivist, verificationist, hypothetico-deductivist, etc. (e.g., Dibbs, 1982; Hodson, 1993). Thus, the views that ended up being ascribed to respondents were more an artifact of the instrument in use than a faithful representation of the respondents' conceptions of the NOS.

By contrast, the use of open-ended questions allows respondents to express their own views on issues related to the NOS. This would alleviate concerns related to imposing a particular view of the scientific enterprise on the respondents. Moreover, by asking respondents to elaborate and/or justify their answers, open-ended questions allow the researcher to assess not only respondents' positions on certain issues related to the NOS, but the respondents' reasons for adopting those positions as well.

The usefulness of open-ended questionnaires in generating faithful representations of respondents' views of science is greatly enhanced by the use of follow-up interviews (Lederman, 1992; Lederman & O'Malley, 1990). During these interviews, respondents can clarify and elaborate their responses. Additionally, the researcher can further probe the respondents' lines of reasoning on issues raised in the questionnaire. Thus, ambiguities can be avoided and the likelihood of misinterpreting responses to the open-ended items is greatly reduced. The questionnaire validity is thus ensured (Abd-El-Khalick et al., 1998; Lederman, 1992; Lederman & O'Malley, 1990).

Finally, for the purposes of the present study, the open-ended questionnaires and semi-structured interviews were used to generate descriptive, in-depth profiles of the participants' conceptions of the NOS. No attempt was made to ascribe labels to participants' views, or to commit them to one or another coherent philosophical stance.

The questionnaire.

The questionnaire used in the present study consisted of nine open-ended items. These items aimed to assess respondents' views of the tentative, empirical, creative, and subjective (theory-laden) nature of science; the role of social and cultural contexts in science; observation versus inference; and the functions and relationships of theories and laws (see Appendix D).

An initial set of nine items was adapted from questionnaires used by Lederman and O'Malley (1990) and Abd-El-Khalick et al. (1998) and compiled by the 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 panel had some comments and suggestions for improvement and the nine items were modified accordingly. The questionnaire items as they were used in the present study were:

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?

The questionnaire items asked participants to elaborate/justify their answers and to support them with relevant examples. This elaboration/justification was intended to assess the depth of the participants' understandings of certain aspects of the NOS. Moreover, the extent to which participants were able to provide evidence to support their views was intended to assess the influence of HOS courses on students' abilities to use examples or “stories” from the HOS to articulate and support their views of the scientific enterprise.

The questionnaire used in the present study was writing-intensive. The two planned administrations were thus expected to consume two instructional periods were the questionnaires to be completed in class. Due to time constraints, the participants completed the open-ended questionnaires at home. However, administering the questionnaires outside a controlled environment raised concerns regarding the validity of student responses. To mitigate, though not eliminate, concerns in this regard, participants were assured that there are no “right” or “wrong” answers to the questionnaire items and that the researcher was mainly interested in their viewpoints on some issues related to science. Moreover, these concerns were further ameliorated by the fact that having no “right” or “wrong” answers, responses to the items did not lend themselves to being “looked-up.”

Student semi-structured interviews.

Each administration of the NOS 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. The purpose of the interview was to clarify student responses to the open-ended questionnaire.

During the first interview, participants were provided their pre-instruction open-ended questionnaire. They were asked to read and explain their responses to each item.

The researcher asked the interviewees to elaborate on certain responses. Follow-up and probing questions were used to pursue participants' lines of thought. Initially, these latter questions were not planned. However, following the first few 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 the NOS questionnaire. Alternatively, other questions or sets of questions were *only* asked when interviewees expressed certain ideas regarding the NOS.

Many interviewees noted, often in response to the first item on the NOS questionnaire, that science is characterized by "the" scientific method or other sets of logical and orderly steps. Upon expressing this idea an interviewee was asked, "Do all scientists use a specific method, in terms of a certain stepwise procedure, when they do science? Can you elaborate?" In their response to the second item many interviewees defined scientific experiments very broadly as "procedures" used to answer scientific questions. In the attempt to clarify such responses interviewees were asked, "Are you thinking of an experiment in the sense of manipulating variables or are you thinking of more general procedures? Can you elaborate?"

Also, mostly in response to the first and second items, many interviewees noted that scientific knowledge is "proven" knowledge or that scientific experiments aim to "prove" or "disprove" hypotheses or theories. Interviewees were then asked, "How would you 'prove' a theory or hypothesis?" A typical response was that scientific claims are "proven" by collecting evidence and/or doing experiments. Interviewees were then asked, "How much evidence or how many experiments does it take to 'prove' a scientific claim?" or "How much evidence and/or how many experiments are 'enough' to prove a scientific claim?"

Some interviewees noted, in response to the third item, that developing scientific knowledge necessarily requires *manipulative* experiments. In an attempt to elucidate how this view relates to the case of "observational" sciences, interviewees were then asked a set of questions. The first question was, "Let's consider a science like astronomy (or anatomy). Can we (or do we) do manipulative experiments in astronomy (or anatomy)?" If interviewees answered in the positive they were asked to explicate their answers and provide examples. This served to further probe interviewees' conceptions of scientific experiments. However, if they answered in the negative, the interviewees were then asked, "But we still consider astronomy (or anatomy) a science. What are your ideas about that?"

Other follow-up questions aimed to assess the depth of interviewees' understanding of the theory-laden nature of science and the role that scientific theories and theoretical expectations play in guiding scientific research. Two of these questions followed interviewees' explication of their responses to the second item that focused on scientific experiments. The questions were, "When scientists perform 'manipulative' experiments they hold certain variables constant and vary others. Do scientists usually have an idea about the outcome of their experiments?" If interviewees agreed, they were then asked, "Some claim that such expectations would bias the results of an experiment. What do you think?" The other two questions followed the third item that related to scientific theories. On noting that scientific theories change, interviewees were asked, "The history of science is full with examples of scientific theories that have been discarded or greatly changed. The life spans of scientific theories, if you will, vary greatly, but theories seem to change at one point or another. And there is no reason to believe that the scientific theories we have today will not change in the future. Why do we bother learn about these theories? Why do we invest time and energy to grasp these theories?" The other question was, "Which comes first when scientists conduct scientific investigations theory or observation?"

A question that followed interviewees' discussion of the fifth item was "In terms of status and significance as products of science, would you rank scientific theories and laws? And if you choose to rank them, how would you rank them?" Two other questions followed when interviewees' responses to the sixth item on the structure of the atom were not informative regarding their views of the role of inference and creativity in science. The first question was "Have we ever 'seen' an atom?" If they responded in the negative, interviewees were then asked, "So, where do scientists come up with this elaborate structure of the atom?" Those interviewees who thought that scientists have actually "seen" an atom were asked to elaborate on their answers. Similarly, the seventh item aimed to assess participants' understanding of the role of inference and creativity in science. On noting that scientists were very certain about the notion of species, interviewees were asked, "There are certain species of wolfs and dogs that are known to interbreed and produce fertile offspring. How does this fit into the notion of species, knowing that the aforementioned species are 'different' species and have been given different names?"

To assess whether interviewees thought of creativity and imagination in scientific investigation more as "resourcefulness" and "skillfulness" or as "invention" of explanations, they were asked, "Creativity and imagination also have the connotation of creating something from the mind. Do you think creativity and imagination play a part in science in that sense as well?" Finally, in response to the item related to the dinosaur extinction controversy, many interviewees thought that the controversy was unjustified given that the evidence supports both hypotheses. In that case, the interviewees were asked, "This is very reasonable. I mean, it is very reasonable to say that the data is scarce and that the available evidence supports both hypotheses equally well. However, scientists in the different groups are very adamant about their own position and they publish very pointed papers in this regard. Why is that?" Another question in this regard was "Why would some scientists consider the idea of a meteor falling from the sky to be unacceptable or strange?"

The same procedure was used during the second interview following the second administration of the NOS questionnaire. The interviewees were provided their post-instruction questionnaire and asked to explain and elaborate on their answers. The same set of follow-up questions was used. In addition to clarifying student responses to the questionnaire and probing their answers in depth, the second interview aimed to assess whether participants' views have changed. After explaining their responses to a certain item, interviewees were asked: "Have your views on this issue changed? In what ways have your views changed? Why did your views change?"

During all the interviews, extended wait-time was observed and feedback to the interviewees was restricted to cues that aimed to help them elaborate on a response or clarify a certain point. The interviews lasted between 30 minutes and one hour. All interviews were audio-taped and transcribed for analysis.

Instructor Interviews: Generating In-depth Profiles of the HOS Courses

The HOS course instructors were interviewed to generate in-depth profiles of the 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. The semi-structured interview was guided by the following set of questions:

1. What are the objectives of your course?
2. What historical method(s) or historiographic tradition(s) do you ascribe to or have you used in developing the course? (Internal, external, Marxist, Hermeneutic, social, etc.)
3. What, in your opinion, is the relation between history of science and science? Between history of science and the practice of science?
4. Is there a role for history of science in science teaching? What is your characterization of this role?
5. What, in your opinion, is scientific literacy? Is there a role for history of science in developing scientific literacy? What is your characterization of this role?
6. What understandings about history of science do you want students in your course to attain?

7. What understandings *about* science / the scientific endeavor / the practice of science do you want students in your course to attain?

8. What, in your opinion, is the best way to inform students *about* science? Would you let students draw their own conclusions from the historical exposition? Would you guide students in drawing those conclusions? Would you convey to students certain conclusions about science?

9. Why did you choose these readings for your course? How do these readings contribute to students' achievement of the course objectives?

10. Why did you choose these assignments for your course? How do these assignments contribute to students' achievement of the course objectives?

The interview was audio-taped and transcribed for analysis. Course syllabi (see Appendix E) and classroom observations were also used in generating in-depth profiles for the investigated courses.

Data Analysis

A process of analytic induction (Bogdan & Biklen, 1992) was used to analyze the data generated in the present investigation. Systematic data analysis began after the conclusion of the study. Data analysis comprised four phases.

Phase I: HOS Course Profiles

The instructor interview transcripts, course syllabi, and classroom observations were used to generate a profile for each HOS course. Each profile included descriptions of the course objectives, topic(s) and historical period(s) covered, readings, and assignments. The profile also included the instructor's priorities, and his/her views about the relationship between science, HOS, and science teaching. Classroom dynamics and instructional approach were also described.

Additionally, the field notes generated from classroom observations were used to document explicit attention accorded to the NOS in each course. Instances in which one or more aspects of the NOS were *explicitly* discussed in class were noted and described in the field notes. The corresponding audio-taped portion of the class was transcribed for analysis. This analysis aimed to describe whether, to what extent, and in what ways were aspects of the NOS explicitly discussed in a certain course.

Phase II: Establishing the Validity of the Open-ended Questionnaire in Assessing Participants' Views of the NOS

The aim of this phase of data analysis was to establish the validity of the open-ended questionnaire in assessing respondents' views of the NOS. The questionnaires and interview transcripts of students in the random sub-samples and focus group were used in this phase of the analysis.

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 the NOS.

The above process was repeated with the transcripts of the semi-structured interviews conducted at the beginning of the term with students in the first sub-sample. This process resulted in a separate profile of conceptions of the NOS 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. In case the two generated profiles matched, the next step in data analysis was undertaken. In case some discrepancies appeared between the two profiles, the data were consulted again to determine which profile represented the participants' views more faithfully. Data analysis only proceeded when all discrepancies were satisfactorily resolved.

The above process was repeated with the questionnaires and the corresponding interviews completed at the end of the term by students in the second sub-sample and focus group. This round of analysis served as a further check on the validity of the questionnaire in assessing participants' views of the NOS. Again this validity was established by comparing the profiles generated from the separate analysis of the open-ended questionnaires with those generated from the analysis of the corresponding interviews.

Phase III: Analysis of NOS Questionnaires

During this phase of the analysis the NOS questionnaires of participants' who completed both the pre-instruction and post-instruction questionnaires were analyzed. Two summaries, pre-instruction and post-instruction, were generated for each participant's conceptions of the NOS. Each summary was coded under the various aspects relevant to this study. These aspects included the specific course in which a participant was enrolled; the participant's background, including class-standing, and science, HOS, and philosophy of science background; and whether the participant's views were consistent with recent conceptions of the NOS prior to enrolling in a HOS course.

Whether participants' views of the NOS were consistent with recent conceptions of the scientific endeavor prior to enrolling in a HOS course was determined on the basis of their responses to the pre-instruction questionnaire. For instance, students with elaborate backgrounds in the history and/or philosophy of science, and students in the focus group who received explicit instruction about the NOS in the Science Methods/Practicum I course, were expected to hold some views consistent with recent conceptions of the NOS. However, whether this was the case or not was determined by analyzing their pre-instruction questionnaires. Having a view "consistent" with recent conceptions of the NOS was determined on an aspect-by-aspect basis. That is, students included in this group did not necessarily have comprehensive views of the NOS that were consistent with recent conceptions. Some students only had adequate conceptions of the tentative nature of scientific knowledge, while others had adequate conceptions of several aspects of the NOS.

The elaborate coding of each generated summary was needed to answer the questions that guided this investigation. As explicated below, in order to answer a certain question, individual summaries were used to construct a profile of the views of a certain group of students. These groups included, for example, students in the focus group, students in a particular HOS course, or students with a framework consistent with recent conceptions of the 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.

As noted earlier, in generating a profile for a certain group, the corresponding questionnaire 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 into a representative profile.

Phase IV: Answering the Research Questions

Even though data analysis was kept fairly open and emergent patterns were accorded attention and pursued, the analysis focused on answering the main questions that guided the present investigation.

The influence of HOS courses on students' conceptions of the NOS.

This question was answered for each HOS course individually. The summaries of participants' questionnaires in a certain course were used to generate pre- and post-instruction profiles of their views of the scientific enterprise. The two profiles were compared and contrasted to establish whether, to what extent, and in what ways each course influenced students' conceptions of the NOS.

An additional comparison of interest was conducted between preservice teachers enrolled in a HOS course and those who did not. This was especially relevant given that both groups have had explicit instruction about several aspects of the NOS prior to the beginning of Fall term.

HOS course aspects related to changes in students' conceptions of the NOS.

Once the impact of each HOS course on students' conceptions of the NOS 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 the inferences generated from this analysis were dependent on whether, first, student views have been 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 the NOS).

The influence of having an adequate conceptual framework of the NOS prior to enrollment in HOS courses.

Assessing the impact of entering a HOS course with a framework of the NOS consistent with recent views of the scientific enterprise was done for each individual course. To answer this question, pre- and post-instruction profiles were generated for two groups within each course. The first group was one judged to have, upon enrolling in the investigated course, more recent conceptions of one or more aspects of the NOS. The second was a group judged to have less adequate views of the NOS. The change, if any, between the pre- and post-instruction profile were described for each group. 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 the NOS, a positive influence of that course was assessed in terms of the extent to which these initial understandings have been enriched. This enriched understanding was assessed by the participants' abilities to, upon completing the investigated course, articulate their views more clearly and use the historical material covered in the course to provide relevant examples to support or elaborate on their views.

About the Researcher

At the time of the study the researcher was a doctoral candidate in Science Education at the university where the investigation was conducted. He has earned a B.S., a secondary science-teaching diploma, and a M.A. in Science Education from another institution. He has taught high school physical science. The researcher's interest in, and systematic study of the NOS began about four years ago. As a doctoral student, the researcher chose to minor in the history and philosophy of science for the purpose of enriching his understandings of the NOS. During the past four years he was involved in five research projects related to the NOS both in high school and teacher education settings. The researcher has had experience in conducting both qualitative and quantitative studies.

The researcher sat through two of the HOS courses investigated in the present study and was enrolled in two courses with the instructor teaching the third investigated course. It was from his experiences within these courses and his interest in the NOS that the present project was initiated.

The researcher, drawing partly on his personal experience with HOS courses and partly on theoretical arguments, believed that approaching HOS with a conceptual framework consistent with current views of the NOS was likely to help students develop more elaborate understandings of the scientific enterprise. Learners draw upon their previous knowledge and conceptions in their attempts to make sense of new experiences. Their prior conceptions determine, to a large extent, the meanings they derive from readings and instruction about any topic, including HOS. A conceptual framework consistent with current views would direct students to examine the historical narrative from *that* perspective. As was the case with the researcher, his experience with HOS has reinforced (and in some instances changed) his conceptions of the NOS and enriched his understandings with examples and relevant historical episodes. It remains for this investigation to shed some light on whether, and to what extent, this personal experience was a reflection of a more generalized pattern.

The Researcher's Views of the NOS

The NOS typically refers to the epistemology of science or the values and beliefs inherent to the development of scientific knowledge. However, no consensus presently exists among philosophers of science, historians of science, scientists, and science educators on a specific definition for the NOS. This lack of consensus, however, should neither be disconcerting nor surprising given the multifaceted nature and complexity of the scientific endeavor. Moreover, the researcher believes that many of the disagreements about the definition or meaning of the NOS that continue to exist among philosophers, historians, and science educators are irrelevant to K-12 instruction. The researcher believes that there is an acceptable level of generality regarding the NOS that is accessible to K-12 students and relevant to their daily lives. Moreover, in the researcher's view, at this level, little disagreement exists among philosophers, historians, and science educators.

Among the aspects of the NOS that the researcher believes correspond to this level of generality are that scientific knowledge is tentative (subject to change), empirically-based (based on and/or derived from observations of the natural world), subjective (theory-laden), partly the product of human inference, imagination, and creativity (involves the invention of explanation), and socially and culturally embedded. Two additional important aspects are the distinction between observations and inferences, and the functions of, and relationships between scientific theories and laws. A brief discussion of the aforementioned aspects of the scientific enterprise follows.

The first aspect is the crucial distinction between observation and inference. Observations are descriptive statements about natural phenomena that are "directly" accessible to the senses (or extensions of the senses) and about which several observers can reach consensus with relative ease. For example, objects released above ground level tend to fall and hit the ground. By contrast, inferences are statements about phenomena that are not "directly" accessible to the senses. For example, objects tend to fall to the ground because of "gravity." The notion of gravity is inferential in the sense that it can *only* be accessed and/or measured through its manifestations or effects. Examples of such effects include the perturbations in predicted planetary orbits due to inter-planetary "attractions," and the bending of light coming from the stars as its rays pass through the sun's "gravitational" field.

Second, closely related to the distinction between observations and inferences is the distinction between scientific laws and theories. Individuals often hold a simplistic, hierarchical view of the relationship between theories and laws whereby theories become laws depending on the availability of supporting evidence. It follows from this notion that scientific laws have a higher status than scientific theories. Both notions, however, are inappropriate because, among other things, theories and laws are different kinds of knowledge and one can not become the other. Laws are *statements or descriptions of the relationships* among observable phenomena. Boyle's law, which relates the pressure of a gas to its volume at a constant temperature, is a case in point. Theories, by contrast, *are inferred explanations* for observable phenomena. The kinetic molecular theory, which explains Boyle's law, is one example. Moreover, theories are as legitimate a product of science as laws. Scientists do not usually formulate theories in the hope that one day they would acquire the status of "law." Scientific theories, in their own right, serve important roles, such as guiding investigations and generating new research problems in addition to explaining relatively huge sets of seemingly unrelated observations in more than one field of investigation. For example, the kinetic molecular theory serves to explain phenomena that relate to changes in the physical states of matter, others that relate to the rates of chemical reactions, and still other phenomena that relate to heat and its transfer, to mention just a few.

Third, even though scientific knowledge is, at least partially, based on and/or derived from observations of the natural world (i.e., empirical), it nevertheless involves human imagination and creativity. Science, contrary to common belief, is not a lifeless, rational, and orderly activity. Science involves the *invention* of explanations and this requires a great deal of creativity by scientists. The "leap" from atomic spectral lines to Bohr's model of the atom with its elaborate orbits and energy levels is a case in point. This aspect of science, coupled with its inferential nature, entails that scientific concepts, such as atoms, black holes, and species, are functional theoretical models rather than faithful copies of reality.

Fourth, scientific knowledge is subjective or theory-laden. Scientists' theoretical commitments, beliefs, previous knowledge, training, experiences, and expectations actually influence their work. All these background factors form *a mind-set* that *affects* the problems scientists investigate and how they conduct their investigations, what they observe (and do not observe), and how they make sense of, or interpret their observations. It is this (sometimes collective) individuality or mind-set that accounts for the role of subjectivity in the production of scientific knowledge. It is noteworthy that, contrary to common belief, science never starts with neutral observations. Observations (and investigations) are always motivated and guided by, and acquire meaning in reference to questions or problems. These questions or problems, in turn, are derived from within certain theoretical perspectives.

Fifth, science as a human enterprise is practiced in the context of a larger culture and its practitioners (scientists) are the products of that culture. Science, it follows, affects and is affected by the various elements and intellectual spheres of the culture in which it is embedded. These elements include, but are not limited to, social fabric, power structures, politics, socioeconomic factors, philosophy, and religion. An example may help to illustrate how social and cultural factors impact scientific knowledge. Telling the story of the evolution of humans (*Homo sapiens*) over the course of the past 7 million years is central to the biosocial sciences. Scientists have formulated several elaborate and differing story lines about this evolution. Until recently, the dominant story was centered about "the man-hunter" and *his* crucial role in the evolution of humans to the form we now know (Lovejoy, 1981). This scenario was consistent with the white-male culture that dominated scientific circles up to the 1960s and early 70s. As the feminist movement grew stronger and women were able to claim recognition in the various scientific disciplines, the story about hominid evolution started to change. One story that is more consistent with a feminist approach is centered about "the female-gatherer" and *her* central role in the evolution of humans (Hrdy, 1986). It is noteworthy that both story lines are consistent with the available evidence.

Sixth, it follows from the previous discussions that scientific knowledge, though reliable, is at best tentative and *never* absolute or certain. This knowledge, including "facts," theories, and laws, is tentative and subject to change. Scientific claims change as new evidence, made possible through advances in *theory* and technology, is brought to bear on existing theories or laws, or as old evidence is reinterpreted in the light of new theoretical advances or shifts in the directions of established research programs. It should be emphasized that tentativeness in science does not only arise from the fact that scientific knowledge is inferential, creative, and socially and culturally embedded. There are also compelling logical arguments that lend credence to the notion of tentativeness in science. Indeed, contrary to common belief, scientific hypotheses, theories, and laws can *never* be absolutely "proven." This holds irrespective of the amount of empirical evidence gathered in the support of one of these ideas or the other (Popper, 1963, 1988). For example, to be "proven," a certain scientific law should account for *every single instance* of the phenomenon it purports to describe *at all times*. It can logically be argued that one such future instance, of which we have no knowledge whatsoever, may behave in a manner contrary to what the law states. As such, the law can never acquire an absolutely "proven" status. This equally holds in the case of hypotheses and theories. Finally, the researcher believes that there is no one method (in the sense of a recipe that anyone with the right mental and physical tools can master) or a set of methods that scientists follow in their work.

Chapter IV

Results

Introduction

The purpose of the present study was to assess the influence of history of science (HOS) courses on college students' conceptions of the nature of science (NOS). The study also aimed to examine whether students, including preservice secondary science teachers, who entered HOS courses with a conceptual framework consistent with current conceptions of the scientific enterprise were more likely to achieve more elaborate and enriched understandings of the NOS. Additionally, the study aimed to assess what aspects, if any, of the investigated courses tended to render the courses more effective in influencing students' conceptions.

The present chapter is divided into five sections. The first section presents a profile of all participants as well as profiles for participants enrolled in each of the investigated courses. The profiles delineate the participants' gender, age, and education with a special focus on their HOS, philosophy of science, and science backgrounds, and other relevant experiences in science. The second section presents overviews of the HOS courses. Each overview includes a description of the course objectives, instructor priorities, teaching approach, assignments and assessment strategies, and classroom dynamics. Additionally, each overview presents a summary of the topics covered in the course and documents, if any, explicit attention accorded to the NOS.

The third section elucidates participants' pre-instruction views of the NOS. Changes in participants' views are explicated in the fourth section. Finally, the fifth section elucidates the relationship, if any, between changes in participants' views of the NOS and their pre-instruction views. The fifth section also relates the observed changes in participants' views of the scientific endeavor to specific aspects of the investigated HOS courses.

Participants

One hundred eighty four college students were invited to participate in the present study. Students comprised two groups. The first included all 169 undergraduate and graduate students enrolled in three HOS courses offered during Fall term in a mid-sized state university on the West Coast. The second group consisted of all 15 preservice secondary science teachers enrolled in a fifth-year Master of Arts in Teaching (MAT) preparation 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 of special interest for the purposes of the present study consisted of the 10 preservice MAT students enrolled in one of the HOS courses chosen for investigation.

One hundred eighty one students completed the courses. Three students withdrew from two of the HOS courses and were thus excluded from the study. One hundred sixty eight students (93%) completed the biographical and background data questionnaire. Data were not available for 13 of the 181 participants. Student responses were used to generate a profile of all participants. Participants, 89 male (53%) and 79 female (47%), were mostly seniors and in their 20s. Their ages ranged from 19 to 45 years with a median of 23 years and an average of 24.5 years with a standard deviation (*SD*) of 5.0 years. Of the participants, 2 (1%) were sophomores, 22 (13%) were juniors, 114 (67%) were seniors, and 30 (19%) were graduate students. Most of the participants (72%) majored in one of the biological sciences (93 students, 55%) or general science (28 students, 17%). Fifteen (9%) were preservice secondary science teachers. Three students (2%) majored in the geological sciences and two (1%) in the agricultural sciences. An additional 27 students (16%) had other majors including anthropology, art, business administration, electrical and computer engineering, economics, education, history, history of science, human development and family studies, language, international studies, philosophy, political science, and psychology.

Data on the participants' HOS, philosophy of science, and science backgrounds, and other relevant experiences in science were also collected. Table 5 presents a summary of these data for all participants. An examination of Table 5 shows that only 25 students (15%) took HOS courses prior to the present study. Of those, 17 students indicated that they completed a single course (3 credits) in the HOS. On a similar note, only 17 students (10%) indicated that they had completed coursework in the philosophy of science. Of those, 13 took one such course (a 3 or 4 credit course). Only seven participants (4%) completed coursework in both history and philosophy of science. As such, it can be seen that an overwhelming majority of participants (85%) had no prior instruction in the history and philosophy of science. Moreover, of those who did, only a few (7 students) took more than one course in the history and/or philosophy of science.

Table 5

Participants' HOS, Philosophy of Science, and Science Backgrounds

Courses	n	M (SD)	Mdn	Range
History of science	25[a]	5.2 (5.2)	3	1-24
Undergraduates	13	3.3 (1.4)	3	3-9
Graduates	12	8.3 (3.3)	6	3-24
Philosophy of science	17[a]	4.0 (1.4)	3	3-7
Undergraduates	9	3.0 (0.8)	3	3-4
Graduates	8	3.0 (2.1)	5	3-7
Undergraduate science	168			
Agricultural sciences		1.3 (3.8)	0	0-65
Biological sciences		33.0 (24.4)	26	0-100
Geo/space sciences		5.4 (11.6)	3	0-100
Physical sciences		27.2 (16.4)	28	0-75
Total		66.9 (36.5)	67	0-169
Graduate science	30			
Agricultural sciences		0.2 (0.8)	0	0-3
Biological sciences		7.7 (11.3)	0	0-35
Geo/space sciences		2.0 (4.8)	0	0-20
Physical sciences		0.3 (1.9)	0	0-10
Total		1.8 (6.9)	0	0-44

Note. Values enclosed in parentheses represent standard deviations. n = number of students, M = mean number of credits, and Mdn = median number of credits.

[a] Number of participants who took history or philosophy of science courses.

It is noteworthy that a larger percentage of graduate students completed coursework in the history and/or philosophy of science. Compared to 9% (13 students) and 7% (9 students) of undergraduate participants, 40% (13 students) and 27% (8 students) of graduate participants took courses in the history and philosophy of science respectively.

However, graduate students did not seem to have taken more courses in these disciplines. With the exception of two graduate students majoring in the history of science, most graduates indicated that they had completed one course in the HOS. Similarly, most of the graduate participants who took philosophy of science courses noted that they completed one course in the 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 (33 credit hours, *SD* = 24.4) and physical (27.2 credit hours, *SD* = 16.4) sciences. It is noteworthy that graduate participants did not differ much in their science background from the undergraduates. An examination of Table 5 shows that graduate participants hardly completed any graduate coursework in the agricultural, geological, and physical sciences. The relatively larger number of graduate credit hours completed in the biological sciences (7.7 credit hours, *SD* = 11.3) could be attributed to eight of the graduate students (27%) who completed between 15 and 35 credit hours in the various biological fields. However, as indicated by the relatively large standard deviation (*SD* = 11.3) and the zero value for the median, most of the graduates did not complete any appreciable coursework in the biological sciences. In general, it seems that most of the graduate participants in the present study (about 73%) had just begun their graduate studies. At the time of the study most of them had yet to complete their first graduate level science course.

Fifty-one participants (30% of all participants) indicated that they had other relevant experiences in science. Of those, 26 students (15%) indicated that they had some research experiences. Some worked as research assistants in their respective science departments or had internships at other campus or off-campus facilities (e.g., the University's marine research center). Others noted that they had assisted graduate students in their research or had field experiences working, mostly, for the State Department of Fisheries and Wildlife. Most of these experiences, however, were relatively short-lived (summer jobs or one-term internships) and mainly involved data collection. Nine students (5%) indicated that they had some experience in science teaching. Of those, seven worked as undergraduate or graduate teaching assistants in introductory level science courses. The remaining two indicated that they taught science courses in a nearby community college. Additionally, seven students (4%) indicated they had worked as lab technicians. Seven other students (4%) indicated that they had done some independent scientific research. Two of them were working on their Masters' theses. Only two participants had extensive fieldwork and research experience (more than 10 years) working for the State Department of Fisheries and Wildlife. It is noteworthy that almost all of the aforementioned experiences were in the biological sciences including botany, zoology, genetics, cellular biology, ecology, marine biology, forestry, and fisheries and wildlife. The only exceptions were two students who had some experience in geological fieldwork and teaching geology in an introductory level course.

Participants' Profiles for the Investigated Courses

Table 7 presents participants' profiles for each of the HOS courses. The participants' science, and history and philosophy of science backgrounds for these courses are presented in Table 8. The corresponding descriptions for participant preservice teachers, enrolled in the Methods course, are presented in Table 9 and Table 10. These profiles were based on data obtained from participants who completed the biographical and background questionnaire. The number and percentage of those participants appear in Table 6.

Table 6
Number and Percentage of Completed Biographical and Background Questionnaires

Course	N	N	P
Survey	45	45	100
Evolution	116	104	94
Controversy	18	17	100
Methods	15	15	100
All courses	194[a]	181[a]	93

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 biographical and background questionnaire. P = percentage.

[a] These totals are larger than the actual numbers of participants (181) and completed questionnaire (168) because 13 participants were simultaneously enrolled in two of the investigated courses.

An examination of Table 6 indicates that biographical and background data were obtained from *all* students enrolled in the Survey, Controversy, and Methods courses, and from 94% of the students enrolled in the Evolution course. It should be noted that the total number of participants (194) and completed questionnaires (181) that appear in Table 6 are larger than the actual numbers (181 and 168 respectively). This apparent incongruency is due to the fact that 10 of the preservice science teachers were also enrolled in the Evolution course. Additionally, three other participants were enrolled in two HOS courses. Of those, two participants were enrolled in both the Survey and Controversy courses, and one participant was enrolled in both the Survey and Evolution courses.

The number of participants enrolled in the Survey, Evolution, and Controversy courses was 45, 116 and 18 respectively. Table 7 indicates that participants in the three courses were almost evenly split by gender. Participants' mean age (and standard deviation) for the Survey, Evolution, and Controversy courses was 25 (SD = 5.0), 24 (SD = 4.0) and 27 years (SD = 7.9) respectively.

An examination of Table 7 indicates that participants' profiles in the HOS courses were similar. Only two appreciable differences can be discerned. First, the percentage of senior students in the Controversy course (39%) was lower than the corresponding percentages for the Survey and Evolution courses (71% and 73% respectively). Correspondingly, the percentages of juniors and graduates in the Controversy course were higher than those percentages in the other two HOS courses. Second, the percentage of students majoring in the biological sciences in the Evolution course (76%) was higher than the percentages in the Survey (24%) and Controversy (28%) courses. These two

Table 7
Participants' Profiles for the HOS Courses

	All courses		Survey		Evolution		Controversy	
Variable	n[a]	P	n[a]	P	n[a]	P	n[a]	P
Gender	168	100	45	100	104	100	18	100
Male	89	53	25	55	53	51	10	55
Female	79	47	20	45	51	49	8	45
Class								
Sophomore	2	1	1	2	0	0	1	6
Junior	22	13	6	13.5	11	11	5	27.5
Senior	114	67	32	71	76	73	7	39
Graduate	30	19	6	13.5	17	16	5	27.5
Major								
Agricultural sciences	2	1	1	2	1	1	0	0
Biological sciences	93	55	11	24	79	76	5	28
General science	28	17	12	27	11	10	6	33
Geo/space sciences	3	2	3	7	0	0	0	0
Science teaching	15	9	0	0	10	10	0	0
Other	27	16	18	40	3	3	7	39

Note. The figures reported in the "all courses" column represent data complied from the HOS courses and the Methods course.

[a] The number of students in each course who completed the biographical and background data questionnaire (see Table 6).

differences were due to the fact that the Evolution course is required of seniors majoring in biology. Indeed, most of the participants enrolled in the Evolution course (73%) were seniors majoring in one of the biological sciences.

Similarly, the participants' HOS, philosophy of science, and science backgrounds for the HOS courses were comparable. An examination of Table 8 indicates only two discernable differences. One is the relatively larger mean and median number of HOS credits for graduate students enrolled in the Controversy course. This difference was due to the fact that two of the six graduate participants enrolled in that course were graduate students in the HOS and had completed an appreciable number of credit hours in the discipline (18 and 24 credits). The other discernable difference was the relatively larger mean and median number of credits (37 and 30.5 credit hours respectively) completed in the biological sciences for students enrolled in the Evolution course. This difference is comprehensible given that, as noted earlier, most of the students enrolled in the Evolution course (73%) were seniors majoring in biology.

Fifteen preservice secondary science teachers, eight male and seven female, were enrolled in the Methods course. Their ages ranged from 22 to 38 years with a median of 23 years and an average of 23.8 years with a standard deviation of 1.3 years. All preservice teachers had earned Bachelor of Science (BS) degrees prior to joining the MAT program (seven in biology, two in environmental science, two in general science, one in fisheries and wildlife, one in chemistry, one in chemical engineering, and one in mechanical engineering). Two of the female student teachers were undergraduate biology teaching assistants and a third taught science in a community college. Two others, a male and a female, worked as research assistants during their undergraduate studies. Another

Table 8
Participants' HOS, Philosophy of Science, and Science Backgrounds for the HOS Courses

Courses	Survey			Evolution			Controversy		
	n (P)	M	Mdn	n (P)	M	Mdn	n (P)	M	Mdn
History of science									
Undergraduates	8 (20)	3.8	3	3 (4)	2.3	3	2 (17)	3	3
Graduates	2 (33)	3	3	4 (23)	6	6	3 (60)	15	18
Total	10 (22)	3.6	3	7 (7)	4.4	3	8 (47)	7.5	3
Philosophy of science									
Undergraduates	2 (5)	3	3	6 (7)	2.8	3.5	1 (8)	4	4
Graduates	2 (33)	3	3	3 (18)	5	5	1 (20)	6	6
Total	4 (9)	3	3	9 (9)	3.5	3.5	2 (12)	5	5
Undergraduate science									
Agricultural sciences	45	0.9	0	104	1.5	0	18	0.6	0
Biological sciences	45	21	12	104	37	30.5	18	29	19
Geo/space sciences	45	8.5	3	104	4	1.5	18	5	0
Physical sciences	45	20	16	104	32	30	18	18	15
Total	45	50	39	104	75	68.5	18	53	50
Graduate science									
Agricultural sciences	6	0	0	16	0.2	0	6	0.6	0
Biological sciences	6	15	12	16	8	0	6	1.4	0
Geo/space sciences	6	4.8	4.5	16	1.7	0	6	0	0

Table 8. (continued)

Courses	Survey			Evolution			Controversy		
	n (P)	M	Mdn	n (P)	M	Mdn	n (P)	M	Mdn
Physical sciences	6	1.6	0	16	0	0	6	0	0
Total	6	21	27	6	10	0	6	2	0

Note. For the history and philosophy of science courses n represents the number of participants in the specified course who took courses in these disciplines. M = mean number of credits, and Mdn = median number of credits.

male had 15 years of field and research experience working for the State Department of Fisheries and Wildlife.

An examination of the first column in Table 9 and Table 10 indicates that participant preservice teachers' profile, and history and philosophy of science backgrounds were similar to the profiles and backgrounds of students enrolled in the investigated HOS courses. The only appreciable difference was the relatively larger number of undergraduate science credits completed by the preservice teachers. This difference is expected given that all participant preservice teachers had already earned BS degrees. In addition, preservice science 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 only difference was that almost all student teachers enrolled only in the Methods course had already taken one course in the HOS while their counterparts enrolled for the Evolution course had not.

Table 9
Participant Preservice Teachers' Profile (Methods Course)

	Methods		Methods and Evolution		Methods only	
Variable	n	P	n	P	n	P
Gender	15	100	10	100	5	100
Male	8	53	5	50	3	60
Female	7	47	5	50	2	40
Undergraduate Major						
Biological sciences	10	67	5	50	5	100
General science	2	13	2	20	0	0
Physical sciences	2	13	2	20	0	0
Other	1	7	1	10	0	0

Note. n = number of students, P = percentage.

The HOS Courses

This section presents overviews of the participant HOS courses. Several data sources were used to generate these overviews. These sources included course syllabi, instructor interview transcripts, field notes, lecture audio-tapes, and selective lecture transcripts. Each overview includes a description of the course objectives, instructor priorities, teaching approach, classroom dynamics, and assignments and assessment strategies. Additionally, each overview presents a summary of the topics covered in the course and documents any explicit attention accorded to various aspects of the NOS.

Table 10

Participant Preservice Teachers' HOS, Philosophy of Science, and Science Backgrounds

Courses	Methods			Methods and			Methods only		
	(n = 15)			Evolution (n = 10)			(n = 5)		
	n (P)	M	Mdn	n (P)	M	Mdn	n (P)	M	Mdn
History of science	7 (47)	3	3	4	2.4	0	4 (80)	3	3
Philosophy of science	3 (20)	2.5	1.5	1 (10)	0.5	0	2 (40)	2	0
Undergraduate science									
Agricultural sciences	15	2	1.5	10	0.8	0	5	1.6	0
Biological sciences	15	70	72	10	49	50	5	73	85
Geo/space sciences	15	8.3	9	10	9	6	5	8.6	9
Physical sciences	15	40	38	10	31	30	5	41	45
Total	15	96	96	10	89	97	5	124	138
Graduate science									
Agricultural sciences	15	0	0	10	0	0	5	0	0
Biological sciences	15	3.3	3	10	0	0	5	2.6	3
Geo/space sciences	15	0	0	10	0	0	5	0	0
Physical sciences	15	0	0	10	0	0	5	0	0
Total	15	2.6	3	10	0	0	5	2.6	3

Note. For the history and philosophy of science courses n represents the number of participants in the specified course who took courses in these disciplines. M = mean number of credits, and Mdn = median number of credits.

During the interviews, all three HOS course professors indicated that they were trained in a fairly traditional internalist approach to the HOS. However, all three noted that they are eclectic in their own teaching and/or research and incorporate both internal and external elements in their courses. All three professors have come to place more emphasis on the social and cultural contexts of scientific disciplines in developing their course materials.

It should be noted that the HOS 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. Participants were enrolled in the courses for undergraduate or graduate credit. Both undergraduate and graduate students attended the same class meetings and were required to complete the same kind of assignments, such as short quizzes, exams, and/or term papers. Graduate students, however, were required to produce elaborate exams and longer term papers that reflected a more in-depth understanding of the material presented in the courses.

The Survey Course

The Survey course, entitled "History of Science" (3 credit hours), 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.

Course objectives and instructor priorities.

The Survey course is mainly concerned with the social and cultural embeddedness of scientific knowledge and practice. During the interview, the Survey course professor noted that the course aimed to teach students about "how science reflects contemporary culture and values, and the biases—both cultural and personal, of those who practice it" (Survey course professor, interview). Moreover, the course aimed to convey to students the notion that developments in scientific knowledge do not occur in leaps and bounds. But that such developments are more incremental. To achieve this latter aim the course focused on the contextual nature of scientific practices and the fact that "scientists do not work in a vacuum . . . but rather present an increment, a new twist, an interesting approach on the major ideas that are available to them in their culture" (Survey course professor, interview).

The Survey course professor indicated that HOS courses could play a role in developing students' scientific literacy. Under scientific literacy, he included "an understanding of the major current theories in science: evolution, the big bang theory, the structure of the universe, and how we think this whole thing is put together" (Survey course professor, interview). The professor did not explicitly include possessing adequate views of the NOS as a component of scientific literacy.

Teaching approach and classroom dynamics.

The Survey course was a mid-sized (46 students), lecture course. Slide-shows were frequently used to illustrate certain aspects of the target cultures or to reinforce certain concepts discussed in the course. Students occasionally asked clarification questions but extended discussions were rare. The Survey course professor indicated his preference for a "guided discovery" approach to help students achieve the desired understandings *about* science.

In his introduction to the course, the professor emphasized that "lessons" about science could be learned by examining its history in antiquity. Nonetheless, he indicated that such "lessons" are not obvious because awareness of current scientific knowledge and practice greatly prejudices the way the "past" is viewed and interpreted. The professor indicated that students would find some of the questions asked in antiquity to be "strange," the methods used by early "scientists" to try to answer them to be "uncommon," and the explanations they arrived at to be "non-scientific." The course, he continued, would attempt to help students appreciate the legitimacy of these questions, methods, and explanations by linking what people did "back then" to contemporary ideas, values, society, and culture. As such, the Survey course professor was aware of the difficulty inherent in "looking back" at "scientific" knowledge and practices in antiquity and deriving generalizations about current scientific practice and knowledge. He noted that students often fail to judge "science" in antiquity from within the worldviews of early cultures. However, the Survey course professor seemed to believe that such judgement could be done. In the context of discussing the "sciences" of early Egypt and Mesopotamia he noted that:

> These kinds of scientific activities and their relation to the social and cultural context in which they were done is a wonderful illustration of how the culture influences this kind of activity. This we can appreciate because we don't have any commitments . . . we are not committed to one side or the other. We are not committed to the science, or whatever it is, because we've

> changed it all, a lot of it. And we are certainly not committed to the religious faith . . . So, we can stand back and analyze it and notice what the connections are, the relationships . . . This is the reason why history is so useful. It allows you to do this kind of thing, to stand back and look at these kinds of relationships. (Survey course, lecture transcripts, 10/14/1997)

Topics covered and NOS aspects explicitly addressed.

The Survey course followed the historical development of major "scientific" ideas and practices from ancient Egyptian and Mesopotamian cultures to the post Roman culture. The course materials were intended to convey to students a sense of the increasing complexity of the questions asked, the inquiry methods used, and the ideas generated in those cultures to account for humans' experiences with the natural world. The ways in which such complexities were related to changes in contemporary society and culture were explored. Indeed, the social and cultural embeddedness of science was the one aspect of the NOS *explicitly* addressed in the Survey course. Throughout the course, the professor explicated the relationships between the "scientific" *claims* and *practices* explored and specific attributes of the social, political, and religious spheres of the contemporary culture.

The first part of the Survey course explored the ancient cultures of Mesopotamia and Egypt. Major historical resources that shed light on these cultures were explored. The successive Mesopotamian city-states and Egyptian dynasties were briefly described. The Survey course professor then discussed at some length Mesopotamian and Egyptian mathematics including number systems, astronomy and calendars, and medicine including both “scared” and more secular practices. The “sciences” of the two cultures were compared and contrasted.

The “practical” aims of these early intellectual endeavors, the rank and status of their practitioners, and the contexts within which they were practiced were explicitly linked to the larger cultural concerns, social structures, and religious beliefs of the Egyptian and Mesopotamian cultures. The professor emphasized that these early intellectual activities were undertaken more with the aim of “coping” with natural phenomena and less with the aim of “explaining” them. Additionally, the professor highlighted the “Mythopoeic” nature of thinking in the two cultures. This thinking was typified by a lack of distinction between the inquiring human subject and the investigated natural object.

Next, the Survey course explored the early Greek culture of Ionia and the rise of Miletus and other Greek city-states as major trade and cultural centers in the Mediterranean region and some parts of Asia Minor. The ideas and contributions of influential Ionian and Minoan philosophers including Thales, Anaximander, Anaximenes, Heraclitus, Pythagoras and the Pythagoreans, Parmenides, Zeno, Anaxagoras, Empedocles, Democritus, and Leucippus were discussed. In these discussions, the Survey course professor emphasized the ways in which these different Greek writers considered, criticized, and added on small increments to each other’s ideas.

As noted earlier, the Survey course professor often linked the explored “scientific” ideas to contemporary society and culture. For example, in his discussion of early Greek philosophers, the Survey course professor noted that in comparison to Egyptian and Mesopotamian records, the Greek philosophers avoided the supernatural or divine in their *explanations* of the natural world. He noted that the religious and political spheres of the Greek city-states had a major influence on the Greek philosophers' search for coherent *naturalistic* explanations for the origin of the universe. For instance, unlike the Egyptian and Mesopotamian, the Greek perceived their Gods to be part of the universe and not its creators. The Greek Gods, as depicted in Homer's writings, were human-like, deceptive, and indulged in petty affairs. These Gods, as such, did not qualify as originators of the cosmos. This attitude toward divinity made the search for natural explanations of "origins" more plausible and desirable.

Moreover, debate and logical argument was central to the political system of Greek city-states. Unlike Egypt or Mesopotamia, a God-king did not rule the Greek city-states. Rather, groups of "men" often with conflicting ideas and interests led the state. Logical, well-articulated arguments between these groups were central to the decisions taken and the choices made regarding the affairs of the state. This aspect of political discourse soon became part of everyday Greek discourse including that between philosophers. In this context, the professor presented the Sophists and highlighted their role in promoting logical discourse through an educational agenda that emphasized rhetoric, grammar, and logic.

Next, the war between the Persians and the Greek, the demise of Miletus and other Ionian city-states, the subsequent victory of the Greek led by Athens, and the rise of Hellenistic culture that was centered about Athens were briefly explored. Then the ideas and contributions of the three major Greek philosophers, Socrates, Plato and Aristotle were discussed at some length. In particular, Plato's views of reality, the world of eternal forms, and the primacy of reasoning and deductive logic in generating knowledge were highlighted. These ideas were compared with Aristotle's views of the primacy of observations of the natural world and the interplay between inductive and deductive approaches in generating valid knowledge. In addition the course presented overviews of Aristotle's cosmology, physics, including his formulation of the four elements and four causes, and works in biology and the classification of animals. Finally, Plato's Academy and Aristotle's Lyceum, their significance in institutionalizing education, and the relationships between the "curricula" at these institutions and the agendas of current liberal education were discussed.

Discussions of other Greek scientific ideas and practices followed. These discussions were made in the context of both Hellenic culture—Greek culture in Greece and mainly Athens, and Hellenistic culture—Greek culture that spread about the Mediterranean as a result of Alexander's campaigns especially in Alexandria under the Ptolemaic rulers. In his discussion of Greek medicine, the Survey course professor explored both sacred and secular practices. He noted that secular medical practices made no reference to divine powers and sought to identify the causes of illness. These attributes of secular medical practices, he continued, were related to the larger, more pervasive philosophical transformation in Greek culture in which philosophers sought natural causes and explanations.

The professor emphasized the role of economic incentives in the rationalization of secular medical practices. The practitioners of secular medicine were considered craftspersons and had low social and economic status. Their practices nonetheless attracted patients, especially rich aristocrats who were mostly educated in the new philosophical rational approach to explaining natural phenomena. To improve their economic status and guarantee an aristocratic clientele, medical practitioners sought an education in the language of philosophy. Thus, the "philosopher physicians" now appealed to a rational empirical approach to investigate the causes of illnesses and treatments. In this context, Hippocrates, the Hippocratic corpus, and the Hippocratic humorial theory were discussed in some detail. Also, the performance of human dissections by Herophilus and Erasistratus in Alexandria and their impact on anatomy were explored.

Next, the Survey course professor presented a lengthy discussion of the background, education, and medical works of Galen. Galen's elaborate theories of the four humors and the physiological functioning of the body and its various organs were discussed. Additionally, Greek mathematics and astronomy were discussed. The mathematical works of Eudoxus, Euclid, Archimedes, Appolonius, Aristarchus, and the Pythagoreans were explored. Finally, the work of Claudius Ptolemy and the Ptolemaic astronomical system was presented.

In the last part of the Survey course, the professor discussed the rise and decline of the Roman Empire, post-Roman European culture, and the decline of the scientific legacy initiated by the Greek. The Professor noted that unlike the Greek, the Romans were practical in orientation. They cared less for philosophy, epistemology, and the theoretical and more for the applied and practical. Consequently, the Romans did not support "science" or institutionalize its activities. Roman writers were primarily concerned with producing encyclopedic works that emphasized facts and undermined theory. With time, almost all of the Greek theoretical and philosophical innovations were left out from the major Roman writings.

This trend continued and became more pronounced after the collapse of the Roman Empire. The Survey course professor noted that the Christian church survived the demise of the Roman Empire practically untouched and was the only institution with enough resources to sustain an educational system. Indeed, the Church practically monopolized education in post-Roman Europe. The clergy educators used Roman encyclopedic works as their texts after having cleared them from what was judged to be incompatible with the Christian doctrine. Education emphasized learning about the natural world in as far as the presented knowledge served to convey and reinforce the teachings of Christianity. The Survey course professor concluded by noting that very little "science" was done during this period and that with the exception of a few additions made by Arab scholars, no new noteworthy scientific innovations were made until the earlier part of the seventeenth century. The intimate relationship between science, culture, and society was also emphasized.

Assignments and assessment strategies.

All students enrolled in the Survey course were required to read Frankfort, Frankfort, Wilson, Jacobsen, and Irwin's *The Intellectual Adventure of Ancient Man.* All other readings were optional (see Appendix E for specific references). The course professor indicated that these readings served "the purpose of providing more detailed and elaborate accounts of what is discussed in class."

Students were administered 12 short (3-10 minute) in-class quizzes. Four of these quizzes asked for factual information presented in the course such as naming the two major pre-Greek cultures, naming the authors of major "scientific" works in antiquity, stating the opening sentence in Aristotle's *Metaphysics*, and providing the plural of the word "phenomenon." Five other quizzes targeted students' knowledge of specific ideas explored in the course. Students were asked to describe Egyptian mathematics and astronomy, the Sophists and their contribution to the development of early Greek "science," Plato's view of the nature of reality, and the humorial theory.

Three other quizzes invited students to reflect on certain ideas or themes discussed in the course. Two of these quizzes asked students to describe "knowledge" from a Mythopoeic perspective and explain what it meant to "know" something and the means that were used to arrive at "knowledge" in a Mythopoeic context. The third quiz asked students to explicate the relationship between specific attributes of Greek culture, religion, and politics and the Greek philosophers' continued discourse about natural phenomena and their efforts to explain such phenomena without recourse to divine or supernatural entities. The Survey course professor noted that these short writings were structured and intended to help "students follow certain lines of thought . . . and reflect on what they are learning in the course" (Survey course professor, interview).

All graduate students and those undergraduates who needed to improve their final course grades were required to complete a take-home final exam. The exam asked students to describe the fundamental assumptions and basic methods that were originated by Greek philosophers and still underlie modern scientific practice. The exam also asked students to outline major Greek scientific innovations and explain why the Romans failed to continue the "scientific" legacy initiated by the Greek. In addition, graduate students were required to write a short biography of a scientist from the period covered in the course.

When asked about the extent to which students were successful in divorcing themselves from current conceptions and knowledge when discussing the sciences of earlier cultures, the Survey professor noted that:

> They usually are not very successful. And most of the time I end up pointing out in their writings aspects that were not known in the period they are talking about. Sometimes I think they get it, but then they ask a question or write something and then I realize that they are still judging the period we are studying from within modern conceptions. (Survey course professor, interview)

The Evolution Course

The Evolution course, entitled "Evolution and Modern Biology" (3 credit hours), focused on the origin and development of Darwin's theory of evolution. The course also explored the reception and history of evolution theory from its inception to the present.

Course objectives and instructor priorities.

The Evolution course professor noted that the course had two main objectives:

> [The first is] to convey to students a broad perspective of the theory of evolution . . . To help students develop an understanding of the basic structure of the theory of evolution . . . and the basic concepts, and to clarify some of the language that is thrown around very loosely: species, individuals, varieties, and variations. [The second objective is to] teach students about the nature of scientific theory, what a theory is, why people accept it, why people reject it, how do theories come into being, how do

> they change, how they are perceived . . . [And] that a scientific theory answers a lot of questions and guides research. (Evolution course professor, interview)

The professor also noted that the course aimed to get students to think of scientific theory as "something that changes in time. It is not absolute and it is deeply infused with cultural ideas and values . . . It is a marvelous intellectual construction, but it is a construction and it changes in time" (Evolution course professor, interview).

The Evolution course professor noted that helping students develop adequate conceptions of the NOS is one of his major concerns. He noted that "in college . . . science is so often taught as a body of information to be mastered, to be memorized, actually without a sense of process." And teaching students "about the nature of science is critical. This helps students develop a sense for the process of science. In a way, what is most interesting about science is that science is a process to gain knowledge about the world" (Evolution course professor, interview).

The Evolution course professor indicated that an understanding of the NOS is relevant to students' lives and impacts the decisions they make regarding various everyday life issues. He noted that:

> Science is just such a big part of our lives; we spend so much money on it. We use scientific experts when we make decisions all the way from national policy to personal life choices. You turn on the television and you are bombarded with purported studies and so on. So, the nature of science is just part of critical thinking, part of training people to think critically about arguments that they would be able to assess them on all levels. (Evolution course professor, interview)

Teaching approach and classroom dynamics.

The Evolution course was a large-sized (116 students), lecture course. Slides of major players who figured in the development and reception of evolution theory were frequently shown at the beginning of lectures. During the lectures, the professor occasionally asked questions of students. However, besides a structured role-playing activity detailed in the "assignments and assessment strategies" section below, interactive discussions were rare in the course.

The course materials were structured to depict the "story" of the theory of evolution. The Evolution course professor noted:

> I try to develop a narrative. I think the narrative helps students to remember a lot of information, a lot of ideas . . . I think that the way I structure the narrative now, it is really one story for me from the time it starts till the end. (Evolution course professor, interview)

In his course, the Evolution course professor aimed to help students "put on a different kind of thinking cap." He noted:

> 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, their ontological assumptions, how complete is their data set. (Evolution course professor, interview)

The attempt to help students examine the "story" of evolution theory from within a perspective that was radically different from their own was clearly reflected in the course assignments and activities that are detailed in the "assignments and assessment strategies" section below.

Finally, when asked about the approach that he would use to convey to students certain notions about the NOS, the Evolution professor noted:

> The more I teach, the more explicit about things that I come to be. Before a lot of the message of the course was implicit and I find myself more and more explicit probably because when I get exams back I discover that students did not get the message that I am trying to convey. (Evolution course professor, interview)

Topics covered and NOS aspects explicitly addressed.

The development of Darwin's theory of evolution was explored in the first half of the Evolution course. The second half of the course was dedicated to the reception of the theory and the reactions it elicited in various European countries and the United States. The Evolution course professor started with setting the background for Darwin's theory. He presented an overview of "natural history" briefly describing Linneaus's artificial system of classification, Buffon's attempts to devise a natural system to classify species, and Cuvier's notion of species as "morphological type" and work in comparative anatomy. This presentation was followed by a discussion of William Paley's *Natural Theology* and his argument for design in nature.

The Evolution course professor also explored 18th and 19th century geology. He surveyed the ideas of Volcanists, such as Buffon, Guettard, and Desmarest, who emphasized the role of heat, and the ideas of Neptunists, such as Werner, who emphasized the role of water in shaping the earth's geological formations. Moreover, there was a discussion of the major geological controversy in the 19th century between James Hutton's uniformitarian doctrine in geology, later elaborated by Charles Lyell in his three-volume *Principles of Geology*, and Cuvier's catastrophic approach to geology. The work of William Smith and the shift in geology to studying fossils and their relationship to geological strata and the age of the earth were explored. The professor also discussed some "evolutionary" ideas, such as those of William Well and Edward Blyth, that were advanced prior to Darwin. This discussion was concluded with the publication of Robert Chambers' *Vestiges of the Natural History of Creation* in 1844 and the negative reactions that this book elicited in England.

Next, Darwin's background and education were explored. The highlights of his voyage on *HMS* Beagle and significant observations were discussed. Darwin's return to England in 1836, publication of the *Voyage of the Beagle*, and active involvement in publishing the zoology and geology of the Beagle were explored. The professor then followed the development of Darwin's ideas on evolution through an examination of Darwin's detailed notebooks. The professor discussed the major ideas in Darwin's first outline of the theory of evolution that he had written in 1842, and those ideas in his 250-300 page essay of 1844. Next, the professor explored the conceptual and empirical issues, and other circumstances that made Darwin reluctant about going public with his ideas as well as his consequent extended work on barnacles. The life and work of Alfred Russell Wallace were then introduced and followed by a discussion of the circumstances that ended with Darwin publishing *The Origin of Species* in 1859.

In his discussion of evolution theory, the Evolution course professor noted that Darwin re-conceptualized the notion of "species," giving it a meaning that was radically different from, for instance, Cuvier's depiction of species as a blueprint. The professor stressed the tentative nature of scientific knowledge, an aspect of the NOS that was explicitly emphasized on four separate occasions throughout the course. He also noted that Darwin's evolutionary theory, like other theories, could not be directly tested. He noted:

> What are you going to do? Get a hundred thousand buffaloes and put them in your field and watch them for a million years . . . You cannot run that kind of experiment . . . evidence here needs to be indirect evidence. (Evolution course, lecture transcripts, 10/17/1997)

At this point, students were asked in the midterm exam to evaluate Darwin's theory as if they were living in the 19th century. In his comments on the midterm exam responses, the professor briefly, but explicitly, discussed students' use of the term "prove:"

> 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)

In the second half of the course, the Evolution course professor explored the reception of Darwin's ideas in England, the United States, Germany, and France. He noted that "the purpose for doing this is to examine how scientists evaluate theories, why they accept a theory or why they reject a theory" (Evolution course, lecture transcripts, 10/27/1997). The professor noted that in England some scientists, such as Thomas Henry

Huxley and Joseph Hooker, were supportive of Darwin's ideas. Others challenged Darwin or, at least, had reservations based on scientific, philosophical or religious arguments. Among the scientific objections to Darwin's theory raised by English scientists were difficulties related to the age of the earth, genetics, variations and their causes, comparative anatomy, and the non-observable nature of the theory's central premise of natural selection. Probably the most serious of these objections were articulated by physical scientists, most notably Lord Kelvin, concerning the age of the earth. In this context, the professor noted that new scientific theories are not merely extensions of current scientific knowledge. Rather, new theories often invite a re-conceptualization of the way the natural world is perceived and contradict other established areas in current scientific knowledge:

> This is what happens with new scientific theories. This is a point that comes over and over again in the history of science. A new radical theory always has problems. It always contradicts other areas that were formerly accepted. So Cuvier's comparative anatomy seemed contradictory to Darwin's theory . . . And the theory contradicted a whole set of laws in physics." (Evolution course, lecture transcripts, 10/29/1997)

In the context of exploring the philosophical arguments that were raised against Darwin's theory in England, the Evolution course professor briefly discussed the nature of inductive and deductive arguments in science noting that 19th century scientists had preference for inductive arguments. He *highlighted* inference and the tentativeness of scientific knowledge. The professor noted that "an inductive statement is a generalization about experience, it is a statement about the future, it is an inference . . . its truth therefore is not guaranteed . . . you can never be 100% certain about it" (Evolution course, lecture transcripts, 10/31/1997). The professor also emphasized the explanatory function of scientific theories. Darwin's arguments, he noted, were not commensurate with scientists' preference for "good" empirical science. Darwin started by *assuming* the existence of natural selection, a mechanism that has no empirical content. However, Darwin's theory was compelling because of its *explanatory* power. The professor noted, "A theory explains the facts, a theory synthesizes large bodies of knowledge and it is not just a simple induction. Darwin's theory was one that made sense of all the facts of natural history" (Evolution course, lecture transcripts, 10/31/1997).

Next, the reception of evolution theory in the United States as echoed in the public debates between the theory's major advocate Asa Gray and its major opponent Louis Agassiz, was discussed. The professor noted that Asa Gray popularized his own "interpretation" of evolution theory. Unlike Huxley and Hooker who saw Darwin as replacing Paley's natural theology, Gray perceived Darwin's ideas as an extension of Paley's. Gray believed that natural selection was part of a larger "designed" scheme. By comparison Louis Agassiz, who was deeply influenced by Cuvier, rejected Darwin's theory and championed the idea of special creation.

In this context, the Evolution course professor briefly highlighted the influence of culture on science. He noted that by 1870, merely 10 years after the publication of *The Origin of Species*, the basic tenets of Darwin's theory had come to be widely accepted in England and the United States. This acceptance, the professor continued, was largely due to the secularization of the Anglo-American culture. By 1870, people were suspect of explanations that resorted to religious or theological arguments and had a general preference for mechanical material explanations, such as those articulated by Darwin.

The professor then turned to discuss the reception of Darwin's theory in Germany. He explored the issues that interested the German scientific community, including cell theory and embryology: issues that were different from those that had caught the attention of the Anglo-American scientific communities, such as classification, distributions, and fossils. Nonetheless, the professor noted, Darwin's ideas were commensurate with the German interests and more importantly with their predominant philosophy at the time, "Wissenschaft," or nature-philosophy that was concerned with knowledge characterized by unity of method and unity of conception. He noted that these factors facilitated the German acceptance of Darwin's ideas. By comparison, the French were interested in a whole different set of issues, including the debates concerning spontaneous generation and the development of experimental physiology. As such, Darwin's ideas did not "fit" into the French scientists' agenda. Moreover, the French dismissed Darwin's theory for several other reasons that were related to Cuvier's influence and the focus scientific on professionalism and empiricism in 19th century France.

As outlined above, the Evolution course professor had made a few brief explicit statements about the NOS. However, upon concluding the discussion of the comparative reception of Darwin's theory, the professor dedicated about 20 minutes for a relatively extended and explicit discussion about the nature of science and scientific theories. The professor described science as an interpretive value-laden social and cultural activity:

> There are a number of historians who say that science is a product of specific scientific communities. They don't talk about science as "international," crosses all boundaries. Some argue that what is objective in Edinburgh is objective in Moscow . . . But that's clearly not the case with scientific theories. Scientific communities have their own values, they have

> their own beliefs, they have their own questions that they think are important. And the reason one group accepts an idea or a theory and another group doesn't is not just a matter of logic, not a matter of going out and let's check the facts and see which is right. The French have the facts, the English have the facts, but they look at it differently. (Evolution course, lecture transcripts, 11/12/1997)

The Evolution course professor then explicitly discussed several aspects of the nature of scientific theories. Although not included in the following excerpt, the professor used specific examples from the "story" of the theory of evolution to substantiate the discussion. The discussed aspects were that:

> Scientific theories are not like observations . . . Rather, theories are complex intellectual structures that have components that are unobservable . . . Theories just explain the observations that we make. That is the function of theories . . . They relate bodies of information . . . They also imply certain general assumptions about nature. When you learn theories, you don't learn assumptions, they are implicit . . . Darwin was looking for a material mechanical explanation . . . This tells you something about his assumptions about the world. That the world is ultimately material, ultimately mechanical . . . Theories also have certain methodological principles. Theories, in other words, define what is the correct way of doing science and what is not the correct way . . . Another important thing about theories is that theories also suggest paths of research. Theories are active and dynamic . . . You can't ever prove a theory . . . The acceptance or rejection of a theory is just so complicated and cannot be reduced to the facts. (Evolution course, lecture transcripts, 11/12/1997)

Then, the Evolution course professor invited students to critically think about a set of questions:

> You should wonder when someone makes the following statement, "evolution is a fact." Can a theory be a fact? Or "this theory is proved." Can this be? Theories are strong or weak, valid or invalid. Theories are not true or false. (Evolution course, lecture transcripts, 11/12/1997)

The Evolution course professor then explored the (sometimes-alleged) impact of Darwin's ideas on 19th century culture including economics, politics, and religion. In this context, he first examined social Darwinism and the Eugenics movement in the United States. Second, the impact of Darwin's ideas on politics was explored within the context of the Nihilist reaction to the political state of affairs in Russia. Finally, the religious reactions to Darwin's ideas in the United States were discussed at some length. The professor concluded this discussion by emphasizing that it is not meaningful to talk about "the" religious reaction in the United States. He emphasized that religious *reactions* to Darwin's ideas were varied and fell on a continuum from a complete rejection by denominations that held a literal interpretation of the scripture, to an acceptance and integration by theists for whom Darwin's ideas were compatible with their religious world view.

The professor then traced the development of Darwin's theory of evolution within biology from 1870 to the present. He noted that the purpose of following the theory's development was to emphasize the tentative nature of scientific theories. The professor started by explicitly re-emphasizing the role of 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 explored the major areas of investigation that were pursued between 1870 and 1910 including natural selection as a mechanism for evolution, the origin of variations, evolution of new organs or organ systems, sexual selection, and the age of the earth. The work of Hugo de Vries and the rediscovery of Gregor Mendel's work were also discussed. The professor then explored the "schools" that emerged as a result of these research programs including Neo-Darwinism, Neo-Lamarckanism, and Isolationism. This was followed by a brief discussion of the statistical studies of Fisher and Haldane, the work of Thomas Morgan with fruit flies, the work of Theodosius Dobzhansky with population biology, and the work of Ernst Mayr with systematics.

All these efforts, the professor noted, were pulled together in the 1940s into what came to be known as the "Modern Synthesis." The relatively few additions made between 1950 and 1980 by the fields of biochemistry, population biology, and animal behavior were explored. Finally, the professor highlighted some of the problems that French scientists and other paleontologists had with the Modern Synthesis. Other issues including punctuated equilibrium, the inadequacies of natural selection in accounting for ecological complexities, philosophers' concerns with the adequacy of the theory as a unifying synthesis, and the whole human dimension (e.g., culture, consciousness, artistic creativity) were highlighted.

The Evolution course professor then discussed modern interpretations of the theory of evolution from within three major perspectives or worldviews: Marxism, Christianity, and scientific humanism. The Marxist and Christian interpretations were discussed in light of the work of Karl Marx and Teilhard de Chardin respectively. The scientific humanist interpretation was presented through the work of Julian Huxley. More recent interpretations of evolutionary theory by scientists, such as Richard Dawkins and Edward Wilson, were briefly discussed. Finally, the professor discussed scientific creationism and the debate about teaching evolution in high schools in the United States. The origins of the debate between evolutionists and creationists were traced back to the 1920s. The debate was then followed all the way to 1987 with the supreme court ruling as unconstitutional the demand of creationists for equal time in the classroom.

In his concluding remarks, the Evolution course professor noted that there is no general consensus regarding the NOS. Then he presented his three-pronged view of the NOS. He indicated that science is: (a) a set of beliefs or assumptions about the nature of the world, (b) a set of methods to learn about the world, and (c) a set of problems that result from attempting to fit observations of the natural world into the aforementioned set of beliefs. He emphasized that all three aspects of science—beliefs, methods, and problems, are dynamic. These aspects have changed throughout the history of science and will continue to change.

The professor also 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 re-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. Finally, the professor emphasized the reciprocal relationship between science and culture.

Assignments and assessment strategies.

During the first half of the course, as the Evolution course professor was exploring the development of Darwin's theory, students were required to skim Darwin's *Voyage of the Beagle* and closely read *The Origin of Species*. The Evolution course professor noted that "*The Origin of Species* is one extended argument and . . . I want students to have a sense of the whole argument. And if they do that, then it would give them the ability to assess the argument" (Evolution course professor, interview).

Students were not assigned any readings during the second half of the course. They were required to prepare a research paper in which they compared the writings of a 20th century figure (e.g., evolutionary biologist, philosopher, theologist) on evolutionary theory with those of Darwin's. The Evolution course professor noted that the aim of having students tackle this topic was to get them to explore firsthand the tentative nature of scientific knowledge. He noted, "the theory is very different today, it has really changed a lot . . . And the idea is to get students to see the difference between contemporary theory and 19th century theory" (Evolution course professor, interview).

Three in-class activities and the midterm exam were aimed to help students examine Darwin's theory and the various reactions it elicited from within a 19th century perspective. The first activity was a short in-class writing assignment that followed a discussion of some of the ideas of Linneaus, Cuvier, Buffon, and Paley. The Evolution course professor addressed students:

> Suppose that you are living in a small English village . . . in the 19th century and you've been studying some natural history, bugs, beetles . . . And what you like to do is to go to a big museum and look at a lot of these insects and find more about them. And you've heard that the natural history museum in

> Paris has the largest collection in the world . . . Of course you are a student, you have no money and so you are writing a letter to the local parish society. Take five minutes . . . to write a letter asking for money to go to Paris to study natural history. (Evolution course, lecture transcripts, 10/3/1997).

The second activity was a more involved in-class role-playing and spanned one 50-minute session. The activity was undertaken after the evolution "story" was traced to the point of the publication of *The Origin of Species* in November, 1859. The professor presented an overview of education in English universities and particularly 19th century Oxford and Cambridge. He emphasized that educational decisions, including curricular decisions, were largely made by the semi-independent colleges within those universities. Students were asked to imagine themselves as being faculty members in various colleges, such King's, Saint Catherine, Queen's, Corpus, Peterhouse, and Trinity during the period immediately following the publication of the *Origin*. The Evolution course professor then divided the class into different groups each representing one of the aforementioned colleges and asked them to take a curricular decision regarding the *Origin* in their respective colleges. Students were given 20 minutes to discuss the issue among themselves and reach a decision. Following group discussions, the class reconvened and a spokesperson from each college presented the college's decision and justified it. Finally, the activity was debriefed by the professor.

The third activity was a short in-class (5 minutes) writing assignment. In the context of discussing the reception of Darwin's theory in the United states, the Evolution course professor highlighted the public debates between Asa Gray, the major advocate of a certain interpretation of evolution theory, and Louis Agassiz, the theory's major opponent. The professor asked the students:

> If you were living in Cambridge, Massachusetts in 1860 and you went to a debate, and there were these debates, public debates between Asa Gray and his interpretation of Darwin's theory and Louis Agassiz who is rejecting Darwin's theory, whom would you be more impressed by and why? (Evolution course, lecture transcripts, 11/3/1997)

Students were required to sit for a 50-minute in-class midterm exam. They were provided the midterm question ahead of time and encouraged to discuss it among themselves. The midterm asked students to evaluate Darwin's *Origin* 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 . . . You can situate yourself anyway you like . . . 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)

Additionally, all students were required to complete a take-home final exam. The exam questions were related to the nature of scientific theories:

> Using as an example what you've learned this term, write an essay the length about the amount you would typically write during a two-hour in-class exam on one of the following topics and not all of them. (1) How and why do scientists construct scientific theories? (2) How do scientists evaluate scientific theories? (3) How do scientific theories change in time? (4) How do scientific theories influence or interact with ideas about religion and society? (Evolution course, lecture transcripts, 12/3/1997)

The Evolution course professor noted that the final exam aimed to get students to "reflect on a set of issues and . . . make them confront what is the center of the course or the major goal: the nature of theories" (Evolution course professor, interview).

The Controversy Course

The Controversy course, entitled "Studies in Scientific Controversy" (3 credit hours), focused on accounts of controversial scientific discoveries. Using case studies from the 17th through 20th centuries, the course aimed to highlight the rational, psychological, and social characteristics that have typified the meaning and methods of the natural sciences.

Course objectives and instructor priorities.

During the interview, the Controversy course professor noted that the course served as "an introduction to thinking about how science works, and how science has changed over time and . . . to examine scientific process in specific localized situations" (Controversy course professor, interview). In addition to exploring scientific process, the Controversy course professor emphasized that centrality of the historical dimension of the course. She noted that the course aimed to:

> Concentrate on some specific historical material. This is a history course and not a philosophy course. So, while I think that at the end it is useful to develop some generalizations, still this is a history class, that is what we are doing. (Controversy course professor, interview)

When asked about the specific aspects of scientific process that would be emphasized in the course, the Controversy course professor noted:

> Well, I suppose that what I want to emphasize . . . is the nature of evidence and how evidence is acquired. And evidence is very often instrumental in nature. And I think that it is important to think about that . . . What does it

> mean to make an observation and what does it mean to make an experiment or to make an observation that is mediated in a conscious way through physical materials as well as conceptual ideas . . . So, mainly how do we observe? How do we think? How do we use evidence in order to make arguments? (Controversy course professor, interview)

It should be noted that as articulated by the Controversy course professor, these latter aspects were not specific in nature. Many generalizations at various levels of specificity and complexity, both from historical and philosophical perspectives, could be discussed under the broad rubric of the relationship between theory or argument and evidence. Regarding the social and psychological characteristics of science, the Controversy course professor noted that the course would emphasize that:

> In the sciences, as in other fields as well, individuals have certain social and economic circumstances in which they find themselves . . . that individuals live in a certain culture, and . . . that the kind of education that one receives is very crucial . . . And I think that there are national factors too that build certain kinds of traditions. That individuals are competitive with one another in their everyday activities and also in matters that have to do with science, and that this competitiveness plays a role at the individual level, the laboratory and institutional level, also on the national level. And that science has had a place to play in terms of prestige as well as having an impact on the economical and technological realms. (Controversy course professor, interview)

Finally, similar to the Survey course professor, the Controversy course professor did not explicitly include possessing adequate views of the NOS as a component of scientific literacy. When asked during the interview, the Controversy course professor noted that:

> Scientific literacy would constitute knowing some of the basic languages of the different sciences, and a basic knowledge of the structure of the different sciences. Some of the basic language, what is referred to as popular science, being able to look at the some of the television programs on science or read

> the science column in a newspaper and not feel alienated by the terminology. (Controversy course professor, interview)

Teaching approach and classroom dynamics.

Compared to the Evolution and Survey courses, a small number of students (18 students) were enrolled in the Controversy course. The Controversy course was interactive in nature and questions were frequently asked of students. Moreover, students were involved in several discussions concerning assigned readings and other ideas explored in the course.

The Controversy course professor used a case-study approach to present the course material. The course explored several controversial episodes in the history of science. In each case, the professor first presented a comprehensive overview of background scientific information. The lives and works of major players featured in a controversy and the relevant historical context were also explored. Next, the controversy and the aspects of scientific process that it highlights were discussed from the specific context of the assigned course readings.

It should be noted that consistent with the Controversy course professor emphasis on the historical dimension of the course material, the presentations and discussions were extensive in their coverage of detailed historical information. Indeed, many of the exchanges in the course were centered about historical details as evident in the following discourse undertaken in the context of presenting Eddington's expedition to test predictions concerning the behavior of light derived from Einstein's theory of relativity:

Professor: Do you remember when the first attempt actually was made to test Einstein's predictions [of the bending of light near massive objects like the Sun]?"
Student #1: 1918.
Professor: That was the second test. When was the first test?
Students: [No answer]
Professor: It was 1914 and there is a team that went out to Russia . . . and they were looking for this shift. And they got to Russia . . . and then what happened?
Student #2: There was a war.
Professor: Yes . . . and they were actually arrested and they eventually got out of it and they were not sent to prison. So, that was the end of that. Then in 1918 there was another attempt to test Einstein's theory . . . And do you remember where the eclipse occurred? What country?
Student #1: United States.
Professor: Yes. Remember where?
Student #1: It was Washington.
Professor: Right, Washington State. The eclipse was observed in Eastern Washington. And there, Campbell who was a very well known American observational scientist was there and took some photographs and analyzed them. It took him about eight months to analyze them. He wrote a paper which appeared in the Royal Astronomical Society Journal in England after the May 1919 eclipse had occurred in which we say Einstein had been confirmed. Campbell results were published. Were they negative or positive? Did he find the predicted bending of star light or not?"
Student #3: No.
Professor: That's right he didn't . . . And Campbell actually has published in 1919 his negative results . . . But his negative results were much overpowered by the results that were . . . announced at a joint meeting of the Royal Society and the Royal Astronomical Society. That was an unusual event to have a joint meeting of these two organizations. And actually J. J. Thompson presided over that meeting . . . and Eddington's results of the 1919 expedition were reported. And what were the sites for that expedition? (Controversy course, lecture transcripts, 12/2/1997)

Topics covered and NOS aspects explicitly addressed.

In the first three lectures, the Controversy course professor surveyed several ideas related to the NOS. This survey, nonetheless, was general. Few *explicit* statements or generalizations regarding the nature of scientific knowledge and practice were made. Moreover, many of the NOS aspects discussed during the first part of the course were not revisited in the context of the scientific controversies explored later in the course.

The Controversy course professor briefly explored the structure of some of the earliest scientific societies. She noted that professional scientific societies, such as the Royal Society of London and the French Academy of Sciences, which were established the 17th century, marked the beginning of professionalization and specialization in science. Statues for conducting scientific investigations were established and codified in the publications of these organizations and societies. The professor also emphasized the tentativeness of scientific knowledge. She noted that "our best knowledge is probable, highly probable knowledge. But logically we can't say that we achieved absolutely true knowledge because we can never have all the facts." (Controversy course, lecture transcripts, 10/7/1997). The various editions of Darwin's *The Origin of Species* and especially the notable differences between the first and sixth editions were given as an example of change in scientific knowledge as codified in textbooks.

Moreover, the Controversy course professor explored the social and cultural nature of scientific knowledge. She noted that scientific knowledge is not independent of "time" and "place." The problems investigated within a certain cultural and historical milieu are intimately related to contemporary education, economics, and social factors. In this context, the professor noted that the notion of "natural law" was closely related to 17th century conceptions of living in an orderly rational world. This conception was in turn related to the idea of creation and the omnipresence of the "Creator." The professor continued that the law-like nature of many 17th century scientific claims was not only related to the contemporary religious and intellectual milieu, but also reflected a political culture of law-like nature that underpinned the French revolution.

A discussion about the nature of scientific theories and laws and their relationship followed. The professor noted that:

> Laws are, in principle, universal statements of relationships that are valid in all time. Theories are conceptual systems, if you like, into which laws are put. Theories being understood to change over time for the most part. Whereas laws, it is argued, often are, with some restrictions, unchanging. They are claimed to be true laws of nature. (Controversy course, lecture transcripts, 10/7/1997)

The Controversy course professor noted that a theory is more than the sum of the laws it relates to. Moreover, she emphasized the mathematical nature of laws and their appeal to elegance and simplicity. These attributes, it is argued, confer special status and power to scientific "laws." The theory-laden nature of scientific observations was also explored. The professor noted that, especially in the context of investigating invisible entities such as genes, "seeing" is often mediated by several factors including what is expected to be "seen" and the theoretical assumptions that underlie the apparatus used to "view" the investigated entities.

Next, scientific experiments were discussed in the context of several examples from Rom Harre's *Great Scientific Experiments*. Among the experiments discussed were Aristotle's work on chick embryos, Theodoric of Freiburg on the causes of the rainbow, Isaac Newton on the nature of colors, Galileo on the law of descent, and Robert Boyle on the measurement of the "spring" of the air. Several ideas about experiments were presented and discussed. The difference between more "passive" observations and proactive experiments that involve manipulation or control was highlighted. Also, the theory-laden nature of experiments and the significance of prior expectations were noted. The Controversy course professor indicated that experiments are often undertaken in the context of larger research programs with the intent of "adjudicating" between rival hypotheses.

Another aspect relevant to the NOS was the notion of "idealization" in science. The Controversy course professor noted that often there is a "leap" from the reality of experimental work to an idealization of the relationships between the investigated entities. Galileo's investigation of the law of free fall and Boyle's work with vacuum, conditions that were not "actually" achieved, were given as examples. Finally, the professor briefly explored the relationship between experiment and theory in the context of Harre's discussion of inductivism, fallibilism, and conventionalism.

Discussions of controversial scientific episodes were started in the fourth lecture. The first controversy was related to Galileo's telescopic observations of 1609 reported in his *Siderius Nuncius* or *Starry Messenger*. Galileo's life and education as well as the contemporary political context were explored. This exploration was followed by a discussion of the development of the telescope and Galileo's observations of the surface of the Moon, Venus, the moons of Jupiter, and the "spots" on the surface of the Sun. In this context, the professor emphasized the relationship between observations and theoretical frameworks. She noted that Galileo conducted his observations with the aim of testing two rival cosmological systems; the Aristotelian-Ptolemaic and the Copernican systems.

Next, the patronage of scientists in the 17th century was discussed in the context of following Galileo's life and professional aspirations following his observations of 1609. The relationship between science and the political realm was highlighted with a discussion of Galileo's use of his connections with the Tucson court to promote and effectively disseminate his observations. The professor then moved to discuss objections to Galileo's observations and the latter's response to those objections. The discussion focused on the doubts and controversies often associated with the introduction and use of a new instruments in science.

The next controversy was related to 18th century theories of electricity and magnetism. In particular, the discussion focused on Antoine Mesmer's practice of "electric medicine" and the efforts of the French Academy of Sciences to discredit his work. An overview of the electrical theories of Jean Mollet and Benjamin Franklin was presented. Additionally, the Controversy course professor discussed Antoine Mesmer's background, interest in magnetism, magnetic fields, and electricity, and clinical practices in Paris. The professor also briefly explored the life and works of Lavoisier, Franklin, and Guillotine who were members of the investigative committee assigned by the French Academy to judge the legitimacy of Mesmeric practices.

In the context of this controversy, power structures within scientific communities and associated influences on what counts as "legitimate" scientific knowledge were explored. Robert Darnton's *Mesmerism and the End of the Enlightenment in France* set the context for the controversy. Darnton's portrayal of the French enlightenment, the atmosphere of hope, excitement, and hoaxes that dominated the period, and the contemporary intellectual and economic spheres were explored. Next, the Controversy course professor noted that in this atmosphere of excitement and suspicion the public questioned all claims made by "healers." Trust was accorded to those "gentlemen" physicians and scientists who were reputable and established in their professions and, probably most importantly, members of prestigious scientific societies. Mesmer and his followers were not members of or were not associated with such elite societies. This, the Controversy course professor noted, might have contributed to the rejection of Mesmerism by the "scientific community."

Next, N-rays and the controversy regarding their existence were explored. In this context, the Controversy course professor briefly discussed the works of Zeeman, Weichart, Rontgen, and Bequerel in relation to radioactive "rays." The relevant works of Thompson at the Cavendish Laboratory at Cambridge and Rutherford at McGill University were also explored. Next, the work of Marie and Pierre Curie and Gustave LeBon with radioactivity was discussed at some length. The professor then discussed Blondlot's background, experiments, and announcement of the discovery of N-rays. Finally, Robert Wood's success in debunking Blondlot's work was presented.

The discussion of N-rays was concluded with the Controversy course professor inviting students to think about several related questions:

> What were the effects that were regarded as demonstrating that N-rays exist? What were the effects that were regarded as demonstrating the characteristics of this radiation? To what extent are these effects subjective? To what extent can they be made to be objective in the sense that they are replicable, they can be quantified, and they can be mechanized? (Controversy course, lecture transcripts, 10/30/1997)

The discussion of N-rays was not brought to closure in relation to the NOS. "Lessons" about the NOS that could have been derived from this historical account were not singled out and explicitly emphasized. Moreover, the aforementioned questions were not revisited later in the course.

In the context of discussing the question of human origins and the Piltdown Man hoax, the Controversy course professor briefly explored the social basis of the notion of "scientific discovery." The professor then explored earlier hominid-remains discoveries, the key characters involved in unearthing Piltdown Man, the dissonance created by this "discovery" in the context of accepted theories about human origins, the discovery of the hoax, and hypotheses about the perpetrator(s). Next, the evidence supporting the hypothesis that Sir Arthur Doyle was behind the hoax was presented. In the context of this episode, the Controversy course professor discussed the notion of anomaly and its relation to the validity of scientific theory. She emphasized that scientific communities sometimes downplay the significance of anomalies and that often a single piece of contradictory evidence does not result in overthrowing a well-established theory.

The controversy over the causes of the extinction of the dinosaurs as presented in David Raup's *The Nemesis Affair* was then discussed. The professor presented an overview of the meaning of "mass-extinction," the major "documented" mass-extinctions, the suggested periodicity of these extinctions, and the "Nemesis" hypothesis and other hypotheses advanced to account for this claimed periodicity. In this context, the Controversy course professor noted that "at the core of this controversy about the extinction of the dinosaurs . . . is the controversy between gradualism or uniformitarianism and catastrophism in geology" (Controversy course, lecture transcripts, 11/11/1997). The professor noted that the uniformitarian doctrine in geology was first formalized in Charles Lyell's *Principles of Geology* published in 1831. The 19th century debate between followers of uniformitarianism and scientists, such as Cuvier, who championed a catastrophic approach to geology was explored. However, the distinction between catastrophism and uniformitarianism as two broad interpretations for earth's geological formations was not explicitly linked to the role of implicit theoretical commitments or worldviews in shaping the explanations that scientists put forth to explain observational evidence.

The "cold fusion" controversy followed. The course professor presented an overview of relevant background theory followed by a discussion of the specifics of the Pons/Fleischmann apparatus and alleged discovery, and the reception of the announcement of cold fusion and the accompanying media frenzy. Efforts undertaken to replicate the Pons/Fleischmann results at various institutions and the scientists involved in those efforts were overviewed with emphasis on the role effected by the media in disseminating information between the involved parties. The objections raised by physicists based solely on theoretical grounds were also discussed.

The Controversy course professor highlighted the institutional, financial, and disciplinary factors that might have led Pons and Fleischmann to their premature announcement. First, there was institutional rivalry between Utah State University and the University of Utah and a race to secure priority, patent rights, and the associated generous funds pledged by the Department of Energy. Second, there was disciplinary rivalry between chemists and physicists that was evident in the disparate receptions of the announcement of cold fusion by these two scientific communities. Grandeur was accorded to the Pons/Fleischmann presentation on cold fusion at the meeting of the American Chemical Society in Dallas and specific remarks were made concerning the failure of physicists to achieve any notable progress in the area of cold fusion. By comparison, demeaning language was used by the physicists at the meeting of the American Physics Society in Baltimore. The physicists described the Pons/Fleischmann announcement as "pathological science." The discussion also touched upon the influences of the State and Federal Legislatures, and Federal Agencies on the course of the cold fusion controversy.

The final case study in the course explored tests of relativity theory. The Controversy course professor presented a brief description of Einstein's life and work and then moved to talk about the Michelson-Morley experiments. These experiments and their results were discussed at some length with attention to procedures and detail. The work of Miller who continued to perform similar experiments after 1887 and the contradictory results he obtained was discussed. Next, the basic tents and some conclusions of Einstein's special and general theory of relativity were discussed. Finally, the Eddington expedition of 1919 and the nature of the evidence it brought to bear on the validity of the theory of relativity were explored.

Assignments and assessment strategies.

The Controversy course was reading intensive. A complete list of the course readings can be found in Appendix E. In addition to the readings, students were administered three related short (20 minute) exams. At least one week prior to each exam, students were provided with a list of 8-10 study questions. Of these questions, four appeared on the exam and students were asked to answer two questions. Some of the questions were related to the "process" of science. For example:

> At the beginning of his book, Harre' discusses three theories of the role of experiments in the natural sciences: inductivism, fallibilism, and conventionalism. Define these three terms, illustrating each term with a historical example from Harre's book. (Controversy course, first short exam)
>
> Drawing upon specific historical details, discuss the relationship between *anomaly* (a puzzle that doesn't fit with widely accepted scientific theory) and *discovery* in *one* of the following cases: (a) theories during the 1980s of an extraterrestrial cause of the extinction of dinosaurs, (b) the controversy over cold fusion during 1989, (c) the results of the Michelson-Morley experiments, originally carried out during the 1880s. (Controversy course, second short exam)

As evident in the following examples, other questions focused on the historical and scientific details of some of the controversial scientific episodes discussed in the course:

> Theodoric in the thirteenth century and Isaac Newton in the seventeenth century each was interested in the rainbow. How did their theories of color differ and what instruments did each use to study color? (Controversy course, first short exam)
>
> Explain key properties of the mineral radiations that became known as "radioactivity." What rival hypotheses were proposed during the period 1896 to 1906 in order to account for the origin of radioactivity and its energy? (Controversy course, second short exam)

The Controversy course professor noted that the short exams were intended "to make sure that students have done most of the readings." Additionally, the Controversy course professor noted that:

> By giving the study questions ahead of time and then giving the quiz in class, students focus on rethinking the lectures and the readings in order to look at those particular kinds of questions. And that can lead . . . to a kind of a triple form of learning which in addition to the first reading, there is another reading in studying for the quiz, and then taking the quiz. (Controversy course professor, interview)

Additionally, both undergraduate and graduate students were required to write a term paper that focused on a scientific controversy of their choice. The controversies chosen by students were related to spontaneous generation, Galileo's telescopic observations, Piltdown Man, cold fusion, relativity theory, plate tectonics, and vitamin "C." In addition, four students chose to pursue the mass-extinction controversy in their term papers. In these papers, students were asked "to explain the origins and significance of a scientific controversy, as well as the balance of logical, psychological, and social factors in its outcome" (Controversy course syllabus). Graduate students were expected to write a more elaborate term paper, and to make use of more primary documents. When asked about the aim of having students make use of primary resources when writing their term papers, the Controversy course professor noted that:

> In order to understand science, students need to read scientists' work. To see how a scientific article is structured, to see how citations are used in a scientific article, to see how scientists do or don't put things in context, and it will also help students to dive into the particular issue at hand. (Controversy course professor, interview)

Summary

All three HOS professors indicated that their courses aimed 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 the NOS. He believed that an understanding of the 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 *specific* aspects about the NOS and the nature of scientific theories.

The priority given to the historical dimension of the course materials was apparent in all three HOS courses, but was most pronounced in the case of the Controversy course. Both Survey and Evolution course professors utilized a lecture teaching approach given the relatively large sizes of their courses. By comparison, discussion was more frequently used 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. This attempt was clearly manifest in the various course activities and assessment strategies.

In general, all three courses did not utilize an *explicit* approach to teaching about the 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 the 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 the NOS. Notably, the Evolution course professor also presented two explicit and relatively extended (10-20 minutes) discussions about the NOS and scientific theories. The NOS aspects emphasized in the Evolution course were related to the tentativeness of science, and the explanatory function of scientific theories and their role in guiding research. The course also emphasized the social and cultural embeddedness of science, the nature of theory testing, and the considerations associated with the use of the term "prove."

Participants' Pre-Instruction Views of the NOS

Responses to the open-ended NOS questionnaire administered at the beginning of Fall term were used to generate a profile of participants' pre-instruction views of the NOS. This profile was further elaborated and explicated by examining the transcripts of the interviews conducted with students in the first random sub-sample and preservice science teachers.

The pre-instruction profile elucidates participants' views concerning the tentative, empirical, subjective (theory-laden), social, and cultural nature of the scientific endeavor. The profile also emphasizes participants' conceptions regarding the role of human inference, imagination, and creativity in science, the experimental approach, and the functions of, and relationships between scientific theories and laws.

It should be noted that the first step in generating this pre-instruction profile was to establish the validity of the open-ended questionnaire in assessing respondents' views of the NOS. This validity was ascertained by comparing the profiles generated from the separate analyses of the questionnaires and the corresponding interview transcripts completed at the beginning of the term by students in the first representative random sub-sample. To further check on the validity of participants' views as derived from the analysis of the questionnaires, a similar round of analysis was conducted using the questionnaires and corresponding interview transcripts completed at the end of the term by students in the second random sub-sample.

These two rounds of analyses indicated that students' conceptions of the NOS as depicted in their responses to the open-ended questionnaire were generally congruent with the views they expressed during individual semi-structured interviews. The interviews, nonetheless, served an additional important function besides helping to establish the validity of the NOS questionnaire. During these interviews students were asked to elaborate on their responses. Follow-up questions were also used to pursue students' lines of thought to finer levels of detail and explicitness. As such, analyses of the interview transcripts served to further clarify student responses and provided valuable insights into the meanings students attach to several key terms and ideas that were recurrent in their responses to the NOS questionnaire.

Profiles of participants' pre-instruction views of the NOS were generated for each of the investigated courses. These profiles were systematically compared and patterns were sought. Comparisons indicated that the participants in the Evolution, Controversy, and Survey courses held similar views of the aforementioned aspects of the NOS. Students' views in the three HOS courses did not differ in any appreciable or discernable manner. Moreover, the views of the five participant preservice teachers enrolled in the Methods course only were not different from the views of the 10 preservice teachers enrolled in both Methods and Evolution courses. However, the views of all 15 preservice teachers enrolled in the Methods course were different in one major respect. As compared to students enrolled in the HOS courses, appreciably *more* preservice teachers held views that were more consistent with current conceptions on *some* aspects of the NOS emphasized in the present study.

Consequently, the present section explicates the pre-instruction views of the NOS for two groups of participants. The first group includes all 141 participants enrolled in the Evolution, Controversy, and Survey courses. This group, however, excludes the 10 preservice teachers enrolled in the Evolution course. The second group comprises the 15 participant preservice science teachers enrolled in the Methods (and Evolution) course.

In the following sections a coding system is used to identify individual participants. Each code consists of one or two letters and a numerical number. The numbers run from 1 to 181 (181 students participated in the present study). The letter(s) indicate the course(s) in which a certain participant was enrolled during the course of the study. The letter "C," "E," "M," and "S," indicates that a participant was enrolled in the Controversy, Evolution, Methods, or Survey course respectively. A code with two letters indicates that a participant was simultaneously enrolled in two of the investigated courses.

The Empirical Nature of Scientific Knowledge

Science is, at least partially, based on and/or derived from observations of the natural world, and "sooner or later, the validity of scientific claims is settled by referring to observations of phenomena" (AAAS, 1990, p. 4). However, scientists do not have "direct" access to most natural phenomena. Observations of the natural world are always filtered through our perceptual apparatus and/or intricate instrumentation, interpreted from within elaborate theoretical frameworks, and almost always mediated by a host of assumptions that underlie the functioning of "scientific" instruments.

Views of participants enrolled in the HOS courses.

The responses to the first item on the NOS questionnaire of a sizable majority of participants (62%) had indications that science is "empirical" or has "empirical" components. Participants used a variety of terms to convey this view. A few participants used the label "empirical." Many others noted that science is based on and/or seeks tangible, concrete, visible, observable, measurable, or physical facts, data, or evidence. This result is rather encouraging. However, a closer examination of the ideas expressed by many participants indicated that the specific meanings they attach to the notion of an "empirical base" might not be congruent with current views of this aspect of scientific inquiry.

Out of 87 participants who indicated that science is "empirical" or relies on observable evidence, 40 believed that scientific knowledge is *solely* based on tangible facts to the exclusion of other important factors. These factors included human and personal attributes, such as interpretation, speculation, guess, intuition, abstraction, personal views or opinions (22 participants):

> Science is something that is straightforward and isn't a field of study that allows a lot of opinions, personal bias, or individual views–it is fact based. (E105, pre-questionnaire)

> Science is the systematic observation of our universe for the purpose of discovering the nature of reality. Science differs in that it is . . . not derived from guessing, intuition, and induction. (S028, pre-questionnaire)

> [Scientific knowledge is] things for which there is evidence. The facts as they are finally presented without any kind of, sort 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)

The other 18 participants believed that reliance on facts exonerates science from the burden of subjectivity or social and cultural attributes, such as values and beliefs:

> Science: empirical . . . study of natural phenomenon [sic]. Science differs from other disciplines such that it is objective . . . the other disciplines subjectify [sic] the universe and abstraction enters through "self-aware" cognitive human beings. (E135, pre-questionnaire)

> Science . . . deals with the physical world [whereas] religion and philosophy are based on beliefs, values, and traditions (C176, pre-questionnaire)

> I think that science is based on facts, something that you can . . . see and study. Science is not based on belief such as religion. (E133, pre-interview)

Additionally, 21 participants believed that science uses observations, facts, or evidence to "prove" its claims right or wrong. These students attributed to observable evidence the *sole* role in adjudicating between scientific claims. They also seemed to believe that absolute "truths" could be obtained through the use of physical evidence:

> I believe science is different . . . because it uses concrete facts that have been proven/ are observable/ can be repeated and seen by someone else to get . . . a right or wrong answer. (S053, pre-questionnaire)

> I think science is the study of natural phenomena to try to understand it [sic] with a methodology that is pretty much . . . using the facts to prove a theory. (C181, pre-interview)

> In science data is gathered, experiments preformed, and hypotheses proven either to be true or untrue. (E166, pre-questionnaire)

> I consider science to be a factual set of ideas that have been gathered over years of hard work. This scientific data is provable, while religion still remains a matter of personal theory. (S019, pre-questionnaire)

Out of 87 participants who indicated that science has some sort of empirical base, the responses of 26 were more consistent with current views. Many of these participants noted that science involves the formulation of ideas such as hypotheses and theories. Evidence in then sought to either support or discount these ideas:

> In science we ask questions and seek evidence for our speculations . . . This differs from religion in the sense that . . . scientists seek evidence to support or refute their explanations. (ES01, pre-questionnaire)
>
> Science is more concerned with empirical knowledge, that which can be observed or experienced. [This is] accomplished by proposing hypotheses and theories and testing these theories by experimentation and observation. (S037, pre-questionnaire)
>
> Science is the study of how the physical world . . . works. It differs from other disciplines in that science uses tangible data to support its theories and laws. (E131, pre-questionnaire)

As such, only 26 students (18% of all participants enrolled in the HOS courses) seemed to believe that science relies on evidence to *support* its claims. Unlike their counterparts who also held the view that science is "empirical," these participants did not indicate that tangible data could be used to "prove" scientific claims or that science is based on observations of phenomena to the exclusion of other personal, social, or cultural attributes.

Nonetheless, it can be argued, and rightly so, that not expressing a certain view does not guarantee that a respondent ascribes to an alternative view. Indeed, as evident in the last three quotes, the majority of these 26 students did not *explicitly* indicate that tangible evidence could not be used to "prove" scientific claims or that the role observable data play in constructing scientific knowledge is mediated by personal, social, or cultural factors. However, holding students to a stringent level of explicitness diminishes the aforementioned number of 26 to a mere six participants (4%). Only six students expressed the explicit view that even though science relies on evidence and observation, there is much in science that is based on belief, conventions, and the non-observable:

> Science involves experiment and observation. I think science is different from other disciplines in that it is more tangible. However, a lot in science is based on "faith." (E127, pre-questionnaire)
>
> Science is the study of the how, why and what . . . Typically experiments and observations are done to answer questions of how, why & what to either document its validity or . . . reject it. [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, pre-questionnaire)
>
> Much of the development of scientific knowledge depends on observation . . . . [But] I think what we observe is a function of convention. I don't believe that the goal of science is (or should be) the accumulation of observable facts. Rather, I think that . . . science involves abstraction, one step of abstraction after another. (E163, pre-questionnaire)

Views of preservice science teachers.

Ten out of 15 student teachers indicated on the pre-instruction questionnaire that science differs from other disciplines of inquiry by its reliance on facts, evidence or observations of the natural world. However, four of these student teachers noted that observations are the *sole* source for the construction of scientific knowledge or the means to reach definitive conclusions. One student believed that observations could be used to get the "right answer:"

> Scientific knowledge is gained through observation and experimental observations. Scientific knowledge must pass a rigorous process of repeated observations . . . In this process there seems to be a goal to come the most correct conclusion, the right answer. (M017, pre-questionnaire)

Three other student teachers indicated that science relies *solely* on observation to the exclusion of others subjective and social factors:

> Science . . . is the study or investigation of events that are observable and repeatable . . . Science by its very nature must be free of personal bias and opinion leaving only the data to speak for itself. (ME04, pre-questionnaire)
>
> Science is based on observing, gathering data about the nature around us . . . I don't believe that we have faith in science. Science is more cut and dry in a way to put it. Science is objective and the other is subjective. (M018, pre-interview)

As noted earlier, about 18% of all participants enrolled in the HOS courses expressed adequate views regarding the empirical basis of scientific knowledge. A much larger percentage of preservice teachers (40%) elucidated such views as evident in the following quotes:

> In both science and religion there is faith, a faith that certain principles or certain bodies of knowledge are in fact true . . . [But] you can have a bunch of philosophers in a room and they can speculate for hours on end, and that would be okay. For science . . . you can speculate but you are going to have to back it up with some empirical evidence. (ME10, pre-interview)
>
> Science is an attempt to explain the world around us on our terms (and *in* our terms [italics in original]). I would say the disciplines of science are different from other disciplines of inquiry because scientific disciplines are based on observations of the physical world. (M015, pre-questionnaire)

“The Scientific Method”

One of the most widely held misconceptions about science is the existence of “The Scientific Method.” This misconception entails that there *is* a recipe-like stepwise procedure that all scientists follow when they “do” science. This notion was explicitly debunked by the *National Science Education Standards* (NRC, 1996) and *Benchmarks for Science Literacy* (AAAS, 1993). There is no single “Scientific Method” (Shapin, 1996). Scientists observe, compare, measure, test, speculate, hypothesize, create ideas and conceptual tools, and construct theories and explanations. Scientists, however, do not follow a cookbook method when they investigate a problem (Lederman, Farber, Abd-El-Khalick, & Bell, 1998).

The NOS questionnaire made no references whatsoever to the phrase “The Scientific Method.” None of the questionnaire items directly elicited respondents’ views regarding the notion of the existence of a single scientific method.

Views of participants enrolled in the HOS courses.

In their responses to the questionnaire and especially to the first item, 10% of all participants enrolled in the HOS courses indicated that science is characterized by the existence of “The Scientific Method” as illustrated by the following representative quotes:

> I think that science differs from religion and philosophy in that it has the scientific method. (S062, pre-questionnaire)

> Science can only proceed really one question at a time and . . . to do science one has to follow the scientific method. (E153, pre-questionnaire)
>
> Science has a particular method of going about things, the scientific method. (E116, pre-questionnaire)

An additional 14% of participants noted that science was typified by a set of orderly steps and rules or a systematic, structured, rigid, standardized, or logical method:

> The key to the difference between science and other inquires, is that science follows a rigid set of rules. (S054, pre-questionnaire)
>
> I think what makes science different from other disciplines of inquiry is the fact that . . . science . . . is a very regimented discipline. It really is very inflexible. (E083, pre-questionnaire)
>
> Science is different from other disciplines of inquiry because there is a very structured and methodical way that scientists follow. (C168, pre-questionnaire)

The particular steps that participants assigned to this "common method," "logical standardized method," "rigid process," or "The Scientific Method," were somewhat different. Participants' characterizations, nonetheless, distilled to one or another set of orderly steps as evident in the following representative quotes:

> Observation, listing all the alternative hypotheses for that observation, experimental design, eliminating alternative hypotheses, execution of the experiment, and then analysis and finally trying to reach a conclusion. (S062, pre-interview)
>
> There is, you know, a set way to do things. You come up with a question and you go from there to developing a hypothesis, from there you go to testing the hypothesis, and then you reach a conclusion and evaluate your hypothesis. (E138, pre-interview)
>
> If you want to study something . . . you look at a certain aspect of it, make a hypothesis about something, you set up an experiment in which you collect data, you do your experiment, get your data and analyze it and see what that

> tells you about your hypothesis. And then you recheck it and recheck it and submit it to everyone else and they recheck it to prove you right or wrong. (C171, pre-interview)

As such, without any prompts, 34 out of 141 respondents (24%) enrolled in the three HOS courses believed that scientists follow a single method during their investigations. Only 1 out of those 141 participants did not embrace this misconception. This student indicated in her pre-instruction questionnaire that "science has no single method, rather, it relies on the creativity of the investigator to find ways to answer his/her question" (ES01).

During the semi-structured interviews conducted at the beginning of Fall term with students in the first random sub-sample, interviewees were explicitly asked whether they thought scientists use a single method or step-wise procedure when they do science. A sizable majority of interviewees (73%) indicated that scientists follow "The Scientific Method" or other sets of logical and orderly procedures. An additional 12% of interviewees noted that scientists do not use a single method. However, further probing of this initial response indicated that these latter participants still believed in a general overarching method. Rather than holding the view that there is no one step-wise recipe for doing science, these participants seemed to believe that scientific investigations only differ in the types and specifics of the *experiments* that scientists conduct:

> Technically, I don't think that there is a definite universal method. I mean, of course there is. They ask a question, they try it out if it works, and then they go to the next step. But if you are talking more specifically about how they do a specific *experiment* [italics added], then that is open to a lot of differences in how they do things. (S020, pre-interview)

> I think everyone has their own probably different method . . . and they are not going to do a method that they are not comfortable with. I think that it is

> totally based on the individual doing the *experiment* [italics added]. Everyone is going to have their own different steps and different procedures. (S030, pre-interview)
>
> Probably not all scientists [use the same method], I think there is lots of variations in the *experiments* [italics added] scientists do. But there is some sort of general, you know they have to come up with an idea in their head and then think what they can do about it, and then design an experiment and actually doing it and collect the results then go on from there. (E145, pre-interview)

As such, when specifically asked, the larger majority of participants (85%) seemed to believe in a single scientific method. Only 15% of all interviewees thought that scientists do not follow a specific method. Some believed that there are discrepancies between the way science is portrayed in scientific reports and the way scientific work is actually conducted:

> Not all [scientists use the same method], I worked in a lab and when it came to the written part, yes. But in other things, our conversations and the general studies, no. (E066, pre-interview)
>
> No [scientists do not use the same method]. You know when you are in sixth grade you learn that here is the scientific method and the first thing you do this, and the second thing you do that and so on so forth. That's how we may say we do science, but there is a difference between the way we say we do science and the way that we actually do science. (E163, pre-interview)

One respondent noted that scientists are creative and resort to different methods when they do science:

> No [scientists do not use the same method] just because of creativity . . . you know, everybody has some creativity when doing something and that would create some variety in the way that different scientists do science. (C177, pre-interview)

Views of preservice science teachers.

In their responses to the NOS questionnaire, 4 out of 15 preservice teachers (27%) noted that science is typified by the use of the scientific method:

> [Science] is a prescribed way of perceiving your surroundings. This prescription is called the scientific method. (M018, pre-questionnaire)
>
> Science is based on information that has undergone the scientific method of proof. (ME06, pre-questionnaire)

When specifically asked during the pre-instruction interviews, only 1 out of 8 student teachers (12.5%) indicated that there is a single scientific method. The remaining seven student teachers held the view that there is "not a certain method to go about . . . research, obviously." (M017, pre-interview). Many preservice teachers clearly explicated this latter notion as evident in the following representative quote:

> There is no one way to doing things . . . I mean in reality sometimes you start with the end and work back. Sometimes you can start with a theory . . . or you can start with an observation and develop a theory from, you can go that way. And you can probably start in the middle and go either way. (ME10, pre-interview)

As such, an equal percentage (about 25%) of participants enrolled in the HOS courses and preservice teachers indicated that science is characterized by the use of a single method on the NOS questionnaire. However, compared to 85% of participants enrolled in the HOS courses, only a minority of preservice teachers (12.5%) expressed this view when specifically asked during the pre-instruction interviews.

The Experimental Approach

The second item on the NOS questionnaire asked participants to define an "experiment." The question was open-ended and did not specify a certain type of experiment or class of experiments, such as laboratory, field, natural or crucial experiments (Diamond, 1986; Ziman, 1991). The third item asked participants whether they thought experiments were *required* for the development of scientific knowledge. These two items were to be used in combination with the intent of exploring whether participants equate scientific investigation with the experimental method which is often erroneously labeled "The Scientific Method" in many high school and introductory college level science textbooks (e.g., Curtis & Barnes, 1985; Emiliani, Knight, & Handwerker, 1989; Hewitt, 1998; Hill & Petrucci, 1996). Obviously, the meaning that participants attach to the term "experiment" was crucial to a valid interpretation of their responses to the third item. Hence the second item. Nonetheless, participants' views of the experimental approach and the logic of experiments were not the primary focus of this part of the NOS questionnaire. Analysis of participants' responses to these two items, however, unveiled some misconceptions regarding experiments and the experimental approach that are worthwhile exploring.

Commonly, experiments are distinguished from observations (Bernard, 1957; Harre, 1983; Ziman, 1991). Unlike observations, experiments generally involve elements of control and manipulation of, and intervention in the course of the investigated phenomena. "Experimenters describe their activities in terms of the separation and manipulation of dependant and independent variables" (Harre, 1983, p. 15). Some might argue, and rightly so, that not all experiments involve manipulation. However, in the very least, an experiment should involve "*contrived observation, carried out under controlled, reproducible conditions* [italics in original]" (Ziman, 1991, p. 56). Experiments and observations, nonetheless, are similar in that both experimenters and observers must have a prior conceptual framework with which to make sense of the outcome of their experiments, and perceive and describe their observations.

Views of participants enrolled in the HOS courses.

Participants' characterizations of experiments were mostly general and poorly articulated. Out of 141 participants enrolled in the HOS courses, 29 noted that an experiment involves observation or the collection of data or information. No reference was made to the contrived, manipulative or controlled nature of experiments. Also, these 29 participants either did not articulate a clear aim for experiments or merely noted that experiments aim to "test" hypotheses or theories:

> An experiment is a way to test a hypothesis based on an observation. (E156, pre-questionnaire)
>
> An experiment is a method by which one could test a theory or hypothesis on something by gathering data. (S047, pre-questionnaire)
>
> An experiment is a scientific method used to obtain data about a certain topic. (E145, pre-questionnaire)

Another 52 participants did not mention that an experiment involves controlling or manipulating some aspects of the investigated phenomenon. However, they noted that an experiment is a test (tool, attempt, project or process) that aims to "prove" or disprove a hypothesis or theory:

> An experiment is a series of steps which seek to either prove or disprove a hypothesis. (E093, pre-questionnaire)

> An experiment is a test used to prove or disprove a theory. (S048, pre-questionnaire)

> An experiment is a sequence of steps performed in order to prove a proposed theory. (C179, pre-questionnaire)

Ten more participants thought that experiments are intended to decide whether a hypothesis or theory is true or false (or right or wrong):

> An experiment is a test of a theory. It determines if a theory is right or wrong. (E068, pre-questionnaire)

> An experiment is testing a hypothesis or theory to see if you are wrong or right. (S046, pre-questionnaire)

> An experiment seeks to answer questions concerning a particular subject. It seeks to prove whether the ideas one may have about the subject are true or false. (C176, pre-questionnaire)

Six participants noted that experiments aim to validate or invalidate a proposed hypothesis. These participants, however, did not allude to the manipulative or controlled nature of experiments:

> An experiment is a method of testing the validity of invalidity of a hypothesis. (C169, pre-questionnaire)

> An experiment is used to support or falsify a hypothesis that is proposed to explain some phenomenon. (E131, pre-interview)

> An experiment is the means by which a person can test the validity of a hypothesis and a hypothesis can be extrapolated to support a theory. (E076, pre-questionnaire)

Eighteen participants indicated that experiments involve manipulation or control but failed to articulate an aim for conducting those experiments:

> [An experiment is] a study in which experimental units are manipulated by the application of a treatment in order to measure the response of the units to the treatment. (E088, pre-questionnaire)
>
> [An experiment is] an observable study where what is being studied can be viewed, manipulated, controlled, rearranged for further understanding of it. (S023, pre-questionnaire)
> An experiment includes a control and then your "experimental" group where the element you're studying is changed. Both environments should be equal. (C175, pre-questionnaire)

These latter 18 participants seemed to understand the general structure of an experiment. However, their responses could not be taken to indicate that they understood the general goal of experiments. This last inference is reinforced by the fact that 10 other participants thought that experiments involve some sort of manipulation or control of natural phenomena but indicated that experiments aim to "prove" hypotheses or theories or show that a scientific claim is true or not:

> An experiment is a test, often done in the laboratory, to prove or disprove a scientific hypothesis . . . A true experiment is manipulative and involves dependent and independent variables. (C183, pre-questionnaire)
>
> An experiment is a test. It is artificial. One [performs] . . . experiments to discover if a hypothesis is true or not. (S035, pre-questionnaire)
>
> An experiment is a study in which a parameter is introduced so the outcome can be analyzed to prove or disprove a hypothesis. (E132, pre-questionnaire)

A small minority of participants (11%) illustrated in their responses to the NOS questionnaire clear understandings of the general intent and structure of scientific experiments as evident in the following representative quotes:

> An experiment is a controlled way to test and manipulate the objects of interest while keeping all other factors the same. When only one factor at a time is changed or manipulated, the observed result can lead the scientist to assume the factor has either a positive or negative or (none) correlation with the outcome . . . It is the result of an experiment that will lead the scientist to believe his/her theory has or doesn't have validity. (S055, pre-questionnaire)

> An experiment is a controlled approach to test the validity of a theory. No experiment can ever fully validate a theory as fact, and so experiments are constantly refined in an attempt to elucidate the implications of a theory as well as possible. (E119, pre-questionnaire)

> An experiment is a task designed to test the validity of a given hypothesis which is formulated as a potential explanation for observed phenomena. It often simulates proposed conditions in which the phenomena exist to see if the phenomena behave as predicted. (CS03, pre-questionnaire)

It is noteworthy that only two participants indicated that experiments cannot "prove" a scientific claim, two others noted that experiments could help uncover cause-effect relationships, and one of the latter two participants noted that an experiment specifically aims to reject the null-hypothesis:

> An experiment is a specific set of methods being used to test or to disprove a theory. When conducting an experiment, a control group must be used. An experiment cannot prove a theory, only disprove the opposite of the theory. (S024, pre-questionnaire)

> An experiment is a process that you technically nullify or attempt to nullify a hypothesis . . . An experiment has certain elements like a control and an aspect that you can vary, that is, a variable that you manipulate, an independent and maybe more than one dependent variables . . . [Experiments can] demonstrate that there is cause and effect between two variables. (E132, pre-questionnaire)

As noted earlier, 52 participants used general terms, such as "test," "procedure," "process" or "activity" to characterize experiments. Thirteen of these participants were among the students who were randomly chosen for the pre-instruction interviews. During the interviews, these participants were specifically asked whether they thought experiments involve elements of control or manipulation. A sizable majority (77%) indicated that control and/or manipulation are not crucial in experiments. These 10 participants were either too inclusive in their definitions of experiments and/or did not discriminate between observations and experiments as evident in the following representative quotes:

> Experiment is everything that involves the act of collecting data and not necessarily manipulation. (E125, pre-interview)
>
> An experiment is, and it doesn't have to be manipulative . . . it is just a way of how we look at things, of actually, just rather than looking at the numbers, go out and experimenting. It is another way of using the senses to gain knowledge. (S043, pre-interview)
>
> I would think [an experiment] does not always involve manipulation. I don't know, maybe if we were doing observational stuff of some naturally occurring thing . . . then we will not be manipulating this. We will be just seeing the behavior. (E153, pre-interview)

The remaining three interviewees noted that experiments involve some control or manipulation. They were able to elucidate clear understandings of the difference between observation and experiment and of the significance of manipulating variables during experiments:

> I think an experiment is something where the experimenter actually manipulates the environment. It differs from observation where you just sit there and you observe what is going on. Whereas in an experiment you actually manipulate, you remove something, you add something, you change the environment. (S030, pre-interview)
>
> An experiment is a task designed to test a given hypothesis. You set up an experiment to test this. You introduce parameters and you introduce a variable that you can control and see. (C176, pre-interview)

Interviewees were representative of participants enrolled in the HOS courses. As such, it can be assumed that 12 out of the 52 participants who used general terms to characterize an experiment believe that experiments involve elements of control or manipulation.

To sum up, a majority of participants (54%) did not ascribe any element of control, manipulation or intervention to experiments. More than one-third of participants (35%) did not articulate a clear aim for experiments and about one-half of participants (51%) believed that experiments could provide *definitive* answers regarding the "truth" of hypotheses or theories. Put together, the responses of an overwhelming majority of participants (81%) did not illustrate clear understandings of the general aim and/or structure of scientific experiments.

The role of prior expectations in designing an experiment and the importance of having a conceptual framework with which to discern and interpret the results of an experiment are too well known to be reiterated here. Harre (1983) noted that "without some prior idea of what might be there to be found out we would not know what to look for in the results of our experiments, nor would we be able to recognize it when we had found it" (p. 5). To assess participants' understandings of this crucial aspect of experiments they were asked during the pre-interviews whether scientists usually have an idea about the outcome when they perform controlled or manipulative experiments.

More than one-half of the participants (54%) did not demonstrate adequate understandings of the role of prior expectations in experimentation. Many participants thought that scientists do not usually have an idea about the outcome of an experiment unless similar experiments have been conducted before:

> I think that is depends on what the experiment is. For instance I worked in genetics and molecular techniques and I know that they expect some results. And so that is an area that has been studied, an area that has been known. And I would say that something not as quite well known you would probably have to do the experiment to know what will turn out. (E133, pre-interview)
>
> I think that it could go either way. Maybe if you have done something like that in the past, then yes. Or you might have a kind of a guess . . . But sometimes, I mean you might not know. You might have a guess that might be so far off that you need to start over again. (C171, pre-interview)

Others thought that scientists usually have an idea about the outcome of experiments. However, they believed that such expectations are undesirable since they often tend to bias the results of experiments:

> Ideally, I would think that in a scientific experiment to be scientific and valid you should not have any bias or ideas in advance. But there have been experiments that were biased. So, you usually have some sort of idea but, you know, it should not tell what the results are. (E125, pre-interview)
>
> Well, human nature, we are biased toward things. You have to narrow down the field of what is going to happen given the initial variables. So, in a way, there has to be some amount of bias, but not towards any particular aspect of the experiment. (E093, pre-interview)

Another 18% of participants indicated that hypotheses are guesses about the expected outcome of experiments. In that sense, scientists usually have an idea about those outcomes. These participants, nonetheless, did not seem to understand the significance of these “guesses” in developing and conducting the experiments:

> If you have a hypothesis you would probably have a reasonable guess as to what the outcome would be. But it does not always come out like that. (E096, pre-interview)

> You form a hypothesis about what, and then you can test the hypothesis which is what you expect to happen. So, you do have a hypothesis. (S030, pre-interview)

Only about one third of participants (28%) explicated a clear understanding of the necessity of having prior ideas when designing and conducting scientific experiments:

> I think that generally you design and conduct an experiment because you have a certain outcome, so we are designing an experiment to see if that outcome will happen. (S024, pre-interview)
>
> For the most part if you are going to organize the experiment you sort of need to know what you are looking for. I always think that they have some kind of idea . . . They will have an idea of where the results would lie, they kind of know that things will be in this area . . . 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)

The third item on the NOS questionnaire asked participants whether they thought experiments are *required* for the development of scientific knowledge. The item explicitly asked respondents to provide an example supporting their view on this issue. The item aimed to assess whether students equate scientific investigation with manipulation and experimentation or whether they realize that several scientific disciplines are mostly based on observation of phenomena.

As noted earlier, 56% of participants did not ascribe any elements of control or manipulation to experiments. Some of these participants believed that experiments are equivalent to observation or data gathering. Others characterized experiments in general terms as being "tests" for scientific claims. As such, it was natural for these participants to indicate that the development of scientific knowledge does indeed require experiments.

These participants' responses, however, are not useful for the purposes of the present analysis. These responses are more likely a reflection of participants' misunderstanding of the nature of experiments than a view regarding the necessity of experiments in the development of scientific knowledge. Nonetheless, it is noteworthy that the larger majority of these participants (80%) did not provide any examples to defend the position that experiments are required for developing scientific knowledge.

Sixty-two participants indicated that experiments involve control and/or manipulation of the investigated phenomena. More than one-third of these participants (36%) indicated that experiments are required for the development of scientific knowledge. Many believed that observation is not enough to produce valid scientific claims:

> Scientific knowledge requires experiments. A phenomenon is observed and conclusions are drawn from these observations. From these conclusions, hypotheses are made which can be tested. Experiments are then necessary to validate hypotheses . . . Only supported hypotheses can be viewed as true scientific knowledge. (E138, pre-questionnaire)
>
> Yes, even the most theoretical of disciplines, theoretical physics, requires experiments for verification of theory such as relativity. (S043, pre-questionnaire)
>
> Yes, science would not exist without scientific procedure which is solely based on experiments . . . The development of knowledge can only be attained through precise experiments. (E116, pre-questionnaire)

The majority of these latter participants (73%) did not provide any examples to support their view as evident in the above quotes. The minority that did mostly provided examples that were related to experimental medicine and testing new drugs as noted in the following representative quotes:

> I believe that the development of scientific knowledge does require experiments . . . For example, in discovering a cure for a disease, experiments need to be done to see if the cure works. (E167, pre-questionnaire)
>
> Yes, developing scientific knowledge requires experiments . . . Example: To determine if a particular drug is causing a negative reaction within the body, the drug must be tested under many conditions, with a control and a variety of variables. (S024, pre-questionnaire)

Out of 141 participants enrolled in the HOS courses, 40 (28%) indicated that manipulative experiments are not required for the development of scientific knowledge. Thirty-six of these participants provided examples that indicated a clear understanding of the fact that several scientific disciplines are observational in nature and that many powerful scientific theories rest solely on observations:

> Experiments are . . . not the only way of acquiring scientific knowledge. Another way of developing scientific knowledge is by observational learning. In this method there is no manipulation of factors. It is simply observing the activities and properties of the subject as it occurs naturally . . . such as recording all fossils found at a site to come up with a theory on population density of a particular species at that time. (S055, pre-questionnaire)
>
> No . . . experiments are not absolutely crucial, especially if there is no way to do an experiment. For example, . . . astronomy does not really involve experiments, per se, but it does prove itself with telescopic observations. (C183, pre-questionnaire)
>
> No. A good example, I think is Darwin's theory of evolution . . . [This theory] cannot be directly tested experimentally. Yet, because of observed data, such as fossils and rock formations, it has become virtually the lynchpin of modern biology. (CS03, pre-questionnaire)

Views of preservice science teachers.

The majority of participant student teachers (67%) did not demonstrate adequate understandings of the nature of experiments. Eight participants did not ascribe elements of control or manipulation to experiments. Some of these preservice teachers indicated that experiments are equivalent to observation and data gathering. Others typified an experiment in very broad terms as a procedure or method to test ideas and hypotheses or to "learn" about things:

> Basically an experiment is where you collect data and make observations to see how something behaves. (ME05, pre-interview)
>
> An experiment is a tangible hands-on approach used . . . as a test for hypotheses and theories. (ME13, pre-questionnaire)
>
> [An experiment] is a method to learn more about something that you don't know enough about. (ME11, pre-questionnaire)

Two other student teachers noted that experiments are often controlled and/or manipulative. However, they believed that experiments aim to "prove" scientific claims as evident in the following quotation:

> Experiments . . . consist of an experimental setup and a control setup. A simple basic experiment would have a question or hypothesis and the experimental setup has one different variable than the control setup. The difference in the results are [sic] then attributed to that one variable . . . We perform experiments to prove or disprove the question. (M018, pre-questionnaire)

The remaining five preservice teachers (33%) demonstrated more adequate understandings of the structure and aim of scientific experiments. These participants were clear on the differences between observation and experimentation. They also noted that experiments could not provide definitive answers to investigated hypotheses or questions:

> An experiment is a test where one or more factors is deliberately changed to observe the outcome. Controls are necessary for experimentation . . . It is different from observation. Like in observation you just go and observe birds feeding in their habitat but you don't end up making an actual change like introducing a new species and seeing how they would interact with each other . . . Scientists need experiments to back up their claims. (M016, pre-interview)
>
> The purpose of a controlled experiment is to either provide evidence for an assumption or idea or to show the shortcomings of a proposed model. Although an experiment can provide support for a proposed hypothesis, an experiment can never prove an idea or model to be true, it can only prove an idea to be invalid. (ME04, pre-questionnaire)

Only a minority of preservice teachers (25%) understood the importance of having expectations prior to conducting experiments as evident in the following quotation:

> I think in my opinion an experiment is planning ahead of time. Thinking what is going to be controlled, what am I trying to test, what don't I want to test, how can I not test the things that I don't want to test, and how can I design the test . . . I think it is something that is pre-thought ahead of time with expected results rather than being something haphazard. (ME04, pre-interview)

The majority of student teachers (75%) did not demonstrate adequate understandings of the crucial role of having prior expectations. Some thought that at times scientists might have such expectations, while at other times they might not:

> Well, I think from my experience that they are going to have a hope of what the outcome is going to be. But again in some cases they have no clue and they don't know, you don't necessarily have to know, you probably, I don't know. (M017, pre-interview)

> I think you usually do have some idea. And hopefully you don't try to find what your idea is. But you don't always have an idea. I think you usually do but you don't, it is not necessary to have an idea always. (ME05, pre-interview)

Others indicated that scientists often have expectations. However, these student teachers indicated that expectations are not desirable since they usually bias the scientists and lead them to manipulate experimental results in order to fit their expectations:

> You have an idea of what you expect and sometimes they manipulate their data to fit that hypothesis. Because I think everybody is biased in going into an experiment from what they expect. And if it does not work out, they will do it again and again and again till it works out . . . But I think the good scientist is open-minded and . . . will not manipulate the data that do not fit their description. (M016, pre-interview)

As noted earlier, only 7 of 15 preservice teachers noted that experiments involve elements of control or manipulation. Six of these student teachers (86%) indicated that experiments are required for the development of scientific knowledge. Many specifically indicated that observations are not enough for generating valid scientific claims:

> Yes, the development of scientific knowledge requires experiments . . . We perform experiments to prove or disprove hypotheses. If we do not perform these experiments properly or just make observations, the conclusions are not accepted by the scientific community. (ME08, pre-interview)
>
> Yes, [the development of scientific knowledge] does require experiments. I think all hypotheses, you need . . . hard evidence to back up what you are saying. If it is just based on observation, if you want to take it to the next level I think you need to do experiments just to convince yourself and to convince other people that it is not just a shot in the dark. (M016, pre-interview)

It is noteworthy that 3 of these 6 preservice teachers did not provide any examples to support their view. The two who did, furnished inadequate examples. These latter two student teachers chose examples from the disciplines of astronomy and anatomy to support their position that valid scientific knowledge can only be based on experiments. Ironically, astronomy and anatomy are the two most commonly cited *observational* disciplines to illustrate the opposite view; that valid scientific claims can also be derived from observations of natural phenomena. One participant's example was an inadequate account of the shift from a geocentric to a heliocentric cosmology. The other noted that experiments are needed to determine the structure of body organs:

> The geocentric theory of celestial motion was presented and subjected to tests . . . Since the alternative theory of heliocentric celestial motion has held up so well to the same testing without substantial modification, the geocentric theory has been neglected. To put the nail into the coffin, experiments were conducted with new interplanetary perspectives that have "disproven" geocentrism. (M014, pre-questionnaire)
>
> For example, the determination of an organ's structure (i.e., kidney) cannot be done without at least a crude experiment. (ME04, pre-questionnaire)

Only one student teacher who demonstrated a clear understanding of experiments noted that the development of scientific knowledge does not require experiments. This participant also provided an adequate example to support her view:

> No scientific knowledge comes from observation. This observation may or may not come from experimentation. The laws of planetary motion are an example of scientific knowledge. This knowledge has come through observation . . . and trying different mathematical models with paper + pencil. It's pretty difficult to manipulate the motion of planets. (M017, pre-questionnaire)

As such, it can be seen that preservice teachers' understandings of the structure and goal of experiments, the role of prior expectations in designing and conducting experiments, and the validity of observationally-based scientific claims are not different from those of participants enrolled in the HOS courses. The majority of participants in both groups did not demonstrate adequate understandings of these aspects of science. It is noteworthy, that experiments were not among the aspects of the NOS that were addressed in the Summer Science Methods course in which preservice teachers were enrolled prior to their participation in the present study.

Scientific Theories

Scientific theories are well-established, highly substantiated, internally consistent systems of explanations (Suppe, 1977). Theories serve to explain relatively huge sets of seemingly unrelated observations in more than one field of investigation. More importantly, theories play a major role in generating research problems and guiding future investigations.

Scientific theories are often based on a set of assumptions or axioms and often posit the existence of non-observable entities. As such, theories can not be *directly* tested. Only indirect evidence can be used to support theories and establish their validity. To test theories (or hypotheses), scientists derive specific testable predictions from those theories (or hypotheses) and check them against tangible data. An agreement between such predictions and empirical evidence serves to increase the level of confidence in the tested theory (or hypothesis).

Science is tentative and never absolute. As such, the different types of scientific knowledge including “facts,” theories, and laws change. Theories change as new evidence, made possible through advances in *theory* and technology, is brought to bear on existing theories, or as old evidence is reinterpreted in the light of new theoretical advances or shifts in the directions of established research programs.

Views of participants enrolled in the HOS courses.

The fourth item on the NOS questionnaire asked participants whether scientific theories change and the reasons behind such change. Only a small minority of participants (16%) indicated that theories do not change. These participants believed that the original theory might be refined, elaborated or extended. The theory itself, however, does not change:

> No, I believe scientific theories do not change. The fundamental view stays the same, but as new information is found new light is brought into the picture and an addendum can be made to the theory . . . Therefore the theory doesn't really change. (E133, pre-questionnaire)
>
> Some theories are modified, some are not. We update old theories by incorporating new information into them. I think some of the new information supplements old info and thus alters the theory. (S025, pre-questionnaire)
>
> I believe that most of the time they [theories] do *not* change because they are basic theories that will only accept *alterations* [italics in original]. (E070, pre-questionnaire)

The greater majority of participants (77%) indicated that theories do change. Almost all participants (94%) attributed this change *solely* to *new* information, discoveries, or experiments and advances in technology as evident in the following representative quotes:

> Scientific theories do change as more knowledge and technology becomes available. (S049, pre-questionnaire)
>
> Theories change over time with new information and technological advances which allow increased accuracy in experimentation. (C179, pre-questionnaire)
>
> Scientific theories can and do change. Theories change as technology improves allowing more in depth research and as new discoveries are made. (E082, pre-questionnaire)

A surprisingly small minority of participants (6%) did not attribute theory change *solely* to new information and technologies. These participants, and rightly so, noted that other factors play as much a significant role in theory change as do new data and technologies. The advancement of new ideas and theories, social and cultural change, and the role of individuals working "out of context" were among the factors that these participants believed contribute to theory change:

> Theories change because one person or a group of people act out, they act out of context basically. Often times their ideas come from people, like a new idea in microbiology might come from a person who has never taken a course in microbiology, an outsider or someone who is just remarkable in the way that they do science and are able to act out of context. I think individuals can have a tremendous influence . . . Also, the reasons we accept or reject theories are so much tied to context in a historical and social-political way. So, to a certain extent we are going to accept the theory that harmonizes with that perspective at the time. (E155, pre-interview)
>
> Theories either often change or constantly change (depending on your point of view), sometimes slowly, sometimes more rapidly. A theory . . . will explain the vast majority (but never all) of the phenomena that the theory is supposed to cover. New data will either strengthen or weaken the acceptance of the theory depending of the "fit" of the data with the theory. Eventually a modification of the theory *or an entirely new theory* [italics added] will "fit" the data better and the old theory will be neglected. (C173, pre-questionnaire)
>
> Theories do change because of new data and because of changing ideas and societies' view of the world changes. (E087, pre-questionnaire)

Of the participants who indicated that theories do change, more than one-half (54%) did not provide an example to support their view even though the NOS questionnaire explicitly asked respondents to provide such examples. Another 21% of participants provided inadequate examples to substantiate the position that theories do change with time. Their examples were either historically inaccurate or included ideas or claims that could not be accurately labeled as scientific theories:

> Yes, theories do change. The theory about the position of the planets was changed by Copernicus when he *observed* [italics added] that the Sun, not the Earth, was the center of the solar system. (S042, pre-questionnaire)
>
> I believe scientific theories do change. They change due to more knowledge about the subject. An example would be that cheetahs were believed to have a declining genetic pool. Now scientists believe it could be predation from lions and hyenas that are causing cheetah population declines. (E157, pre-questionnaire)
>
> I believe that theories do change. There was a point in time when scientists believed that the earth was flat. That theory changed as people gained knowledge through exploration and realized that the earth was in fact round. (E140, pre-questionnaire)

Only about 25% of participants who indicated that theories do change provided adequate examples. Evolution theory and atomic theory were the two most commonly cited examples of theory change. These two theories accounted for 51% and 23% of all the examples provided by participants respectively. It is noteworthy that both these theories were mentioned in the item on the NOS questionnaire that asked whether scientific theories change. Other examples of theory change came from geology, such as the shift to plate tectonics theory, and biology, such as the rejection of the theory of spontaneous generation. The shift from a geocentric to a heliocentric cosmology was the example most commonly cited from the discipline of astronomy:

> Yes, they [theories] do change. Scientists continue to test a theory put forward at one time like when they developed the model of the atom. When they had new information that no longer fits the theory they had to change it. (C172, pre-questionnaire)
>
> Theories can and do change as time goes on . . . For example, Nicolas Copernicus was not satisfied with the accepted Ptolemaic theory of his day that it was the Earth that sat in the middle of our solar system. Through years of toying with Ptolemy's theory Copernicus was more or less able to shed light on some of the inconsistencies of Ptolemy's theory which, in turn, led us to the modern day understanding of a heliocentric solar system. (S047, pre-questionnaire)
>
> Scientific theories change as new evidence is discovered or obtained through experimentation. Today's theory of evolution is not the same as in Darwin's day, because there has been so many advances made in various areas of science like genetics since the 19th century. (E159, pre-questionnaire)

Participants' responses to the third item on the NOS questionnaire revealed other misconceptions about the nature of scientific theories. The responses of about 37% of all participants indicated that they do not recognize that theories are elaborate and well substantiated systems of explanations. Many of these participants believed that a scientific theory is "just a theory" in the vernacular sense of the word. Participants indicated that a theory is simply a guess or someone's idea about what occurred or might occur:

> A scientific theory is just that–a theory. It is just a guess as to what might have possibly happened or what might happen. (S040, pre-questionnaire)
>
> A scientific theory is just that, an idea about how something works. (C172, pre-questionnaire)
>
> Theories are just that, one person's view or thought on what occurred. (E091, pre-questionnaire)

Many others believed that scientific theories are untested ideas or speculations that lack empirical support:

> A theory is an untested idea, or an idea that is undergoing additional tests, Generally it hasn't been proved to the satisfaction of the scientific community. (S054, pre-questionnaire)
>
> Theories are true as far as we know, but there aren't enough facts to back them up. (E079, pre-questionnaire)
> In my opinion theories are still speculation and can be altered because there's still not enough evidence for them. (E095, pre-questionnaire)

These misunderstandings of the nature of scientific theories seem to be rooted in yet another misconception. The responses of the greater majority of these latter participants to the third and fourth items on the NOS questionnaire indicated a lack of an adequate understanding of the nature or logic of testing scientific theories. Many participants did not seem to understand that theories could only be tested indirectly through checking predictions derived from theories against empirical evidence. Participants insisted that theories could only be tested through the collection of "direct" evidence:

> 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, pre-questionnaire)
>
> Theories of origin can't be backed up by evidence. No one was there to see what happened. There is no written record of what happened and scientists can't go back in time to see what happened and test the theory. (S049, pre-questionnaire)
>
> Many theories can't be completely tested, e.g. the theory of evolution can't be tested unless you create your own world and then live for millions of years. (E167, pre-questionnaire)

The responses of very few participants (4%) indicated an adequate understanding of the well-supported nature of scientific theories as evident in the following quotation:

> In the vocabulary of a scientist the word theory is used differently than in the general population. It does not mean someone's idea that can't be proven. It is a concept that has considerable evidence behind it and has endured the attempts to disprove it. (E137, pre-questionnaire)

The third item on the NOS questionnaire also asked participants why we bother to learn about scientific theories if they are going to change. This question aimed to assess participants' understandings of the role that theories play in providing explanations of the workings of natural phenomena, generating viable research programs, and guiding further investigations. To further assess their understandings of the function of theories as guiding frameworks for research, participants were asked during the pre-instruction interviews "Which comes first when scientists conduct scientific investigations, theory or observation?"

More than one-third of participants (36%) recognized the explanatory function of scientific theories. These participants noted that scientific theories help us explain or are the "best current explanations" for natural phenomena as evident in the following quotes:

> We learn scientific theories to help us explain what we know with the evidence we have available. (S026, pre-questionnaire)
>
> We bother to learn scientific theories because at the present time they are most accurate explanations using the most available resources. (C179, pre-questionnaire)
>
> I think we learn scientific theories because they explain so much and incorporate so many other theories and info into one package. (S025, pre-questionnaire)

Another 24% of participants noted that we strive to learn about scientific theories because of our desire to know or understand or because theories are informative:

> We learn scientific theories because they give us knowledge about the world around us. (E068, pre-questionnaire)
>
> We learn about scientific theories . . . because it is our nature and genetic make up to seek knowledge. (C180, pre-questionnaire)
>
> We bother to learn about scientific theories because mankind is curious and has been driven by science since the beginning. (E147, pre-questionnaire)

Another 27% of participants noted that theories serve as building blocks, springboards, stepping-stones or starting points for expanding our knowledge and understanding. Some participants indicated that knowledge of scientific theories allow scientists to refute them or to avoid reinventing the wheel:

> We learn scientific theories so that we have a "base" from which to develop. They are starting points, not end points. (S026, pre-questionnaire)
>
> We bother to learn scientific theories because they help us to understand things and they act as a stepping stone for new knowledge, (E099, pre-questionnaire)
>
> Theories change all the time . . . but this doesn't mean that the scientists have to start all over from the beginning their own new theories, rather they just can add to the old ideas. (E117, pre-questionnaire)
>
> It's important for us to learn currently accepted scientific theories so that we might . . . test them and find flaws in existing theories that may lead us toward new revised scientific knowledge. (S047, pre-questionnaire)

At first these latter quotes seem to reflect an understanding of the role of scientific theories as guiding frameworks for investigation. However, further probing during the interviews indicated that participants' responses were more indicative of a "knowledge builds on itself" or "building blocks need to rest on other blocks" view. Participants did not seem to understand that theories play an active role in generating research problems and guiding investigations:

> We have to start somewhere and we can learn from the mistakes, we can learn from what others did. And I think like most, a lot of theories, I think all of them have a bit of truth in them because people have made some observations. So, we have to start somewhere. (C171, pre-interview)
> You have at least to know the part that is known now and then you can go on, but if you don't know anything where are you going to go. The knowledge kind of builds on itself, so you have to have something so that you can progress. (E088, pre-interview)
>
> I think you have to have some sort of basis where to start from, you know. It is kind of; you can't build something unless you have some foundational blocks to add other block and another block on top of them. (S029, pre-interview)

This latter inference was reinforced by interviewees' responses to the question of which comes first when conducting scientific investigation, theory or observation. The question was general and respondents were not expected to provide a "right" answer. Rather, it was expected that participants would, at least, ponder over an answer. The overwhelming majority of participants (85%) indicated without any hesitation that observation comes first:

> Observation comes first. You see something and then you try to figure it out some way or the other and then you develop a theory about whatever is that you want to know about. (S040, pre-interview)
>
> I guess observation [comes first] because you observe things and then your ideas are created from your observation. (C176, pre-interview)
>
> I think observation [comes first]. I think most scientists start out as children looking at the world and asking how does this thing grow and where did it come from and then build theories from their observations. (E166, pre-interview)

A few interviewees (15%) pondered the question for a minute before they noted that it is kind of the "egg and chicken" story. They noted that it could go either way. As such, these participants realized, at least, that investigation could be triggered by scientific theories:

> Well, I don't know if I can answer that. That is almost like the chicken and the egg thing. I mean you can observe something and make a theory from it. Or you think about something and then try to look at the data and see how it fits it. Let's take relativity theory. Theoretical physics often starts with a general principle and then looks at the data rather than record data first. Depending on your perspective they can be reversed. (CS03, pre-interview)
>
> I think that it could either way. I think that it goes either way and I haven't done much scientific research myself to know which follows which most of the time. From what I have done and I have done some research and it was theory followed by observation. (E156, pre-interview)
>
> I think it can be either one some times. I think some times the theory comes first and then you look and see if you can find things that would support your theory. But probably more often you observe things and then develop a theory based on your observation. (E144, pre-interview)

Only a small minority of all participants (13%) seemed to appreciate the significant role that theories play as general guiding frameworks for scientific investigation as evident in the following quotes:

> We learn theories because a theory becomes a guide or a tool for discovering new things. It is a method of focusing your inquiry on some particular problem rather than a more random study. (E144, pre-questionnaire)
>
> The reasons for learning these theories are, among others, the way in which a theory will point to ways of gathering new data, and that a theory allows one to have an overall framework upon which to hang these discrete and otherwise unconnected data. (C173, pre-questionnaire)
>
> Theories set a framework of general explanation upon which specific hypotheses are developed. Theories, even if temporary, advance the pool of

> knowledge by stimulating hypotheses and research, which may support the current theory or lead to new theories. (E088, pre-questionnaire)

As such, the greater majority of participants (77%) indicated that theories do change. However, 75% of participants did not provide examples or provided inadequate examples to substantiate the position that theories change with time. Almost all participants attributed theory change *solely* to new information and technologies. Only 6% of all participants recognized that new ideas and theories as well as social and cultural factors might also play a role in theory change. About 37% of all participants did not recognize that theories are substantiated systems of explanations. Only 4% of all participants demonstrated adequate understandings of the well-supported nature of scientific theories. A majority of participants lacked in their understanding of the nature of theory testing. Participants did not seem to understand that only indirect evidence could be used to support theories. Additionally, only one-third of the participants recognized the explanatory function of scientific theories. And only a small minority of all participants (13%) indicated that theories function as guiding frameworks for scientific investigation.

Views of preservice science teachers.

All participant student teachers indicated that scientific theories change. Like participants enrolled in the HOS courses, the greater majority of preservice teachers (80%) attributed theory change solely to new information and/or technological advances:

> Yes, theories change. We have better technologies today than we did even yesterday. New methods are constantly being discovered to see things that are infinitesimal in size or larger than life, yet far away. (ME06, pre-questionnaire)
>
> Scientific theories do change as new knowledge and supporting data is collected and/or discovered. (ME07, pre-questionnaire)

Only 3 of 15 preservice teachers noted that factors other than new information, discoveries, and technologies contribute to theory change. They indicated that theories might change due to the reinterpretation of extant data, new insights and perspectives, and changes in values:

> Theories change either because more evidence (data/observations) is taken, or because someone interprets existing data differently. (ME05, pre-questionnaire)
>
> Yes, theories change . . . There is always the possibility for new observations and *insights* [italics added] that can modify the way theories explain the universe. (M017, pre-questionnaire)
> Scientific theories are tentative, subject to change as knowledge, perspectives, and values change. (ME10, pre-questionnaire)

Two preservice teachers (13%) did not provide examples to support their view that theories change in time. Two other student teachers provided inadequate or contrived examples:

> Yes theories change . . . as technology & scientific knowledge advances & increases . . . For example if some day we discover a living organism w/out cells we will then disprove the cell theory which will then become worthless & be thrown out of the door. (M018, pre-questionnaire)
>
> Theories change, a case in point is when AIDS was discovered . . . it was called a different name and it was only believed to be transferred in homosexual relationships. Toady we know that this is not true. (ME06, pre-questionnaire)

The greater majority of preservice teachers (80%) provided adequate examples of theory change. Again, theory of evolution was the most commonly cited example of theory change:

> Yes [theories change]. For instance, the mechanism of evolution is a theory which has undergone change. Today the term "The Modern Synthesis" is used to describe Darwin's theory of natural selection along with more recent knowledge about the molecular basis for heredity. The topic of evolution is still an area of active research and the theory of evolution of today may change tomorrow. (M017, pre-questionnaire)
>
> Yes, theories change due to theory failing to explain an observed phenomenon . . . An example is the development and changes in the evolution theory as more information is collected. (M015, pre-questionnaire)

Compared to 37% of participants enrolled in the HOS courses, none of the preservice teachers indicated that scientific theories are "just theories" or guesses that lack empirical support. However, the responses of only two student teachers (13%) had explicit references to the well-supported nature of scientific theories as evident in the following quotes:

> The use of the word theory implies that the idea is well supported by various observations and is generally accepted in the scientific world. (M017, pre-questionnaire)
>
> The established theories in science are not just a bunch of hot air. They are supported by observations . . . They have merit and in most cases have withstood the test of time. (ME13, pre-questionnaire)

However, the responses of 20% of preservice teachers indicated that they do not understand the nature of testing scientific theories and hypotheses. Like their counter parts in the HOS courses, these preservice teachers did not seem to understand that only indirect evidence can be used to support theories and hypotheses:

> Take a theory, say gravity versus evolution theory . . . I think gravity, we can see its effects *directly* [italics added] in front of us . . . But I think like evolutionary theory on the other hand, the time process is so long. I don't have the observable side in the sense that I can put down, I can sit down and make the time and see it. Or within the frame of my existence I can actually see this thing I am observing. With evolutionary theory I think the time is so long that observations are limited to inference. (ME04, pre-interview)
>
> Like the extinction thing . . . It is not possible to test the extinction hypothesis, I mean we don't know for sure exactly why, we will never know because we weren't there at the time when the dinosaurs became extinct. I mean we did not *see* [italics added] how the dinosaurs became extinct. (M016, pre-interview)

The majority of preservice teacher (60%) recognized the explanatory function of scientific theories as evident in the following quotes:

> We bother to learn scientific theories because at the present time a theory is the best and most likely way to explain what is happening around us. (ME11, pre-questionnaire)
>
> Scientific theories are important to learn. They serve to explain lots of phenomena in the natural world. (M014, pre-questionnaire)

However, preservice teachers did not demonstrate adequate understandings of the role of theories in guiding scientific research. The greater majority of student teachers (87%) indicated that theories serve as building blocks, stepping-stones or starting points for advancing our knowledge:

> We learn scientific theories because they are the best available information at the time about science. They could be looked at as stepping stones to someday understanding the world. (ME12, pre-questionnaire)

> We need to learn what is the current knowledge available. It gives us a basis for understanding when the theories are challenged and then changed. (ME06, pre-questionnaire)

> We bother to learn about scientific theories because our understandings are based in the here and now . . . Now is the building block for tomorrow's understanding, w/out toady's understanding there can be no change for tomorrow. (ME08, pre-questionnaire)

These latter responses are similar to those mentioned by students enrolled in the HOS courses as justifications for learning scientific theories even though such theories are likely to change. Again, further probing of these responses during the pre-instruction interviews indicated that the meanings preservice teachers attach to "theories as stepping stones or bases" are not congruent with the notion that theories are guiding frameworks for research:

> Why we learn them [scientific theories] even though they change? This is my favorite question. I can't really justify it. I mean I want to learn them, and I think that most people want to learn them, because you need to have an explanation for what is going on. But I don't know if I can talk about using a theory to predict something. I guess, but that is like using a law to predict something, that is the thing. When I wrote that scientists could use a theory to predict something I came back to the ideal gas laws and something like that which is really just a law anyway. So why you need the kinetic molecular theory when it is just explaining something. I don't know. (ME04, pre-interview)

> We learn scientific theories because it is interesting . . . You want to know. And it is not innate, like if my father knew it I know it. I need to learn it too and you need to know and learn to learn more . . . So if I don't know what my teacher learned and is working on, say chaos theory, so if I don't learn what he learned then how can I work on this thing. We need a base knowledge and we need that *base knowledge to get above it* [italics added]. It is not like we can just jump over that hurdle without knowing other things. (M018, pre-interview)

The inference that most preservice teachers did not understand the guiding role of scientific theories is also supported by the fact that most of them (87%) indicated that observation comes before theory when scientists conduct scientific investigations:

> Observation [comes first]. You have to make an observation before you think of a theory. (M017, pre-interview)

Only a small minority of student teachers (13%) demonstrated adequate understandings of the role that scientific theories play in guiding research as evident in the following quotes:

> Theories guide experimentation. The new theory of plate tectonics gave scientists a new perspective on geology that lead to new questions and experiments. The theory also spawned new ways to look at Biogeography and evolution. Einstein said something like: Theory give us the framework to understand facts. (ME10, pre-questionnaire)
>
> I suppose they [theories] are useful for keeping things in order and for giving us a common language/model to refer to. They enable us to make predictions and lead us into designing certain experiments. (ME05, pre-questionnaire)

The Difference and Relationship between Scientific Theories and Laws

Generally speaking, scientific laws are statements or descriptions of the relationships among observable phenomena. Scientific theories, by contrast, are inferred explanations for observable phenomena or regularities in those phenomena. Students often hold a simplistic, hierarchical view of the relationship between theories and laws whereby theories become laws depending on the availability of supporting evidence. As such, students believe that scientific laws have a higher status than scientific theories.

They fail to recognize that theories are as legitimate a product of science as laws. Scientists do not usually formulate theories in the hope that some day they would acquire the status of "laws." Theories and laws are different kinds of knowledge and one can not become the other.

Views of participants enrolled in the HOS courses.

The overwhelming majority of participants held inadequate conceptions of laws (90%) and the relationship between theories and laws (97%). The responses of about 90% of participants harbored the misconception that scientific laws are absolute or certain. Participants thought that through repeated testing laws can be "proven" true. The fallacy of this inductive dictum is well known because "no rule can ever guarantee that a generalization inferred from true observations, however often repeated, is true" (Popper, 1988, p. 25). Additionally, these participants generally believed in a hierarchical relationship between theories and laws. Their responses indicated that scientific theories are less valid or supported than scientific laws or that theories are merely precursors to scientific laws.

Participants' particular responses were somewhat different but all harbored the aforementioned misconceptions. About one-third of the participants (28%) explicitly indicated that theories become laws when "proven" true or when tested "over and over and over again:"

> There is a difference [between a theory and a law] in that a law doesn't equal a theory. A theory can become a law only if that theory can be proven over and over again. (S059, pre-questionnaire)

> I do believe that a theory becomes a law only after a lot of experiments have proved it. (C171, pre-questionnaire)
>
> 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, pre-questionnaire)

Another one-third (31%) of all participants noted that theories and laws differ because laws are "proven" to be correct or true while theories are not:

> Scientific law, I believe, are ideas which have been proven to be true. While scientific theory are ideas suspected to be true, but not proven; The evidence may be there to support the theory, but it's not proven. (C176, pre-questionnaire)
>
> Yes, there is a vast difference between a scientific theory and a scientific law. A theory is something which is believed to be true by some but has yet to be proven (via experimentation, observation, etc.) beyond a reasonable doubt . . . A scientific law on the other hand, is a principle which has been proven to hold true without exception, e.g., the law of gravity. (S021, pre-questionnaire)
>
> Yes [there is a difference], a theory is just a suggestion. The knowledge it suggests must be tested in order to prove if it is right or wrong. A law has already been proven to be right and is accepted. For example, the theory of evolution is just a suggestion, it has not been proven to be right or wrong. The law of motion is proven and is accepted as true. (E068, pre-questionnaire)

Yet another 23% of participants indicated that theories and laws differ because laws are true or set in stone and thus do not change. Theories on the other hand are more likely to change:

> I believe that a scientific law is somewhat set in stone, proven to be true beyond a reasonable doubt. A scientific theory is apt to change and be proven false at any time. (S027, pre-questionnaire)
>
> I tend to think of a scientific law as something that has been proven, and therefore will not change because it is true. The law of gravity has been proven and as far as we know, nobody contests it. A scientific theory

> however is open to change with increased data collection and further experimentation. (E164, pre-questionnaire)
>
> A law has been tested and cannot be changed . . . A theory can be changed. (CS02, pre-questionnaire)

A small minority of participants (8%) expressed similar views. These views, nonetheless, were cast in different terms. These participants *seemed* to realize that laws cannot be "proven." However, they still believed laws to be "true." As such, instead of indicating that laws have been proven, these participants noted that laws have not been disproven. There were no indications, however, that these participants thought laws are apt to change when and if they are "disproven," even though they noted that theories can be "disproven:"

> Yes there is [a difference]. A scientific theory can be proven wrong. A scientific law has not been proven wrong for such a long period of time that it is considered to be true. (S044, pre-questionnaire)
>
> Scientific laws are theories that have not been proven wrong for many years. (E082, pre-questionnaire)
>
> Yes, there is a difference between a scientific theory and a scientific law. A scientific theory is the best guess a scientist has made with the current circumstances or resources available and can be proven false through experiments. A scientific law is one that has never been proven false. (E0114, pre-questionnaire)

Participants' belief in a hierarchical relationship between theories and laws was also evident during the pre-instruction interviews. Participants were asked, "In terms of status and significance as products of science, would you rank scientific theories and laws? And if you choose to rank them, how would you rank them?" The majority of interviewees

(69%) indicated that they would rank theories and laws. And the greater majority of these participants (84%) ranked laws above theories:

> I think that laws are ahead of theories. Theory is made, and if it is not disproven over time then it becomes a law. (E143, pre-interview)
>
> I would rank laws definitely first because every scientist has to rely on the laws that he was taught in college in order to come up with a new theory. (S029, pre-interview)

A few of these interviewees (16%) ranked theories above laws because they believed that "nothing can be done" with laws since laws will not change. Scientific theories on the other hand may lead to new investigations:

> Probably theories are more important. I don't know. I mean because you can start with a theory and maybe diverge and come up with a different question . . . You know what I am thinking, laws will not change, I mean in laws there is nothing more to do. (E158, pre-interview)

Other interviewees (31%) chose not to rank theories and laws. As evident in the following quotes, however, their responses did not reflect more adequate conceptions of the functions of and/or relationship between scientific theories and laws:

> Well, I think that laws are seen as static, factual and they are not going to change. But a theory is close to being factual but it is still apt to change. So, I think that you, both of them are important to learn. So I don't know that of you can really rank them. (E096, pre-interview)
>
> That's kind of a tough question because some theories are much more viable than laws and some laws are much more viable than theories. There are a lot more theories than laws. (E066, pre-interview)

The responses of a small minority of participants (10%) reflected more adequate conceptions of laws and/or their relationship with theories. Some (7%) indicated that laws are not certain or absolute. These participants, nonetheless, believed that theories and laws are not different since both are subject to change:

> No, there is no difference between the two [theory and law] . . . the idea of an absolute is ridiculous. Even Newton's laws have been reduced to principles because in some cases they don't apply. All laws & theories are just the best explanations currently possible for phenomena. As more data are available they all change. (E129, pre-questionnaire)
>
> A scientific law is a theory with an attitude. Our conception of the universe, the scope of detail of the things we can know will always change. As these change, the things that humans thought were immutable truths or laws will change as well. (C173, pre-questionnaire)
>
> I don't know the difference between these two [theory and law]. But it seems awkward for me to call something a "law," like gravity, when what we know is based only on what we've seen *so far* [italics in original]. (E156, pre-questionnaire)

Only a few participants (3%) explicated clear understandings of the functions of and relationship between scientific theories and laws. These participants believed that laws describe patterns in observable phenomena, while theories explain such phenomena often in non-observable terms:

> Well, I guess a law would be something that you know, something that holds true while describing what is happening. Whereas a theory is why that happens. An original thought. Like the theory of gravitation . . . Actually a law would be much more descriptive, it is something that happens. Whereas a theory explains why it happens. (C182, pre-interview)
>
> A scientific law describes quantitative relationships between phenomena such as universal attraction between objects. Scientific theories are made of concepts that are in accordance with common observation or go beyond and propose new explanatory models for the world. (E124, pre-questionnaire)
>
> A scientific theory is a generalized principle supported by a considerable amount f evidence whereas a scientific law is an exact principle which occurs in events and is observable and uniform under certain conditions. (E133, pre-questionnaire)

Finally, it is noteworthy that one-half of all participants provided adequate examples of scientific laws. "Gravity," Newton's laws of motion, and the laws of thermodynamics constituted about 90% of all examples provided. Twenty-three percent of participants did not provide any examples of laws even though the fifth item on the NOS questionnaire explicitly asked for such examples. About one-third of the participants (27%) provided inadequate examples of scientific laws. These participants particularly seemed to confuse scientific laws with empirical "facts" as evident in the following quotes:

> An example is the scientific law that light travels faster than sound. (E162, pre-questionnaire)
>
> An example of scientific law is Murphy's law = one law of science that states that the unexpected will occur when you are not expecting it. (S048, pre-questionnaire)
>
> A scientific law has been proven and will always be that way. A methyl group (CH_3) will always be a methyl group. (E106, pre-questionnaire)
>
> Example of law: there is oxygen in the atmosphere. (CS02, pre-questionnaire)

As such, about 90% of all participants believed that scientific laws are absolute or certain. Also, an overwhelming majority of participants (97%) did not demonstrate adequate understandings of the relationship between scientific theories and laws. They generally held a hierarchical view of this relationship whereby theories become laws with the accumulation of supporting evidence. Finally, about one-third of all participants provided inadequate examples of scientific laws.

Views of preservice science teachers.

Student teachers' views of laws and their relationship with theories were appreciably different from those of students enrolled in the HOS courses. The greater majority of preservice teachers (87%) demonstrated adequate understandings of the functions of and relationship between scientific theories and laws as evident in the following quotes:

> Scientific law states, identifies or describes relationships among observable phenomena. Scientific theories are inferred explanations for observable phenomena. (ME13, pre-questionnaire)
>
> Yes there is a difference. A law is a statement (often a mathematical relationship) that says how things are / how they behave, but it does not include an explanation. A theory includes an explanation, but it is not *directly* observable [italics in original]. (M017, pre-questionnaire)
>
> Laws like theories are tentative. I look at a law as something that is observable, like empirical. It is not an explanation or a mechanism, but it is essentially categorizing a set of observations. The theory, in a sense, is an explanation. It tries to explain the mechanism. (ME10, pre-questionnaire)

When asked during the interviews, the greater majority of participants (75%) indicated that they would not rank theories and laws. Some of these participants noted that theories and laws serve different functions and ranking them would not be "fair." Others reiterated their belief that there is no hierarchical relationship between the two:

> You can't rank them. It would not be fair. It is like comparing apples to oranges. They have different purposes and different reasons for being formed. (ME04, pre-interview)
>
> I don't think they are rankable. I don't think that there is a hierarchy here. I don't think that there is a hierarchy like a theory is going to develop into a law. (M017, pre-interview)

Two interviewees chose to rank theories and laws. One ranked scientific theories as higher than laws because theories provide explanations for the laws. The other student teacher thought that laws have higher status since laws are more valid than theories:

> I think, actually, I would rank theories higher than laws because they are the actual explanations and the meat behind the law. But they are always subject to change again. And I think that learning about why something happens the way it does is better than just trying to find another observable pattern. (M016, pre-interview)
>
> Laws are higher than theories. Well, I am saying as far as what you really can count on as being true, something that is valid. You don't have to say well there is another law that contradicts that law. Like a theory, you might have two different theories that are in opposition. If two laws are in opposition then one of them obviously cannot be a law. (M018, pre-interview)

Only two of all preservice teachers (13%) held a hierarchical view of the relationship between theories and laws. Also, one of these latter two teachers, the one who ranked laws as "higher" than theories, seemed to believe that laws are absolute since they are "proven" true through repeated testing:

> I am having a hard time pinning down in my mind just what exactly makes the two things [theory and law] distinct. I am not sure but I think that theory was precursor to law and after some time the theory was granted the status of law. (ME06, pre-questionnaire)
>
> Laws are theories that have been proven to be a consistent truth through many years of repetitive testing. (M018, pre-questionnaire)

Finally, it is noteworthy that the greater majority of student teachers (93%) provided adequate examples of scientific laws. Again, "gravity" and the laws of thermodynamics were the ones most commonly cited. One preservice teacher did not provide an example of scientific laws.

The Tentative Nature of Scientific Knowledge

Scientific knowledge, though reliable, is at best tentative and *never* absolute or certain. This knowledge, including "facts," theories, and laws, is subject to change. Tentativeness arises from the fact that scientific knowledge is inferential, creative, and socially and culturally embedded. Moreover, there are compelling logical arguments that lend credence to the notion of tentativeness in science. Indeed, as noted earlier, scientific hypotheses, theories, and laws can *never* be absolutely "proven." The impossibility of "proving" scientific claims holds irrespective of the amount of empirical evidence gathered in the support of one of these ideas or the other (Popper, 1963, 1988).

Views of participants enrolled in the HOS courses.

The overwhelming majority of participants (90%) did not seem to believe that scientific knowledge is tentative. About 16% of all participants explicitly indicated that science differs from other disciplines of inquiry in that scientific knowledge is definitive, correct or "proven" true:

> Science is the exploration of life and the elements of all things. Compared to philosophy and religion . . . science demands definitive answers with right & wrong answers. (E073, pre-questionnaire)
>
> Physics, biology and other science disciplines differ from non-science disciplines in that they are universal truths. (S042, pre-questionnaire)
>
> I think 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, pre-questionnaire)

As noted earlier, 77% of all participants indicated that scientific theories change. At first, this result might be reassuring because it suggests that a large majority of participants embrace a tentative view of science. However, as indicated in the previous section, 90% of all participants noted that laws are absolute or "proven" true. This view, coupled with these participants' belief in a hierarchical relationship between scientific theories and laws, suggests that participants do not ascribe to a tentative view of science. Participants seem to believe that theories are just a stage in the progression toward the "truth." As such, theories change not because scientific knowledge is dynamic or tentative, but rather because theories are "just theories" and have yet to attain the status of law or "proven" fact:

> A theory is not a fact and is therefore subject to change. (E108, pre-questionnaire)
>
> A scientific theory is just that a theory and so it can change. (S038, pre-questionnaire)
>
> Theories are always subject to change, that's why they're theories. They haven't been proven to be true or not. (E113, pre-questionnaire)

Only 15 participants (10%) explicitly indicated in their responses to the NOS questionnaire and/or during the pre-instruction interviews that science is dynamic and that scientific knowledge is not absolute. As was evident in the quotes cited in the previous section, most of these participants expressed this view by asserting that both scientific theories and laws are not absolute and are subject to change.

Views of preservice science teachers.

Unlike the participants enrolled in the HOS courses, the responses of an overwhelming majority of preservice teachers indicated that they ascribe to a tentative view of science. Only one preservice teacher (7%) indicated that "through using scientific methods . . . [science] can prove something to be true" (M018, pre-questionnaire). The same preservice teacher noted that scientific laws are absolute. The remaining student teachers (93%) did not indicate that science or scientific knowledge, including laws, are certain, "proven" or absolute. One-half of the preservice teachers explicitly indicated in their NOS questionnaires that science is tentative as evident in the following quotes:

> [Science] strives to ask questions and is fueled by the desire to answer such questions and the acceptance that science is not absolute. (ME07, pre-questionnaire)
>
> Scientific theories change w/ the increase in understanding, knowledge, technology, etc . . . The one thing that is certain in science is that things will always change. (ME08, pre-questionnaire)
>
> Laws like theories are tentative. (ME10, pre-questionnaire)

The Creative and Imaginative Nature of Scientific Knowledge

Scientific knowledge is, at least partially, based on and/or derived from observations of the natural world (i.e., empirical). The development of scientific knowledge, nonetheless, involves human imagination and creativity. Science, contrary to common belief, is not a lifeless, rational, and orderly activity. Science involves the *invention* of explanations and theoretical entities, which requires a great deal of creativity on the part of scientists.

Views of participants enrolled in the HOS courses.

Only 3 out of 141 participants indicated that scientists do not use imagination and creativity in their investigations. These participants noted that creativity and imagination characterize the "arts" and not the sciences as evident in the following representative quote:

> I *don't* think [italics in original] scientific investigation is best characterized by creativity or imagination. I think a composer can be creative, a novelist can be imaginative, etc. . . . Scientific investigations are often tedious and repetitive, with the sole purpose of generating new data on the basis of previous data. (E124, pre-questionnaire)

Four participants (3%) thought that scientists use imagination and creativity. These participants, however, noted that such use is not desirable. They continued that imagination and creativity are often used to bias or "distort" investigations in order to fit scientists' agendas to publish and/or secure funding:

> They use them [imagination and creativity] at all stages of an investigation: planning, design, data collection and after data collection. Because all of these stages are creatively *distorted* [italics added] to make the experiment reflect their preconceived notion as to how the experiment will turn out. They use their imagination to get published in scientific journals and, to receive monetary grant from the government and corporations. (S036, pre-questionnaire)

The overwhelming majority of participants (95%) indicated that imagination and creativity are needed in scientific investigation. These participants, however, differed in the choice of the specific stages in which they thought scientists use imagination and creativity. Forty four percent of participants thought that imagination and creativity permeate all stages of scientific investigation including planning and design, data gathering, and the stages following data collection:

> Yes, scientists must be creative at every stage of their work. They must use their imagination from designing a theory, planning experiments all the way to finding creative ways to present the results and finding or changing original theories to fit the new data. (S061, pre-questionnaire)
>
> Yes. Scientists often use imagination and creativity in all stages of experimentation/investigation in order to conceive of explanations to questions as well as conceiving proper methods of data collection and interpretation. (E084, pre-questionnaire)
>
> Of course they use their imagination and creativity. If not, science would not progress. They must come up with a testable hypothesis then create an experiment to test the hypothesis and collect data. Collecting data can be tricky and therefore imagination plays a big part. Also one must decide how to interpret the data. (C171, pre-questionnaire)

About one-third of participants (34%) indicated that scientists only use imagination and creativity in the planning and design stages of investigation. They believed that using imagination and creativity in data collection, data interpretation or in deriving conclusions would result in "incorrect" findings. Rather, conclusions should be based solely on the data:

> I think scientists use a lot of creativity and imagination during the planning & design of an experiment—if they didn't all experiments would be the same and no new data would be collected. During and after data collection scientists shouldn't be, and usually aren't, creative as that would cause all value of the experiment to be lost. If scientists are creative with data then

> incorrect conclusions are made and information perceived as valid is distributed to an audience that is misled. (S042, pre-questionnaire)
>
> Scientists do use their creativity and imagination during their investigations. It is used in the planning and design stages of investigations. They should not use it during the collection of data. Nor should it be used after data collection in the conclusion stage. Conclusions should be made based on the data alone and if the conclusion can not be supported by the data then further experiments are needed. (E131, pre-questionnaire)
>
> In the process of investigation, imagination and creativity are confined to the planning and design portion, I mean in the vast majority of cases. I have to say like the part where you need to look at your data and look at what conclusions you have here. I think you need to sort take away your mind after you collect the data, you need to take away what you want to come out of the data. I think that you need to take that out of your mind and look at the data factually. You don't want to be creative when you interpret the data. (E125, pre-interview)

Finally, about 13% of participants indicated that scientists use imagination and creativity in all stages of investigation with the exclusion of data collection:

> Scientists do use creativity and imagination during planning and design and after data collection. (S045, pre-questionnaire)
>
> Creativity and imagination do play a part in planning and design and after data collection . . . Scientists must learn to devise experiments that eliminate unwanted variables but still focus on the validation of their theory. After the collection of data, the whole of the data must be analyzed, and the results must be interpreted. (C172, pre-questionnaire)
>
> Yes. They must use their imagination in the planning and design stage to come up with the experimental design. During the data collection stage they should not use creativity. After data collection they must use creativity to some extent to try to tie their results together somehow or to show that there is no correlation. (E145, pre-questionnaire)

The fact that participants assigned imagination and creativity to different stages of scientific investigation *suggests* that they attach varying meanings to the phrase "imagination and creativity" or to the individual terms. Indeed, close examination of participants' responses to the NOS questionnaire and further probing during the interviews substantiated this inference. The majority of participants (70%) did not use these terms to refer to the *invention* of explanations, models or theoretical entities. Most students used imagination and creativity in the sense of "resourcefulness" "skillfulness" or "cleverness:"

> Scientists are always being imaginative and creative . . . especially when something is taken out of its natural environment and brought into the laboratory. The scientist must create a situation in the lab that is as close as possible to the subjects' natural setting. This is the only way to be sure that only one factor at a time is being manipulated. (S055, pre-questionnaire)
>
> Scientists use creativity and imagination in the planning stages. Also it takes some imagination to collect some data. For example, if a scientist wants to study prairie dogs, how will they catch their specimens? Chase them over the prairie? Probably not. They would need to use their creativity in order to collect their data. (E164, pre-questionnaire)
>
> I think creativity and imagination come in at all levels . . . like in designing an experiment and the nitty-gritty details of everyday lab work. When I worked we ran into problems all the time and the lab technician was extremely creative. She would like build little things, I mean if something wouldn't work right she would modify it. And she used all sorts of wooden things that she would build, you know just to make gels run just right. It is like you almost need, in a sense you need to be an engineer just to get the experiment done. It all looks so neat and nice on paper. In the lab it doesn't work that way, you always have some problems. (E099, pre-interview)

Others associated creativity and imagination in scientific investigation with being open-minded, considering all the possibilities, and examining a situation from "all the angles" as evident in the following quotes:

> I think they use creativity. You know, everybody has some amount of creativity . . . Creativity kind of help look at things from a different angle and develop better understandings. (C177, pre-interview)

> Definitely they use them because sometimes you have to do some creative stuff . . . You have to have an open-mind and be creative and say, Oh, maybe I need to check this too as well when you examine your data. (S020, pre-interview)

Among the various other meanings that participants included under the label of creative and imaginative activities in scientific investigations were "being curious," "maintaining interest," using "appealing" ways to present results, and not "copying" other scientists' designs and experimental procedures:

> I think it depends on who the scientist is at first. Because some scientists include lots of graphics and big huge metal models of molecules. But sometimes it is just cut and dry and they have it on paper and it is not the same. (E066, pre-interview)
>
> Yes, some scientists use their imagination and creativity . . . I think it takes a creative mind to be curious, to remain focused, and to allow the project to remain interesting. (S038, pre-questionnaire)
>
> Scientists . . . also use imagination & creativity in the step after data collection where they can conclude certain things and disseminate their findings to people through demographics, bar charts, graphs, maps, etc. Scientists have quite an imaginative & creative and use it to make their experiments seem more appealing to their audience. (E114, pre-questionnaire)

The responses of only 22 participants (16%) indicated that scientists use imagination and creativity in the sense of inventing explanations, models and theories to explain the patterns in the phenomena that they investigate:

> Logic plays a large role in the scientific process, but imagination and creativity are essential for the formulation of novel ideas . . . to explain why the results were observed. (E088, pre-questionnaire)
>
> Yes, scientists use creativity and imagination during their investigations . . . to come up with plausible explanations for the data and possible other questions to pursue answers to. (C183, pre-questionnaire)

> Scientists use imagination & creativity to determine the best way to interpret their physical world and to make sense of it. (E125, pre-questionnaire)

Finally, the vast majority of participants (88%) did not provide any examples to support their views concerning the use of imagination and creativity in science. A few participants (6%) provided examples derived from everyday life situations rather than from science or scientific practice:

> Police investigators try to recreate a crime scene not knowing everything that happened so they have to use their imagination to fill the holes. (E095, pre-questionnaire)
>
> Creativity is needed because often old methods are inadequate . . . A good analogy would be baking a pie. There is a basic recipe, but we also know subjectively what tastes good. We use creativity to add to or take away from the recipe to investigate the "right" combination of ingredients. (S058, pre-questionnaire)

A small minority of participants (6%) provided adequate examples. Not only were these examples taken from the HOS, they also conveyed adequate views concerning the role of creativity and imagination in developing scientific knowledge:

> Yes, I think that scientists are imaginative and creative by nature. Look at Sir Isaac Newton. He created calculus. That definitely required creativity and imagination. To think of the "great" scientific theories and laws one must be creative and have a large imagination. I don't think that Albert Einstein would be considered uncreative or lacking in imagination after developing the theory of Relativity. (S040, pre-questionnaire)
>
> Darwin's own contribution to science was not founded on formal methods and hypothesis testing, but rather in extensive, detailed observation followed by an intense period of thought and creative conceptualization. (E163, pre-questionnaire)

As such, 16% of all participants believed that scientists use imagination and creativity to *invent* theories and/or explanations. And only 6% of participants were able to furnish adequate examples from the HOS to support this latter view.

Views of preservice science teachers.

Student teachers' views were not appreciably different from those of participants enrolled in the HOS courses. Student teachers assigned the use of imagination and creativity to different stages of scientific investigation. Forty percent of student teachers thought that creativity and imagination are used in all stages of investigation:

> Yes, scientists do use their imagination and creativity throughout their investigations from planning and design all the way through post data collection. (ME11, pre-questionnaire)

Another 40% of student teachers thought that scientists use imagination and creativity only in the planning and design stages of investigation as evident in the following quote:

> Imagination and creativity should only be used at planning & design stage. At data collection it should be straight from the logic & reality of the experiment. After data collection . . . imagination & creativity leave the door open for untestable, unpredictable possibilities that doesn't belong in science. (ME08, pre-questionnaire)

Three student teachers (20%) indicated that scientists use imagination and creativity in all stages of investigation to the exclusion of data collection:

> Scientists definitely use creativity & imagination at all stages of their investigation . . . however, scientists don't use too much imagination in data collection to fudge the results. (M016, pre-questionnaire)

The responses of the greater majority of preservice teachers (80%) indicated that they do not use "imagination and creativity" in the sense of inventing explanations. The meanings these student teachers ascribed to this phrase were similar to those of participants enrolled in the history of science courses. These meanings included being resourceful in solving problems of a practical nature, originality (not "copying others' experimental designs), and looking at problems from different angles. Additionally, all these latter 12 student teachers did not provide any adequate examples to support their views about the role of imagination and creativity in science:

> I think our perception of what the problem is will be different. And I think here the creative aspect comes in. There are many different solutions to different problems and many different approaches. For example moving from one point to another on the globe, some people walk and some others look and see animals and try to ride them, the horse. Then there is a problem well how am I going to catch the animal. And then scientists try to solve the problem and use different solutions and different approaches. (ME11, pre-interview)

> Scientists must use imagination and creativity in all stages of an investigation . . . to solve a problem in a new and original way, they need to look at it from different angles. (ME07, pre-questionnaire)

Only 3 of 15 preservice teachers (20%) thought that imagination and creativity are essential for developing scientific knowledge in the sense of inventing theoretical models and entities. Only one of these preservice teachers provided an adequate example to support her view:

> Imagination and creativity are used to develop the idea, to set the experiment, and to draw inferences . . . Scientists used imagination and creativity in developing the double helix model of DNA. It hasn't been observed, it was inferred from the knowledge that was available. (ME12, pre-questionnaire)

Inference and Theoretical Entities in Science

The world of science is inhabited by a multitude of theoretical entities or terms, such as atoms, molecular orbitals, photons, magnetic fields, and gravitational forces to name only a few. These latter examples come from the physical sciences. Nonetheless, theoretical entities also abound in the biological sciences. For instance, "'species' like the terms 'gene,' 'electron,' 'non-local simultaneity,' and 'element,' is a theoretical term embedded in a significant scientific theory" (Hull, 1998, p. 146). Theoretical entities are *not directly* observable and can *only* be accessed and/or measured through their effects or manifestations. In other words, theoretical entities are *inferred explanations or models* that aim to account for regularities in the *observed* "behaviors" of phenomena. It follows that inferential entities, such as atoms and species, are functional theoretical models rather than faithful copies of "reality."

The sixth and seventh items on the NOS questionnaire aimed to assess participants' understandings of theoretical entities and the crucial distinction between observation and inference. The two items asked participants whether they thought scientists are *certain* about the structure of the atom and the characterization of species respectively. Participants were also asked about the kind of evidence they thought scientists used to determine the structure of the atom and the notion of species.

Views of participants enrolled in the HOS courses.

An alarmingly high percentage of participants (25%) thought that scientists are certain about the structure of the atom because high-powered electron microscopes were used to determine what an atom "looks" like. These participants indicated that scientists have actually "seen" atoms. These participants lacked in their understanding of the inferential nature of the "atom" and of the distinction between observation and inference:

> Scientists are pretty certain that we know what an atom looks like. We have great new instruments such as electron microscopes where we can actually see them. Before we could see atoms there were many theories on the subject but it definitely took better instruments in order to bring confidence to the findings. (E088, pre-questionnaire)
>
> They [scientists] are very certain, 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, pre-questionnaire)
>
> I think scientists are pretty sure about the structure of the atom. The evidence they use is microscopic pictures of the actual atoms. (C170, pre-questionnaire)

About one-third of participants (33%) indicated in their responses to the NOS questionnaire that scientists are certain about the structure of the atom. However, participants' responses were fairly general. These responses neither had explicit indications that participants thought atoms were or could be "seen," nor that they understood the inferential nature of the concept of the atom or the kind of evidence used to infer its structure as evident in the following representative quotes:

> Scientists are very certain of the structure of the atom. Our own Linus Pauling was very instrumental in this area. I believe that it was he who advanced the VSPR (valence shell electron pair repulsion) theory. I believe

> Niels Bohr also had something to do with atomic structure. (S021, pre-questionnaire)
>
> From what I've heard, "they" are very certain about the structure of the atom. I feel they used what they saw while doing experiments, along with previous study. (E073, pre-questionnaire)
>
> Scientists are 100% certain of the structure of atoms. The evidence they use is how everything is structured by atoms. The world could not exist if the structures were any different. Molecules such as water have to have a specific shape and by knowing this, the structure of the atom must be correct. (E092, pre-questionnaire)

An additional 10% of participants indicated that scientists are certain about the structure of the atom. These participants noted that they were not familiar with the evidence used to arrive at the structure. Nonetheless, participants indicated that they have faith in scientists and the efforts that were expended to arrive at the current structure of the atom:

> I personally don't understand how scientists can determine the structure of an atom. But I am certain that they have concrete evidence on atoms. I have no idea how scientists determine them. (S031, pre-questionnaire)
>
> I think scientists are very certain about the structure of the atom. Unfortunately, I haven't a clue as to what specific evidence scientists used to determine what an atom looks like. So far, in my undergraduate studies at [the University], we have only been told that this is how an atom is structured, we never learned how scientists proved this. (E089, pre-questionnaire)
>
> Scientists are almost entirely certain. It takes years of investigating & experimenting before determining something so small as an atom. They didn't just wake up one morning and say "I believe this is what an atom looks like." And the structure of an atom is based on the observations of many scientists, not the conclusions of just one. (E103, pre-questionnaire)

During the pre-instruction interviews participants who provided general or vague responses to the NOS questionnaire were explicitly asked whether scientists have seen an atom. About one-half of these interviewees (53%) thought that atoms have not been actually seen. The other half (47%) indicated that scientists have actually "seen" atoms through electron microscopes. These latter interviewees were then informed that technologies including scanning tunneling microscopy do not allow scientists to actually "see" atoms (Hoffmann, 1993). Interviewees were then asked, "If scientists cannot see atoms, where do they come up with this elaborate structure of the atom?" The majority of these interviewees (67%) struggled as they attempted to cognize the fact that scientists can have a fairly reliable idea about the structure of an atom even though they have not seen one. Participants failed to recognize the relevance of indirect evidence and inference to arriving at the structure of an atom:

> Well, I think there is much work involved [in arriving at the structure]. I mean there were people working on that for a long time, and then people still worked more on the quantum theory and things like that. I am not sure. (E166, pre-interview)
>
> It is a good question. I don't know [how they arrived at the structure]. It is like the question, I don't understand computers but you turn them on and they work . . . It is something that is just so out there I couldn't understand. You know, how somebody would just know something like that. (S030, pre-interview)
>
> I don't know, you measure the things that you can't see so that you can get an idea of what it is doing, I have no idea. (E153, pre-interview)

Only about 30% of all 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. Many of these participants indicated that the structure of an atom is a *model* intended to explain observations of the "behavior" and/or "properties" of atoms in reaction to various experimental manipulations:

> I don't think scientists are really certain that an atom looks that way. I think they have decided that that is the most likely explanation for their observation, much the way geologists have agreed on a basic idea of what the inside of the earth looks like, even though they've never seen it. (S041, pre-questionnaire)
>
> 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, pre-questionnaire)
>
> Models of the structure of the atom are frequently being updated. Current theories of the structure of the atom explain observed phenomena with a fairly high degree of certainty, but only indirect evidence can be used to formulate such theories. (E088, pre-questionnaire)

Participants' views of the construct of species were not different from their views concerning the model of the atom. About one-half of participants (51%) indicated that scientists are certain about the notion of species. These participants advanced several reasons for their belief in scientists' certainty about species. The greater majority of these participants noted that scientists use a variety of observational evidence, especially DNA sequencing, to determine species membership:

> There is also a scientific certainty [about the concept of species]. While in the early days it was probably a matter of trial-and-error (mating two animals to see if viable offspring is produced), nowadays genetic testing makes it possible to define a species precisely. (S021, pre-questionnaire)
>
> Scientists are certain about their characterization of a species. Scientists use morphology, reproductive cycles, and bone structure to determine a species. Genetic information obtained from DNA also aids scientists in determining species. (C179, pre-questionnaire)

> Scientists have many ways of classifying species. Phenotypic, genotypic, behavioral, and geographical similarities are all used to help determine what a species is. Other things like internal organs is also used to help scientists define species. I believe that scientists are certain about their characterization of what a species is. (E140, pre-questionnaire)

Other participants noted that the characterization of species was established through conducting experiments such as cross breeding various organisms. They continued that such experiments confer certainty on the notion of species:

> Scientists are very certain of the major species of each geographical area. Scientists most likely tested each species through cross-breeding experiments and basic genetics. (S050, pre-questionnaire)
>
> Scientists are very certain about the characterization of what a species is. Years of experiments (interbreeding, etc.) have lead scientists to their conclusions. (E089, pre-questionnaire)
>
> I think they'd be fairly certain. They have tons of experiments with different animals with breeding. And they must have had some failures and some successes. (E151, pre-questionnaire)

Additionally, circular logic typified the responses of some participants as they attempted to defend the position that scientists are certain about species. These participants noted that scientists are sure that a species is a group of similar organisms that interbreed and produce fertile offspring because only organisms of the same species can interbreed and produce fertile offspring:

> I think that they [scientists] are very certain about their characterization. The evidence used was most likely the fact that only animals which have similar characteristics can mate and have fertile offspring. When other animals tried to mate and couldn't, they realized that they obviously couldn't be the same species. (C168, pre-questionnaire)
>
> I feel they [scientists] are certain. If two animals can interbreed successfully, then it is of the same species. (E104, pre-questionnaire)

> I believe scientists are fairly certain about species characterization. Specific evidence would be breeding. Successful breeding is an indicator of a species group. (E157, pre-questionnaire)

During the pre-instruction interviews, follow-up questions were asked of participants who indicated on the NOS questionnaire that scientists are *certain* about their characterization of species. These interviewees were provided with an example of *two* species of wolfs and dogs that are known to interbreed and produce fertile offspring. Interviewees were asked, "How are such instances possible if scientists were certain about species?" A few interviewees (18%) noted that the lines scientists draw among various species are not clear-cut. They continued that variations exist in nature and it is not possible to "get it right" all the time. Such cases are inherent to scientists' work on classification. However, the greater majority of these interviewees (73%) noted that such cases are only mistakes in classifying certain organisms. Some continued that with advances in technology, especially DNA sequencing, scientists will be able to "figure out" such mistakes:

> With what is starting to happen with genetic sequencing, they are discovering how they thought one species was not related to another, that they are actually related. So I think that there are some gray areas and when they have the technology they will be able to figure them out. (S040, pre-interview)
>
> This [case] does effect the idea of a species because what we know is not really, if they [dogs and wolfs] interbreed then what we have about one species is incorrect. They might be wrong in classifying the species. (E151, pre-questionnaire)
>
> There are lots of animals that had a certain name and they come to find out that the scientific name is something totally different, and they come to realize that that was a goof up on the common name because they found out it belonged over here to another species. (E157, pre-questionnaire)

About 15% of participants indicated that scientists are not certain about their characterization of species. These participants advanced several reasons to justify their position. Some noted that there are many disagreements among scientists about the notion of species. Others argued that variations among organisms abound and result in gray areas and exceptions that defy classification and blur the lines between certain species. A few of these participants argued that according to evolutionary theory scientists could not be certain about the notion of species since speciation is an ongoing process. The responses of these participants, nonetheless, had no indications that "species" is a human construct or the result of a man-made attempt to classify organisms:

> The characterization of what a species is is still under some debate. With new DNA technology scientists have found that some species are more related to others than previously believed. This new information has made it a little more clear as to which species an animal/plant belongs but there are still no concrete definitions. (E131, pre-questionnaire)
>
> Scientists have difficulties when attempting to pigeonhole organisms into a classification of species. The study of genetics reveals a large spectrum of variations between species. Scientists cannot be too certain about classification because of these variations. I think scientists generalize about particular similarities among organisms to organize species. (S033, pre-questionnaire)
>
> The idea of species may be vague sometimes. The evidence probably started with different physical characteristics; now it may becoming based upon genetic differences. I don't think the lines can always be distinct, especially if evolution is correct. The lines may be like gradients sometimes. (C176, pre-questionnaire)

A minority of participants (16%) noted that "species" is a human construct, or part of a man-made classification system intended to help scientists bringing some order to the enormous variety between and among various groups of organisms observed in nature. Like other classification systems, the concept of "species" has some merits. For instance, it helps scientists classify, make sense of the relationships between, and communicate about various organisms. But like all other classification systems, the concept of "species" has limitations and leaves much to be desired. Sharp lines are often difficult to draw among certain groups of organisms that seem to simultaneously belong to more than one species. Such groups of organisms seem to belong to gray areas that span the terrain between the blurred lines that often run between closely related groups of organisms. Thus, these participants demonstrated adequate understandings of the theoretical nature of the "species" construct as evident in the following quotes:

> Species is a relative term that humans have come up with to order & help explain our surroundings. I would argue that criteria for a species (or any classification) must be seen for what it is—a man made description to help his understanding of his surroundings. (E074, pre-questionnaire)
>
> Scientists have currently defined species as a population that does not interbreed with another population, has a distinct territory, habitat, and physical characteristics. This definition by scientists own admission will sometimes leave questions and controversy over whether or not two groups constitute different species . . . Current characterizations of species seem to have taken a very pragmatic approach: if the schema works to help you classify and understand the subject in a productive way then use. If it does not work, then use another schema; there are more than one especially in the field of microbiology. Classification we must remember, is not an end in itself, but a means of studying and understanding. (S026, pre-questionnaire)
>
> Species is something that we have used and it is a completely human creation. It is a convenient framework for categorizing things, animals and plants. And I think in general it is a good system but I think the more they learn the more they realize that they don't have the foggiest idea of what a species is . . . because of the small variations. And we cannot draw the line between species or sub-species or sub-populations of a sub-species. (E166, pre-interview)
>
> A 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, pre-questionnaire)

As such, only about 30% of all participants demonstrated adequate understandings of inference and theoretical entities through their discussion of atomic structure. A smaller percentage of all participants (16%) demonstrated adequate conceptions of theoretical entities through their discussions of the concept of species. It is noteworthy however that only a few participants were common to these latter two groups. Only 8 participants (6%) indicated that both the structure of an atom and the concept of species were theoretical or inferential entities advanced to explain observations about certain natural phenomena.

Views of preservice science teachers.

Appreciably more student teachers demonstrated adequate understandings of inference and inferential entities in their discussions of the structure of the atom. Compared to 30% of all participants enrolled in the HOS courses, 73% of preservice teachers indicated that the structure of an atom is a model intended to explain observations of the "behavior" of atoms. They noted that only indirect evidence is used to determine the structure of an atom:

> This structure [of the atom] is more of a diagram constructed through experimentation and inference. It is like inspecting the soil morphology layers, you know. You can't open the whole earth and look at it. You have to make observations of parts of it and you have to infer to connect the dots. Basically that is what you are doing to make a general pattern of what you are seeing. Obviously if you open up the whole earth it would not be exactly the way you mapped out, but it is kind of connecting the dots using our imagination basically. (M016, pre-interview)

> I don't know how scientists could be sure about the structure of the atom. We really cannot see an atom and are forced to infer an atom's structure

> from indirect measurements that may influence the very structure we try to determine. Science has theories, abstractions of structure, that are considered tentatively correct until experiment disproves theory. (ME10, pre-questionnaire)

The remaining four preservice teachers (27%) did not demonstrate adequate understanding of the role of inference in generating the structure of the atom. These participants indicated that technologies such as "powerful electron microscopes" were used to visualize the atom and arrive at its structure:

> Well, from my understanding they have powerful microscopes that they utilize to get to the structure. When they were finally able to look at the atom at that level or at least what they've seen when they used those microscopes there appeared to be like shells with a central core. (ME11, pre-interview)

> Scientists are certain of the structure of atoms to a point . . . I believe we can visualize the nucleus . . . but we cannot visualize the electrons. (M018, pre-questionnaire)

Preservice teachers' views of species, however, were not different from those of participants enrolled in the HOS courses. About one-half of student teachers (47%) indicated that scientists are certain about the notion of species. They noted that scientists use a variety of observational evidence and breeding experiments to determine species membership. Additionally, circular logic typified the responses of three of these student teachers:

> Scientists are pretty certain about their characterization of species . . . Specific evidence is obtained by breeding experiments. If two individuals interbreed and produce viable offspring, then those two individuals are of the same species. (M016, pre-questionnaire)

> I think that species are determined according to two principles. The members of a species must be able to interbreed and produce fertile

> offspring only among themselves. They must also resemble each other and be structurally different in some respects from members of any other species. (ME09, pre-questionnaire)

Four student teachers (27%) indicated that scientists are not certain about their characterization of species. These participants noted that there are many disagreements among scientists about "species" as evident in the following quote:

> I think science textbooks are zoo-centric. Botanists and microbiologists have different ideas about what a species is. Even within a branch of biology there is much ambiguity about "species." Often historical taxonomic distinctions are used even when current knowledge would better place the organism as a sub-species or variety. (ME12, pre-questionnaire)

Only 20% of preservice teachers indicated that "species" is a human construct intended for the pragmatic purpose of classifying organisms:

> I think, [with species] . . . we are trying to fit nature which has no sharp distinctions into our little boxes because this makes us feel comfortable . . . I think that at some level it is fine to say we have species. But when it comes right down to it, I mean we know darn well that the whole idea of the species falls apart. My experience is with salmon and we have different stocks and different races of salmon. And everyone is hammering to make sure that they have different stocks in their areas and it gets political and there are different things going on. And you know there is a reason why I would like to have a stock in my back-river. (ME10, pre-interview)

The Subjective and Theory-laden Nature of Scientific Knowledge

Scientific knowledge is subjective or theory-laden. Scientists' theoretical and disciplinary commitments, beliefs, previous knowledge, training, experiences, and expectations actually influence their work. All these background factors form *a mind-set* that *affects* the problems scientists investigate and how they conduct their investigations, what they observe (and do not observe), and how they make sense of, or interpret their observations. It is this (sometimes, collective) individuality or mind-set that accounts for the role of subjectivity in the production of scientific knowledge.

The ninth item on the NOS questionnaire presented participants with a recent controversy in science. The controversy relates to the cause(s) of the extinction of dinosaurs and the hypotheses that have been advanced to explain their "relativity" rapid disappearance from the fossil record. The item focused on two rival hypotheses that are still being debated in many scientific circles (Glen, 1990, 1994; Raup, 1986). These hypotheses are the "meteor impact" hypothesis (e.g., Alvarez & Asaro, 1990) and the "volcanic eruptions" hypothesis (e.g., Courtillot, 1990). Students were asked to explain how is it possible for scientists to advance different hypotheses to explain the extinction of dinosaurs if scientists have access to and use the same set of data.

Views of participants enrolled in the HOS courses.

The majority of all participants (62%) attributed the mass-extinction controversy to the scarcity of the available "data." Participants presented this view in at least three different ways. First, 20% of participants seemed to equate data relevant to the extinction issue with "seeing what has happened." Not only did these participants misconceive the meaning of "data" or "evidence" they also demonstrated misunderstanding of the logic of hypothesis testing. They noted that since scientists were not around 65 million years ago to witness the extinction, could not go back in time to "see" what happened, or could not crash meteorites into inhabited plants and make volcanoes erupt, scientists can only produce "theories" (in the vernacular sense) about what happened:

> Different conclusions are possible because no talking dinosaurs survived whatever catastrophe it was to tell us what exactly happened, neither did they leave us a written record . . . We can only build theories since we have a hard time formulating planets to hit with meteors or forcing volcanoes to blow up. This testing may take a while. (S026, pre-questionnaire)
>
> It is possible [to reach different conclusions] because the scientists were not around when the dinosaurs became extinct, so no one witnessed what happened . . . I think the only way to give a satisfactory answer to the extinction of the dinosaurs is to go back in time to witness what happened. (E089, pre-questionnaire)
>
> No one can find data that will disprove either of the two theories. We cannot physically go back in time and observe what occurred. (C179, pre-questionnaire)

Second, 33% of participants seemed to use the term "data" adequately to refer to artifacts left by either hypothesized event—meteorite impact or volcanic eruptions. Some of these participants indicated that both hypotheses are consistent with the available data. Most noted that there simply is not enough or conclusive evidence to champion one hypothesis over the other or to "prove" that one of the two is "correct." The obvious consequence of this present "lack of data" is that the controversy would be resolved if there were "enough" or "complete" data or if such data is obtained in the future. As such, these participants failed to recognize that factors other than "data" might play an important role in generating and supporting scientific claims. They did not seem to understand that data need to be *interpreted* from within certain theoretical frameworks to acquire any significance as supportive of one scientific claim or another:

> The data is limited at best. Some people use the evidence to support one theory while other people use that evidence to support another theory. While neither can prove the other wrong, neither can provide enough evidence to prove themselves right. (S043, pre-questionnaire)
>
> Clearly the available data and observations support both theories in this case. Further observations and more data are needed before either theory can become better established. (E088, pre-questionnaire)
>
> Since these are only hypotheses, there is not much proven evidence to support either one at this time. When more data is collected one of these hypotheses will be disproved, allowing the second to be more accepted . . . The different conclusions are possible since evidence is limited. (E164, pre-questionnaire)

Third, 9% of participants indicated that it is possible for scientists to reach different conclusions starting from the same set of data because of imagination and creativity. These participants, however, did not seem to believe that imagination and creativity are integral to scientists' work. Rather, they indicated that scientists are "forced" to use these attributes to "fill in gaps" if and when the data is scarce. Again, the implication being that if there were "enough data" the controversy would be non-existent since then scientists need *only* refer to the data in drawing their conclusions:

> Different conclusions are possible for a number of reasons. It seems that the data is scarce; therefore, scientists are *forced* [italics added] to "fill in the gaps" using their imagination and creativity. (S021, pre-questionnaire)
>
> Creativity and imagination. When the observed facts are few, then more and more explanations to account for them can be possible. As the number of gathered facts increases then certain explanations can be ruled out. (C173, pre-questionnaire)
>
> This [controversy] might be an instance where, because of lack of real evidence, scientists *did* [italics in original] use their creativity and imagination. (E069, pre-questionnaire)

In this regard, some of these participants explicitly indicated that the use of imagination and creativity in such cases as the mass-extinction controversy is even undesirable:

> This is the danger of creativity and imagination. I think this [reaching different conclusions] happens when scientists put there own ideas and creativity into their research, instead of looking at the available raw data only. (E069, pre-questionnaire)

Alternatively, about 33% of participants indicated that the controversy could be attributed to factors other than, or in addition to, the lack of evidence. These participants' responses could be grouped into three categories. First, 13% of participants noted that scientists arrive at different conclusions because they interpret the data differently. These participants, however, did not explicate any reasons as to why different scientists would interpret the same data differently as evident in the following quotes:

> The two groups of scientists interpreted the data differently; formed different theories and found correlations that seemed to prove their hypotheses. (S037, pre-questionnaire)
>
> I believe that the data collected suggested a massive event that caused the extinction of dinosaurs. Both groups suggested large events (meteorite and volcanoes) and interpreted the data in different ways. (E110, pre-questionnaire)
>
> These two groups have different theories as to how the dinosaurs became extinct. Even though all of the data is the same, interpretation of it can be different. (E068, pre-questionnaire)

Second, 3% of participants indicated that factors such as scientists' egos and fame, and their race to secure funds for research are behind the extinction controversy. These participants seemed to understand that science is another human activity and is thus infused with human attributes characteristic of such activities including competitiveness, and the thirst for power, fame, and other personal interests:

> These conclusions are possible because it's profitable to keep the debate going. If they came to the same conclusion in regards to the cause of the extinction they might loose their jobs and big research grants. (S036, pre-questionnaire)
>
> I think part of the controversy is just ego. Some scientist gets a piece of data then says this must be the answer. So they base their reputation on that and they say this must be right and they fight it out to the bitter end . . .This happens a lot when the scientists are famous and there is a lot of money in the grant or the research. (E166, pre-questionnaire)

Nonetheless, these latter representative quotes taken from responses to the NOS questionnaire appear to convey a "negative" message. It seems that these participants thought that factors, such as competitiveness and the race for recognition, are not only foreign to science but also undesirable. Participants' responses during the pre-instruction interviews substantiated this latter inference.

Nineteen interviewees had indicated in their NOS questionnaires that the controversy is due to the lack of evidence. These participants were asked, "It is very reasonable to say that the data is scarce and that the available evidence supports both hypotheses equally well. However, scientists in the different groups are very adamant about their own position. Why is that?" The greater majority of these interviewees (67%) referred to factors such as money, prestige, ego, and the race to publish as possible causes for the controversy. These participants, moreover, thought that such factors are hindrances to the "real" search for knowledge and cooperation among scientists:

> Well, when you are competing for grants with universities or the government, there has to be competition. There is not the cooperation that

> scientists really should have. If it is really the search for knowledge and explaining why things happen, then all scientists would share all their information and work on it together. But it is a matter of society, money, and prestige. (E093, pre-interview)
>
> Well, they are trying to make a big name for themselves and they are trying to be, you know, hot shots out there . . . I am saying that you have something that you insist is the truth and you say, "I am going to fight for it tooth and nail." They might not believe it but they say, "it is my own argument and it is going to make me a more powerful scientist in the community." I am not saying that they make this stuff up and they don't believe it necessarily. But if they fight tooth and nail to me it is politics, pure politics. (S055, pre-interview)
>
> I would guess that, you know, neither one of them want to say that their idea did not occur. So, I think it is just kind of these people doing studies and getting published all over the place . . . You know, the big thing as far as scientists is to get published. If you don't publish, you are not a scientist. (S030, pre-interview)

Third, only about 17% of all participants explicated adequate understandings of the subjective (or theory-laden) nature of scientific knowledge. These participants indicated that different scientists might derive different conclusions from the same set of data because they interpret or perceive the data from within various frameworks. These frameworks often vary with the scientists' disciplinary training and educational backgrounds, personal experiences, preferences, and opinions, and basic guiding assumptions and philosophies:

> 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, pre-questionnaire)
>
> Both conclusions are possible because they may be different interpretations of the same data. Different scientists may come up with different

> explanations based on their own education and background or what they feel are inconsistencies in another's ideas. (CS03, pre-questionnaire)
>
> That's [the controversy] is a complex question. (a) The particular scientist's background/personal beliefs may weigh into it. (b) The "school of thought" the scientist was trained in, his professors' ideas, etc. (c) Giving some elements from the "data set" more weight because of how it "feels" to them, as in intuition. (E156, pre-questionnaire)

Some participants noted that disciplinary commitments and preferences might also lead scientists to place disproportionate emphases on various "parts" of the data. A few of these participants (3%) referred to specific disciplines and explanatory preferences (especially terrestrial versus extraterrestrial explanations) that were relevant to the extinction controversy:

> Scientists are human and when the geophysicists get together and examine the evidence they are doing it from a certain perspective—that of a geophysicist, and tend to emphasize the geophysics data. The paleontologists come along, see the same data and interpret it from their perspective. Scientists, people of a certain ilk, see the world through rose tinted glasses. (S061, pre-questionnaire)
>
> There are different conclusions because the scientists have different backgrounds . . . And it is more a geologist or one group that are 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, you know, and that group is more into that and they are going to think that it was a meteor. I mean everything is going to have more than one theory, because different people are going to look at it from their own perspective. (S030, pre-interview)

Finally, during the interviews participants were asked, "Why would some scientists consider the idea of a meteor falling from the sky to be unacceptable or strange?" The question aimed to assess whether participants had any notion of the disciplinary commitments, such as geologists' implicit preference for uniformitarian explanations, relevant to the extinction controversy. Only one interviewee (see previous quote) provided an adequate answer to the question.

As such, the majority of participants (62%) attributed the controversy in one way or another to the lack of data. A small minority (17%) articulated clear understandings of the subjective or theory-laden nature of scientific knowledge.

Views of preservice science teachers.

Compared to 62% of all participants enrolled in the HOS courses, 40% of student teachers attributed the extinction controversy solely to the lack of data thereby excluding other subjective factors:

> The data set has holes that, if filled, would confirm or reject either of the hypotheses. Maybe there is some evidence for both but not enough . . . to tell if one of the hypotheses is correct. (M015, pre-questionnaire)
>
> The answers could be different because of *incomplete* data [italics in original]. They may discover more evidence in the future that rules out one of these two possibilities. (ME05, pre-questionnaire)

Appreciably more student teachers demonstrated an understanding of the subjective or theory-laden nature of scientific knowledge. Compared to 17% of all participants enrolled in the HOS courses, 47% of student teachers indicated that scientists' personal biases, educational backgrounds and training, and other subjective factors influence the way they perceive or interpret evidence. As such, it is possible for different scientists to derive different conclusions from the same set of data:

> Different conclusions are possible when scientists use the same set of data to derive their conclusions because of different interpretation. The human factor is involved. Scientists, based on their cultural and social upbringing, come to different conclusions when presented with the same data. (M016, pre-questionnaire)
>
> What an individual knows affects that person's decisions. These scientists probably have knowledge expertise in different subject areas from one another. Therefore, the knowledge affects their conclusions & produces different conclusions from the same set of data. (M018, pre-questionnaire)

Finally, two preservice teachers (13%) indicated that the extinction controversy is altogether "outside the realm of science." They demonstrated lack of understanding of the nature of evidence and hypothesis testing. They noted that personal biases and prejudices come into play in such "non-scientific" cases as the extinction controversy and result in data manipulation:

> In this question, I think that science crosses the fine line between "true science" and philosophy. The event that is described in the question was not observed, was not measured, and *is unable to be repeated in the laboratory* [italics added]. Because of these factors, this discussion moves beyond the realm of what science can accomplish. By moving beyond science, personal bias and prejudices can be freely introduced and . . . data can be massaged to support many different ideas. (ME04, pre-questionnaire)

Additional Attributes of Participants' Views of the NOS

The earlier sections explored participants' views of the empirical, tentative, subjective, inferential, creative, and imaginative nature of scientific knowledge. These sections also explicated participants' conceptions of scientific method, the experimental approach, and scientific theories and laws. Participants' responses to the NOS questionnaire and interview questions, nonetheless, shed some light on other noteworthy aspects. These aspects characterized the NOS views of the greater majority of participants including those enrolled in the HOS courses and preservice science teachers. Three of these aspects are discussed in the present section and include the meanings participants attached to the term "prove," the fragmented and inconsistent nature of participants' views of the NOS, and the relationship between participants' views and demographic and background variables.

The meanings of the term "prove."

The NOS questionnaire had no references whatsoever to the term "prove." However, as noted in earlier sections, many participants used the terms "prove" and "proven." Indeed, these terms were the ones most frequently used by almost all participants in one context or another. These terms were often used when participants attempted to delineate the differences between science and other disciplines of inquiry and to explicate the goals of experiments. The term "proven" was also frequently used to distinguish between scientific theories and laws. Additionally, participants often employed the term "prove" when discussing the mass-extinction controversy. As such, it should "prove" worthwhile to explore in some depth the meaning(s) that students attach to this term.

Participants' responses to the NOS questionnaire had some indications that they ascribed different meanings to the term "prove." For instance, some participants equated the term with providing "support" for a hypothesis as evident in the following quote, "An experiment is a designed test to prove or disprove/support or knock down an existing hypothesis" (C170, pre-questionnaire). However, many participants, as was indicated in the earlier discussion about participants' distinction between scientific theories and laws, used the term to refer to an "absolute truism" as evident in the following quote, "A law is something that is absolute. It has been proven" (E117, pre-questionnaire). These latter participants seemed to have used the term "to prove" in one of its most common connotations, that is "to establish as true; demonstrate to be a fact" (Neufeldt & Guralnik, 1996, p. 1082).

Out of 40 participants interviewed at the beginning of the present study, 28 (70%) had used the terms "prove" or "proven" in their responses to the NOS questionnaire. These participants were asked to explicate what they meant by these terms. They were also asked to explain how would scientists go about "proving" hypotheses, theories or laws. About 10% of these interviewees equated the term "prove" with collecting tangible evidence or "physical" data to support or "back up" a certain scientific claim. When asked what they meant by the term "prove," these participants replied:

> I think it's maybe gathering information in the physical world rather than other things. Like in religion, you can believe in religion but, and I guess that you can say you can prove it, but you cannot. It would be hard to prove religion in the physical world. (E145, pre-interview)
>
> That is what I mean by prove, naturally explaining and giving evidence rather than making a statement without backing it up. (ME09, pre-interview)
>
> [Prove means] to have some sort of concrete evidence that the hypothesis could possibly be true. (S030, pre-interview)

However, 39% of interviewees were aware of the connotations of the term "prove." They did not perceive "proving" as simply providing supportive "physical" evidence. These participants either indicated that "proving" a scientific claim or hypothesis is extremely difficult or noted that the term "prove" implies that a scientific claim is "factual," "absolute," "permanent," or "unequivocal:"

> You pretty much don't prove theories, I don't think. I think you can make them more likely or less likely but I don't know that you prove them 100%. To prove something is to give unequivocal evidence of how it is. I mean this is how it is, this is a fact, and no body can disclaim it or provide proof against it. I don't think that there are a lot of things that are proven in science. (E157, pre-interview)
>
> You can't prove a hypothesis . . . I don't know if you can really prove anything. Hypotheses are hard to prove. Prove is real absolute. (C171, pre-interview)
>
> I guess I hesitate to say we prove a theory. It seems like more of a concrete word. I mean, I think prove seems to me like a permanent term, whereas theories may not be permanent. (S026, pre-interview)

About one-half (54%) of these latter interviewees noted that a scientific claim cannot be "proven" but can only be "disproven." When asked to explain their position, one-half of these interviewees were not able to clearly articulate why they thought scientific claims cannot be "proven" as evident in the following quote and dialogue:

> We can't prove why it is true because, I don't know, there is just, in my mind, and this is kind of philosophical, I guess that in my mind it is just, how do we know what we think is the truth is the truth. You know there is no, to the best of our ability, how do we know that that is honestly the truth. (E138, pre-interview)
>
> Researcher: Why do you say a hypothesis can only be disproven and not "proven?"
> Participant: Well, I don't think that science, it is not true or not true, there is some reasonable, I guess there is a certain level of uncertainty, I guess, on whether something is more true than false. I guess that you can disprove something but you can't actually prove it.
> Researcher: And why can't scientists "prove" something?
> Participant: Because there is a certain amount of things, I mean . . . [long pause] . . . I guess I don't know why. (E088, pre-interview)

Only half of the interviewees who indicated that a scientific claim cannot be "proven" were able to explicate adequate justifications for their position. These participants noted that a scientific claim could not be "proven" because there is always the possibility that an instance "down the line" or in the future may not behave in accordance with a certain theory or law:

> Well, you can't even prove a law. In a sense you can say a law is just that, you know it has never been known to fail but maybe sometime down the line they'll do a test and it will fail. You can never be certain because you don't know what might happen in the future. You just don't have infinite knowledge. (E144, pre-interview)
>
> I don't think it [a law] can be proven because I think it only takes one counter example to disprove a law. The laws usually behave that way to a point within certain parameters. But you need only one counter example to disprove it. And you can't necessarily investigate all the possibilities everywhere. I don't necessarily think that you can prove one. (ME05, pre-interview)

In this regard, a few interviewees (7%) indicated that a hypothesis or theory is "going to be proven if they [scientists] are not able to disprove it" (E096, pre-interview). These participants, however, had a difficult time providing an adequate response to follow-up questions such as, "How many tests or how long would it take scientists before they ascribe the label 'proven' to something that is not yet disproven?"

Another 11% of interviewees indicated that scientists "prove" hypotheses and theories by conducting experiments. When explicitly asked how many experiments are needed to "prove" a scientific claim, these interviewees indicated that one or a few experiments would suffice if the results support the tested claim. These participants, nonetheless, did not seem to use the term "prove" in its "absolute" sense:

> If you have a theory and you wanted to prove it, I guess you would go out and design an experiment that would prove your theory, I guess. (E089, pre-interview)
>
> I think you start with a plan and you say I am going to prove this hypothesis and then you have the experiment and it either works or it doesn't . . . And I am not really sure that it is a matter of numbers. It is not really the quantity of the experiments. I can't give an example, but I think that the nature of some of the hypotheses on which you do experiments are very simple . . . like you know my hypothesis is that this enzyme creates this set of amino-acids. Then I would say you do the experiments half a dozen times and that proves it. (E166, pre-interview)
>
> I guess proving something, well, you have to do experiments first . . . And it depends, you know. If the experiment is done right, then one good experiment can allow you to prove the hypothesis, but it depends. (S043, pre-interview)

Finally, about one-third of interviewees (32%) seemed to ascribe to the inductive fallacy. These participants indicated that scientific claims could be proven true through repeated testing. If a hypothesis or theory is tested "over and over and over again," and if the results "came out the same again and again" then the hypothesis or theory is "proven" true:

> Researcher: You noted here that scientific theories could be "proven true." How would you "prove" a certain claim in science?
> Participant: We do experiments over and over and over again, experiments that someone else could reproduce and get the same results.
> Researcher: So, how many experiments does it take to "prove" some claim in science?
> Participant: I don't think that one or a few experiments are enough . . . I think that you need to be able of repeating the experiments a lot of times. (C177, pre-interview)
>
> I guess that when you do an experiment over and over and over and you get the same result like gravity then you prove something. (E153, pre-interview)
>
> To prove a theory basically you have to test it over and over again, and I guess that different scientists have to test it and see that it is replicable. And

> we have to be able to prove it over and over again and have basically now doubt that it is true. (S020, pre-interview)

As such, it is evident that the term "prove" means different "things" for different participants. A few participants used the term to refer to gathering tangible evidence, while others equated the term with conducting experiments. However, substantially more participants used the term "prove" in its more definitive or absolute sense. Some indicated that scientific claims can only be disproven but never "proven." Many of these latter participants, however, were unclear why it is not possible to "prove" scientific claims. Other participants thought that scientific claims can be "proven" given one or a few supporting experiments. Many others believed in the inductive fallacy. They indicated that scientific claims could be "proven" through repeated testing. Additionally, the same participants seem to have used the term "prove" in different senses in their responses to different items on the NOS questionnaire or to various questions during the interviews. The multiplicity of meanings ascribed to the term "prove" and the various ways participants thought scientists go about "proving" claims coupled with participants' indiscriminate use of the term seem to have resulted in some confusion or difficulty with what will be labeled here as the *proving dilemma*.

This dilemma was particularly apparent in participants' responses to the fifth item on the NOS questionnaire that asked them about the differences between scientific theories and laws. Some participants faced difficulties trying to "by-pass" or reconcile the conceptual and logical problems associated with adopting the view that scientific laws are somehow "proven" or "absolute" while at the same time recognizing the implausibility of "proving" any scientific claim as evident in the following quotes:

> A theory is something of interest that is still in the process of being tested. It has not been disproven, but for whatever reasons it has not given good enough correlation to support its validity either. A scientific law . . . also has never been disproven but it has never been disproven more. To the best of all party's knowledge it has been tested to the point that is believed that it can't be disproven. (S055, pre-questionnaire)
>
> Yes, there is a difference between a scientific theory and a scientific law. Evolution is a theory that cannot be disproven but is still not considered completely disprovable. It just has not been disproved. A law on the other hand, like the law of gravity, has not been disproved but it cannot be avoided. It *is* [italics in original], and is not being attempted to be disproved. (E126, pre-questionnaire)
>
> The difference between a law and a theory as I understand it is that a law is something that has been proven that it cannot be disproven. A theory is something that is widely accepted as a fact but the possibility for changing it could someday happen. In other words, a theory may be easily disproven than disproving a law. (E092, pre-questionnaire)

Thus, it should be noted that confusion about the meaning of the term "prove" has left many participants struggling to reconcile the acclaimed certainty of science with its well-documented tentativeness. At best, participants' conceptions of the term "prove" reflect inaccurate use of the term. However, participants' views might also reflect the belief that scientific claims can achieve an "absolute" status.

The fragmented nature of participants' views of the NOS.

The NOS views of a majority of participants lacked coherence. Participants' responses to the various items on the NOS questionnaire and interview questions were often typified by inconsistencies and, at times, outright contradictions. Such inconsistencies were idiosyncratic and few trends or patterns were notable. This section presents a few examples of the observed inconsistencies. The present section is intended to shed light on the fragmented nature of participants' views rather than comprehensively document all the noted inconsistencies and/or contradictions.

The responses of about 36% of all participants to the NOS questionnaire revealed one inconsistency or another. Such inconsistencies were often evident when a participant's responses to the various items were compared. For example, in her response to the sixth item on the NOS questionnaire that asked about the structure of the atom, this student noted that:

> In science nothing is certain. Scientists can't be certain about the structure of the atom. My personal knowledge in this field is limited, so I don't know the specific evidence that was used to determine the structure of the atom. (S020, pre-questionnaire)

However, in her response to the next item on the questionnaire that asked about the concept of species, the same participant indicated that:

> Scientists are pretty certain [about the characterization of species] . . . Specific evidence: geographical location, genetic similarity, and many more that I don't remember right off hand. (S020, pre-questionnaire)

These two items, it should be emphasized, were consecutive and spatially separated by the flip of a page.

Inconsistencies were sometimes evident in participants' responses to the same item on the NOS questionnaire. For example, the same participant indicated in her response to the fourth item that scientific theories *change* and are *constant* in the one and same paragraph:

> I believe they [theories] do *change* because as time goes on, our knowledge grows, so theories must change. We learn theories, for the most part because

> they are *constant* [italics added]. They explain science in a precise way. (S027, pre-questionnaire)

The fragility of participants' views was also apparent when their responses to the NOS questionnaire were compared with their responses to the interview questions. Such inconsistencies, however, were not frequent. Nonetheless, they are noteworthy because participants were provided their NOS questionnaires during the interview and asked to consult their written responses before elaboration or follow-up questions were asked of them. For example, in his response to the fourth item on the NOS questionnaire, a preservice science teacher noted that "theories change (the very nature of science is tentative). Therefore, all science (theories included) is subject to change" (M018, pre-questionnaire). As such, this participant explicitly expressed his belief in the tentativeness of scientific knowledge and "all of science" for that matter. However, as evident in the following dialogue, the same preservice teacher seemed to believe that experiments can be used to "prove" scientific claims which then become "constant:"

> Researcher: You said here that science is looking at the world in a prescribed way. What do you mean by that?
> Participant: Science is cut and dry and you are going to look in, scientists you know have a prescribed way . . . You have to make a proof, you have to prove it or disprove it with experiments. And the experiments have to be repeatable and then when the experiments are in agreement, then it becomes a *constant* and you *prove it* [italics added]. (M018, pre-interview)

Another participant indicated in his response to the third item on the NOS questionnaire that experiments "are required to develop scientific knowledge. Without trial and error and creative thinking and doing the experiments to test theory, there is no way to 'prove' scientific truth" (E137, pre-questionnaire). When asked to elaborate on his response during the pre-instruction interview, the same participant indicated that experiments are not required because disciplines such as ecology may only rely on observation:

> Researcher: Does the development of scientific knowledge require manipulative experiments?
>
> Participant: [After reading his response in the questionnaire] I am disagreeing with my own answer, that's funny. I originally said yes. But you know, okay I see. I said yes because you do also thought experiments to prove your theory or base your theory off of. And you still get your hypothesis even though your are not actually physically in a lab. In ecology we just observe for example. (E137, pre-interview)

However, inconsistencies were frequently revealed when follow-up or probing questions were asked of participants during the pre-instruction interviews. Such inconsistencies were evident in the case of the majority of interviewees (54%). One of the most frequently noted inconsistencies was the discrepancy between participants' responses to the first and eighth questions that asked, "What makes science different from other disciplines of inquiry?" and "Do scientists use imagination and creativity in their investigations?" respectively. In delineating science from other disciplines of inquiry, participants often indicated that science is rigid, systematic, or divorced from individuals' opinions, beliefs, or interpretations. However, in their responses to the eighth question, many of these participants noted that scientists use their imagination and creativity to interpret the results of experiments. The following dialogue embodies an example of this inconsistency in participants' views. It should be noted that the participant in this example did not recognize the discrepancy in his views:

Researcher: What, in your view, is science? What makes science different from other disciplines of inquiry? [Question #1]

Participant: Science isn't so much explaining something . . . like history explains why something happens. Science is the search for knowledge . . . Things for which there is evidence. The facts as they are finally presented without any kind of, sort 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 . . . .

Researcher: You indicated in your questionnaire that scientists use imagination and creativity. Can you elaborate on that? [Question #8]

Participant: I think they have to. There is no way to get around it. If they went straight with the facts, you can't go from having a set of facts to having a conclusion without in a way tying all those facts together. The facts themselves don't directly point and say 1 + 1 = 2. You have to take them and interpret them to come up with something.

Researcher: Let me take you back to the first question. You basically said that science differs from other disciplines in that science takes "the facts as they are finally presented without any kind of . . . human interpretation." And then you said, "In religion and philosophy we interpret everything and not just take it for how it is plainly right there as we see it." Now, it seems that you are saying there is a role for human interpretation, imagination and creativity in science. Do you see any tension between these two notions? And if yes, how would you reconcile these seemingly opposing elements in science?

Participant: You can still be creative about it if your creativity doesn't interfere with the information you are receiving and the information that you are putting out. I guess I don't see a conflict between the two ideas. (E093, pre-interview)

The following dialogue is another example of the discrepancy between participants' views of the "objective" NOS and their indication that science involves "subjective" factors such as imagination, creativity, and personal beliefs. However, it should be noted that unlike the previous student, the participant in the present case realized the "contradiction" and attempted to reconcile his relatively disparate positions:

> Researcher: What, in your view, is science? What makes science different from other disciplines of inquiry? [Questions #1]
>
> Participant: I think science has a systematic way about it rather than abstract or really liberal way of thinking about the world and things and how things are discovered. It is more rigid, less philosophical, like, you know, it is more like a systematic way . . . .
>
> Researcher: Do scientists use their creativity and imagination during their investigations? [Question #8]
>
> Participant: It is used in the beginning . . . and then in interpreting the data as well. The data is data; it is not one way or the other. So, it is up to you to come up with some sort of creative, imaginative explanation to explain it. And different scientists come up with different interpretations because they are all individual and they have creativity about how things work . . . .
>
> Researcher: It is very reasonable to say that the available evidence supports both extinction hypotheses equally well. However, scientists in the two groups are very adamant about their own hypothesis. Why is that? [Question #9]
>
> Participant: Because individual scientists have some very strong beliefs about their work and it is very personal for them. And nobody likes to be told that they are wrong, that's for sure. I think that there is less compromise in science than in other things.
>
> Researcher: Going back to the first question, you said that science is a more "rigid and less liberal" way of thinking. But now it seems you are saying scientists' beliefs, individuality, and creativity affect the way they think about science. How is that possible?
>
> Participant: That's true, it is kind of a contradiction almost. But still I say overall though the way that they have to approach the data collection. I think that the liberal interpretation of their work or liberal aspect of their work play a part but they don't play a total part in what they do versus things like religion or philosophy where it is more liberal overall. (C177, pre-interview)

In another example of the fragmented nature of participants' views of the NOS, one participant indicated that theories *do* change and then noted that theories *do not* change in her response to the same question as evident in the following dialogue:

> Researcher: After scientists have developed a scientific theory, does the theory ever change?
>
> Participant: I said theories *do change* because theories, like evolution, people come up with theories on how the world evolved. And those theories, I think that theories change because there would

> be other people who come up with more theories and prove it, try to prove it. I think that theories *don't change* because the old ones are still there [italics added]. A theory is just a theory.
> Researcher: What do you mean by "it is just a theory?"
> Participants: It is just a theory. Theories are, I don't know, just theories.
> Researcher: So do you think that theories change or do not change?
> Participants: I just contradicted myself. Well, I guess theories change. (E151, pre-interview)

In a final example, one participant used the term "prove" in her response to the first question during the interview. When asked how would scientists "prove" scientific claims, the participant noted that "nothing" could be "proven" in science. However, when elaborating on her response, the same participant then noted that a scientific hypothesis could be "proven" through repeated testing:

> Researcher: What, in your view, is science? What makes science different from other disciplines of inquiry?
> Participant: I basically said science, you have right and wrong answers and you have a hypothesis, you have a test it, you go through and you prove or disprove your hypothesis.
> Researcher: How do I "prove" a hypothesis?
> Participant: You test it.
> Researcher: Fine. So I tested a hypothesis and the result came out positive. Did I "prove" the hypothesis?
> Participant: I don't know if you proved it, like this is definitely the right answer. Maybe you validate your hypothesis. You don't necessarily prove anything because somebody might do the same experiment and come up with a totally different. So, I guess you don't prove anything. I guess when you do an experiment over and over and over and you get the same result over and over and over then you prove something. (E156, pre-interview)

As such, it can be seen that the majority of participants lacked a coherent framework for their *own* ideas about the nature of scientific knowledge. The views of many participants were "internally" inconsistent and fragmented. They seemed to hold compartmentalized views regarding various aspects of the NOS. Very few or no connections seemed to bridge their conceptions. Checks for consistency or coherence among those views also seemed to be lacking. However, these aspects of participants' views of the NOS should not be surprising. Many participants indicated that they have not thought about several of the issues asked of them during the present study. Many of them indicated during the interviews that they have not really thought about one question or that they were thinking "on their feet" about another as evident in the following quotes:

> Researcher: Do scientists use a specific method, in terms of a certain step-wise procedure, when they do science?
> Participant: No, I am not thinking of a particular method. I am thinking that generally it is structured . . . I think and I realize this as we talk right now, other backgrounds are more similar to science than I originally thought. I am kind of working this in my head right now. (E131, pre-interview)

> Researcher: What is an experiment?
> Participant: I think of it as having a control then also your experimental group, class or whatever. And then you have a control that you know works and you know it is the right thing that you have decided to test the difference in. An then you do it and see if you come up with a different answer. That's how I see it, you are forcing me to think about all this now. (E089, pre-interview)

> Researcher: So, how many times do scientists repeat those tests before they consider that the hypothesis has been "proven?"
> Participant: I don't know, I've never though about that. Like gravity, obviously things are going to fall. But . . . how did they take into account the wind blowing something this way, you know. Things appear to be falling faster, like iron balls as compared to feathers. You know the feather has so many more variables. I am just not sure. (S062, pre-interview)

The relationship between participants' views and demographic and background variables.

Systematic analyses were conducted to determine whether participants' views of the NOS were related to their gender and background variables, including class standing, major, and science, HOS, and philosophy of science backgrounds. As noted earlier, summaries of each participant's conceptions of the NOS were generated and coded under the aforementioned aspects. The pre-instruction summaries were used to generate profiles for participants' pre-instruction views when grouped according to the relevant variables. For instance, profiles of undergraduate and graduate participants' views were generated. These profiles were compared and contrasted, and patterns were sought.

Analyses revealed no notable patterns or trends when participants' views were grouped according to gender, and class standing (graduate versus undergraduate). When grouped according to major (biological, geological, and agricultural sciences, general science, MAT, and other majors), preservice teachers' views of some aspects of the NOS were appreciably different from those of other participants. These differences were elucidated in the previous sections.

Additionally, participants' views of the NOS were not related to their history and philosophy of science background (participants who took history and/or philosophy of science courses versus participants who took no such courses). In this regard it should be noted that an overwhelming majority of participants (85%) had no prior instruction in the history and philosophy of science. Moreover, the greater majority of participants who had such instruction completed *only* one course in the history and/or philosophy of science.

Finally, participants were grouped according to the number of science credit hours completed. Participants were divided into four groups that corresponded to those who completed 0-18, 19-36, 37-60, and more than 60 science credit hours. This grouping, it should be noted, respectively corresponds to the number of science credit hours typically completed by science majors by the end of sophomore, junior, and senior year, and the number of science credits required for post baccalaureate science studies. Analyses revealed no notable trends or patterns when participants' views of the NOS were compared across the four groups. As such, participants' conceptions of the scientific endeavor were not related to their science backgrounds.

Summary

The overwhelming majority of participants enrolled in the HOS courses (90%) did not seem to believe that scientific knowledge is tentative. Alternatively, the responses of a corresponding majority of preservice teachers (97%) indicated that they ascribe to a tentative view of science.

Similarly, an overwhelming majority of participants enrolled in the HOS courses (82%) did not demonstrate adequate views of the empirical NOS. They either indicated that tangible data could be used to "prove" the "truth" of scientific claims or that science is solely based on observations of the physical world to the exclusion of other personal, social, or cultural attributes. Only a small minority of participants (4%) explicitly noted that even though science relies on evidence and observation, there is much in science that is based on beliefs, assumptions, and the non-observable. By comparison, 40% of preservice science teachers explicated adequate conceptions of the empirical nature of scientific knowledge.

Without any prompts, an equal percentage (about 25%) of participants enrolled in the HOS courses and preservice teachers indicated that science is characterized by the use of a single method. However, only a minority of preservice teachers (12.5%) expressed this view when specifically asked during the pre-instruction interviews. By comparison, when explicitly asked, the larger majority of participants enrolled in the HOS courses (85%) indicated that scientists follow "The Scientific Method" or other sets of logical and orderly procedures.

An overwhelming majority of participants enrolled in the HOS courses (81%) did not demonstrate adequate conceptions of the general goal and/or structure of scientific experiments. These participants did not ascribe any element of control, manipulation or intervention to experiments, did not explicate a clear aim for conducting experiments or believed that experiments could provide *definitive* answers regarding the "truth" of hypotheses or theories. Additionally, only about one-third of participants (28%) explicated a clear understanding of the crucial role of prior expectations in designing and conducting scientific experiments. Moreover, only 25% of 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 rest solely on observations.

Preservice teachers' understandings of the structure and goal of experiments, the role of prior expectations in designing and conducting experiments, and the validity of observationally-based scientific claims were not different from those of participants enrolled in the HOS courses. Only 33% of preservice teachers demonstrate adequate conceptions of experiments and 25% endorsed the importance of having expectations prior to conducting experiments. Only one student teacher (7%) that demonstrated a clear understanding of experiments noted that the development of scientific knowledge does not require experiments and provided an adequate example to support this view.

The greater majority of participants (77%) indicated that theories do change. However, 75% of the participants did not provide examples or provided inadequate examples to substantiate this position. Almost all participants attributed theory change *solely* to new information and technologies. Only 6% of the students recognized that new ideas and theories as well as social and cultural factors might also play a role in theory change. Additionally, the majority of participants did not demonstrate adequate understandings of the functions of scientific theories. Only one-third of the participants recognized the explanatory function of scientific theories and 13% recognized the role of theories as guiding frameworks for research. Only 4% of the participants demonstrated adequate understandings of the well-supported nature of scientific theories. Moreover, a majority of participants lacked in their understanding of the nature of theory testing. Participants did not seem to understand that only indirect evidence could be used to support theories.

By comparison, 20% of preservice teachers noted that in addition to new information and technologies, theories might change due to the reinterpretation of extant data, new insights and perspectives, and changes in values. The greater majority of preservice teachers (80%) provided adequate examples of theory change and 60% of them recognized the explanatory function of scientific theories. However, only 13% made explicit references to the well-supported nature of scientific theories and demonstrated adequate understandings of the role that theories play in guiding research. Finally, the responses of 20% of preservice teachers indicated that they do not understand the nature of testing scientific theories and hypotheses.

An overwhelming majority of participants enrolled in the HOS courses (90%) believed that scientific laws are absolute or certain. And about one-third of participants provided inadequate examples of scientific laws. Additionally, 97% of participants held a hierarchical view of the relationship between scientific theories and laws whereby theories become laws with the accumulation of supporting evidence. By comparison, the greater majority of preservice teachers (87%) demonstrated adequate understandings of the functions of and relationship between scientific theories and laws. Only two preservice teachers (13%) held a hierarchical view of this relationship and one (7%) seemed to believe that laws are absolute. Finally, it is noteworthy that the greater majority of student teachers (93%) provided adequate examples of scientific laws.

Views of the imaginative and creative NOS of participants enrolled in the HOS courses and those of preservice teachers did not differ. The overwhelming majority of all participants (90%) indicated that imagination and creativity are needed in scientific investigation. Participants, however, assigned imagination and creativity to various stages of investigation including planning and design, data gathering, and the stages following data collection. About 40% of participants thought that imagination and creativity permeate all stages of scientific investigation and another 40% indicated that scientists only use imagination and creativity in the planning and design stages of investigation.

About 15% of participants indicated that scientists use imagination and creativity in all stages of investigation except when collecting data.

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 these terms in the context of science. Among the meanings that participants included under the label of creative and imaginative activities in scientific investigations were being resourceful, skillful, open-minded, and curious, using appealing ways to present results, and not copying other scientists' designs and experimental procedures. Only about 16% of participants indicated that scientists use imagination and creativity in the sense of inventing explanations, models or theories to explain the patterns in the phenomena that they investigate. Finally, the vast majority of participants (94%) did not provide any examples or provided inadequate examples to support their views concerning the use of imagination and creativity in science.

Only about 30% of participants enrolled in the HOS courses 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. An alarmingly high percentage of participants (25%) thought that scientists are certain about the structure of the atom because high-powered electron microscopes were used to determine what an atom "looks" like. Appreciably more student teachers demonstrated adequate understandings of inference and inferential entities in their discussions of the structure of the atom. A majority of preservice teachers (73%) indicated that the structure of an atom is a *model* intended to explain observations of the behavior of atoms in reaction to various experimental manipulations. However, preservice teachers' views of species were not different from those of participants enrolled in the HOS courses. More than one-half of all participants indicated that scientists are *certain* about their characterization of species. Only a minority of all participants (16%) demonstrated adequate conceptions of theoretical entities through their discussions of the concept of species. They noted that "species" is a human construct, or part of a man-made classification system intended to help scientists bring some order to the enormous variety between and among various groups of organisms observed in nature.

The majority of participants enrolled in the HOS courses (62%) attributed the mass-extinction controversy to the lack of evidence thus failing to recognize that factors other than "data" might play an important role in generating and supporting scientific claims. Only about 17% of participants explicated adequate understandings of the subjective (or theory-laden) nature of scientific knowledge. These participants indicated that the 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. Some participants noted that disciplinary commitments and preferences might also lead scientists to place disproportionate emphases on various "parts" of the data. A few of these participants (3%) referred to specific disciplines and explanatory preferences (especially terrestrial versus extraterrestrial explanations) that were relevant to the extinction controversy. By comparison, 40% of student teachers attributed the extinction controversy solely to the lack of data thereby excluding other subjective factors. Appreciably more student teachers (47%) demonstrated an understanding of the subjective or theory-laden nature of scientific knowledge.

As such, compared to participants enrolled in the HOS courses, a substantially larger percentage of preservice science teachers held adequate views of the tentative, empirical, and subjective nature of scientific knowledge. Also, relatively more student teachers demonstrated better understandings of the explanatory function of scientific theories, the relationship between scientific theories and laws, and the role of inference in generating scientific knowledge (when discussing of the structure of the atom). It should be noted that differences between preservice science teachers' views of the NOS and those of participants enrolled in the HOS courses were expected given that preservice teachers had received *explicit* instruction on several aspects of the NOS in the Summer Science Methods/Practicum I course prior to their participation in the present study.

However, preservice science teachers' views were not different from the views of participants enrolled in the HOS courses regarding several other aspects of the NOS. These aspects included the general aim and structure of experiments, the validity of observationally based scientific disciplines, the role of scientific theories as frameworks for guiding future research, the logic of hypothesis and theory testing, and the creative NOS.

Several other attributes characterized the NOS views of participants in the present study. First, many participants lacked in their ability to provide any examples or adequate examples from the history or practice of science to support or defend their views. Participants' inability to provide examples was pronounced in their discussions of experiments, observationally based scientific disciplines, theory change, scientific laws, and the creative nature of scientific knowledge.

Second, participants seemed to use the term "prove" indiscriminately. They ascribed a variety of meanings to the term and explicated various ways with which they thought scientists go about "proving" scientific claims. A few participants used the term to refer to gathering tangible evidence, while others equated the term with conducting experiments. However, substantially more participants used the term "prove" in its more definitive or absolute sense. Some participants thought that scientific claims can be "proven" given one or a few supporting experiments. Many others believed in the inductive fallacy. They indicated that scientific claims could be "proven" through repeated testing. This confusion about the meaning of the term "prove" left many participants struggling to reconcile the acclaimed certainty of science with its well-documented tentativeness.

Third, the NOS views of a majority of participants were fragmented. Inconsistencies and the lack of a coherent framework typified these views. Participants seemed to hold compartmentalized views regarding various aspects of the NOS. Few or no connections seemed to bridge their conceptions. Many participants indicated that they have not thought about several of the issues asked of them during the present study. Finally, systematic analyses indicated that participants' views of the NOS were not related to their gender and background variables, including class standing, and science, HOS, and philosophy of science backgrounds.

Changes in Participants' Views of the NOS

Eight aspects of the NOS were emphasized in the present study. These aspects included the tentative, empirical, inferential, creative, and subjective (theory-laden) nature of scientific knowledge. Additional aspects included 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 were highlighted. Three additional aspects emerged from analysis of participants' responses to the NOS questionnaire and interview questions. These aspects included 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.

Analyses of post-instruction NOS questionnaires and interview transcripts revealed little change in participants' views of the aforementioned aspects of the NOS. Change was evident in the views of a relatively small minority of students enrolled in the investigated HOS courses. Moreover, almost all the changes in individual participant's conceptions were related to *only* one aspect of the NOS or another. The views of only four participants (3%) changed in regard to two or three aspects of the NOS emphasized in the present study. The post-instruction responses of *none* of the participants revealed substantial change with regard to NOS views. Moreover, no significant patterns typified the observed changes.

A comprehensive profile of all participants' post-instruction NOS views or profiles of participants' views in the individual HOS courses are not presented in the current section. Such profiles are so similar to the pre-instruction profile in almost every respect that the few observed changes would be hardly discernable. Alternatively, the present section provides detailed descriptions of the *changes* that were evident in the views of participants enrolled in each of the HOS courses.

The post-instruction views of the five preservice science teachers enrolled only in the Methods course were not different in any respect from their pre-instruction views. Indeed, such changes were not expected given that NOS was not addressed throughout the Fall Science Methods II course. As such, any changes in the views of participants in the focus group (preservice teachers simultaneously enrolled in the Evolution and Methods courses) could be attributed to their experiences in the Evolution course.

In addition to explicating changes in participants' views, the present section describes those participants' views that were enriched. As indicated earlier, in their pre-instruction questionnaires many participants failed to provide, or provided inadequate examples from the history or practice of science, to support their views. Participants' views of an aspect of the NOS were considered to be enriched if those participants provided in post-instruction questionnaires specific examples discussed in a HOS course to support or defend their views regarding the target aspect. It should be noted that these participants' views were indistinguishable from their pre-instruction views save the additional adequate examples that were provided.

The Survey Course

Change was evident in the views of seven participants (16%) enrolled in the Survey course. Nonetheless, the observed changes in the views of six of these participants (86%)

were *only* with regard to one aspect of the NOS or another. The views of only one participant changed with regard to two aspects of the NOS.

One participant had indicated in his response to the pre-instruction questionnaire that experiments are required for the development of scientific knowledge. At the conclusion of the Survey course the same participant noted that experiments are not necessarily required for developing scientific knowledge since "astronomy and cosmology are largely experiment-free" (S043, post-questionnaire).

Three other participants recognized a role for new ideas in theory change after having indicated in their pre-instruction questionnaires that new information and technologies are solely responsible for changing scientific theories. Now, these participants seemed to believe that new *ideas* could result in theory change if they better *explain* extant observations:

> Theories change because someone came up with a better idea that more accurately explains the outcome of the experiments. (S028, post-questionnaire)
>
> I think theories change because everyone has their own ideas on how to explain the workings of things . . . A new person may come along challenging an old idea and develop another idea that seems to "fit" the observed truths better, replacing or modifying the first theory. (S034, post-questionnaire)
>
> I think that scientific theories do change. And they change due to new technology and new ideas . . . Like when they had the geocentric model in which the earth is at the center 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, post-interview)

Three more participants demonstrated adequate conceptions of the theoretical or arbitrary nature of the concept of species after having indicated at the beginning of the study that scientists are *certain* about the notion of species given years of observation and experimentation. These participants now indicated that the notion of species is not necessarily a characteristic of nature. Rather, "species" is a human-made tool intended to help scientists classify, understand, and communicate about organisms:

> I think the existing taxonomy works pretty well. Not everything fits perfectly. But nature didn't grow and develop according to our characterization. We just use it as a tool to help us understand and communicate about organisms we share our world with. (S055, post-questionnaire)
>
> Well, species, it is not like Mother Nature out there is saying, okay, there is a kingdom and phylum, you know. This is what we put on them, that's kind of our way of seeing things and we set the rules of the classification. (S039, post-interview)
>
> I don't think that they [scientists] are very certain . . . I think the concept of species helps them to classify and to understand. Like in a scientific group when they are talking about the taxonomy they need to have an exact language to talk about these things. (S053, post-interview)

Additionally, one participant attributed the mass-extinction controversy in her response to the pre-instruction questionnaire solely to the lack of data. Her response to the post-instruction questionnaire indicated a better understanding of the role of subjective factors; particularly background knowledge and personal preferences, in influencing the conclusions scientists derive from available data:

> Depending on the background knowledge of a scientist, different conclusions may be drawn. Also, sometimes scientists will try to find a different theory simply because they believe another cannot be true. (S048, post-questionnaire)

Moreover, it is noteworthy that with the exception of one student (2%), none of the participants enrolled in the Survey course used any of the examples discussed in the course to support any of their views of the NOS.

Finally, during the post instruction interviews participants were explicitly asked whether their views regarding the NOS questionnaire items had changed. All 10 interviewees indicated that their views have not changed as evident in the following quote:

> I don't know that my views have changed. My ideas about science are still pretty much the same. I think my ideas about like all these questions and issues are pretty much the same. (S028, post-interview)

The Controversy Course

Change was evident in the views of three participants (20%) enrolled in the Controversy course. The change in these participants' views was *only* in regard to one aspect or another of the NOS. The conceptions of five other participants (33%) were enriched as evident by these participants' use of examples or case studies discussed in the course to support their views. These latter participants' views, it should be emphasized, were not different from their pre-instruction views.

In his responses to the post-instruction questionnaire, one participant demonstrated better understandings of the theory-laden nature of scientific knowledge. This participant had made no references to this aspect of science in his pre-instruction questionnaire. However, in the post-instruction questionnaire he noted that "scientific theories provide us with a way of viewing the universe with a certain framework in mind" (C172, post-questionnaire). Also, in his discussion of experiments, this participant seemed to realize the importance of having expectations prior to designing or conducting an experiment. He noted that “an experiment is a process initiated with some expected result in mind” (C172, post-questionnaire). Moreover, his understanding of the subjective or theory-laden NOS was evident in his response to the ninth item on the NOS questionnaire. This participant had indicated in his response to the pre-instruction questionnaire that the mass-extinction controversy is due to the lack of data. Now, the participant recognized the role of scientists’ theoretical commitments and personal beliefs in guiding their interpretation of data:

> It is possible to reach different conclusions based upon the same set of data because scientists are “reading” the data and drawing conclusions with *their* theory in mind [italics in original]. Those believing in extraterrestrial causes of extinction read the data with reference in mind to meteorites and their associated evidence of crash, like iridium, etc. Those believing in terrestrial causes, view the evidence (like iridium) in terms of their theory of volcanic eruptions and evidence of their occurrences. (C172, post-questionnaire)

As evident in this latter quote, the participant substantiated his view of the theory-laden NOS with the specifics of the mass-extinction controversy. 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. Compared to her pre-instruction views, this participant demonstrated more adequate conceptions of the influence of subjective factors, such as training and personal beliefs, on the conclusions that scientists draw from data as evident in the following quote:

> Scientists who prefer volcanic eruptions do not believe in meteorites. While meteorites are more accepted nowadays, some scientists still prefer a "more-down-to-earth" terrestrial explanation (i.e., volcanic eruptions). (C183, post-questionnaire)

On completion of the Controversy course, a third participant demonstrated a better understanding of the controlled nature of scientific experiments. This participant had indicated in her pre-instruction questionnaire that "an experiment is the observation of circumstances to discover a result" (CS02, pre-questionnaire). In her post-instruction questionnaire, the same participant noted that "usually a scientific experiment involves two groups—one of which is controlled and the other is not. Both are then compared to each other" (CS02, post-questionnaire).

As noted earlier, the views of five other participants were enriched. Three of these participants had indicated at the beginning of the present study that scientific theories do change due to new information and technologies. However, none of these participants had provided examples to support their views. On their post-instruction questionnaire these participants provided such examples. Two of them referred to the shift from a geocentric to a heliocentric conception of the solar system. The third participant cited the change from Newtonian physics to Einstein's theory of relativity as an example of theory change. Both examples were discussed in the Controversy course.

Another participant provided the Michelson-Morley experiment as an example to support his view that scientists use imagination and creativity in their data collection procedures. This participant's views were also enriched in another respect. On his pre-instruction questionnaire he indicated that scientists' background and education affect their interpretation of data. However, as evident in the following quote, he did not provide any examples to support his position:

> Both conclusions are possible because they may be different interpretations of the same data. Different scientists may come up with different explanations based on their own education and background or what they feel are inconsistencies in another's ideas. (CS03, pre-questionnaire)

The same view was conveyed in his response to the post-instruction questionnaire. Nonetheless, in this case the participant referred to the mass-extinction controversy discussed in the course to substantiate his view:

> Scientists are very much influenced by their training which will affect how they interpret the data or even what data they consider to be significant. These scientists who have access to the same data, but draw different conclusions represent different traditions within science in terms of training. They have been educated in a certain point of view based on their discipline: geologists will look at terrestrial evidence in rocks, whereas astrophysicists may look for evidence that supports extraterrestrial causes. (CS03, post-questionnaire)

Another participant noted on her pre-instruction questionnaire that "scientists use creativity and imagination during their investigations . . . to come up with plausible explanations for the data" (C183, pre-questionnaire), but provided no examples to support her views. In her post-instruction questionnaire this participant provided two examples from the Controversy course to support her views:

> Without imagination and creativity no one could have come up with ideas as to what caused the extinction of the dinosaurs. [And] . . . the general question of human origins involves imagination when paleontologists think up ideas such as the multi-regional theory or the out-of-Africa theory to explain where the first humans came from. (C183, post-questionnaire)

Finally, when specifically asked during the post-instruction interviews, four of five interviewees indicated that their views have not changed. Only one interviewee noted that his views have "matured a little bit just in the way of looking at things. Like just thinking of the social events, the eras, and the time periods" (C172, post-interview). Indeed, as indicated earlier, change was evident in this latter participant's views of the theory-laden NOS.

The Evolution Course

Change was evident in the views of 35 participants (37%) enrolled in the Evolution course. Six of these participants were preservice science teachers in the focus group (i.e., preservice teachers simultaneously enrolled in the Methods and Evolution courses). However, the views of 32 of these participants (91%) changed *only* with regard to one aspect of the NOS or another. Additionally, the views of 18 participants (19%) were enriched as evident in their use of examples discussed in the Evolution course to substantiate their views. Again, it should be noted that the views of these latter 18 participants were not substantially different from their pre-instruction views.

Preservice teachers in the focus group are of special interest for the purposes of the present study. As such, changes in these preservice teachers' views of the NOS are discussed separately from changes in the views of other participants enrolled in the Evolution course. As noted earlier, no changes were evident in the views of the preservice teachers enrolled only in the Methods course. As such, changes in the views of preservice teachers in the focus groups could be attributed to their experiences in the Evolution course.

Changes in the views of the Evolution course participants excluding preservice teachers.

Change was evident in the views of 29 participants enrolled in the Evolution course. Nonetheless, the views of 28 of these participants (97%) changed *only* with regard to one aspect of the NOS or another. The views of one participant (3%) changed with respect to two aspects of the NOS.

In their responses to the pre-instruction NOS questionnaire, 12 participants enrolled in the Evolution course had indicated that scientific theories do not change and/or theories are *only* modified and refined. In post-instruction questionnaires, four of these participants noted that "scientific theories change all the time [due to] . . . new info from new technologies and research" (E127, post-questionnaire). All four participants attributed theory change to new information and technological advances.

Five other participants recognized a role for new ideas, theories or social and cultural factors in theory change. Also, two of these participants noted that scientists' personal experiences and beliefs might lead them to advance new ideas that challenge existing theory:

> A theory can change if something like a longstanding belief is not true anymore like . . . after Darwin's introduction of the theory, the scientific community more readily accepted his theory because they believed it was true . . . I think he had some kind of compelling views that changed their minds somewhat. And people at the time were pushing more toward the enlightenment and scientific ideas and they were searching more for

> scientific ways of viewing things rather than religious ways of viewing things. (E114, post-interview)
>
> Theories change because of new information but also, and probably more important, people have different personalities and different perspectives on life and different life experiences . . . And new information and also old information as well are related. If I don't agree with the theory of evolution I am going to be checking out what they missed, or if I believe it I am going to go out and get more support to it. (E148, post-interview)

At the conclusion of the Evolution course six other 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, 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:

> We learn scientific theories because they assist in pointing the direction of future research. (E159, post-questionnaire)
>
> Darwin's theory . . . was like a catalyst, like many people were not thinking along those lines and then Darwin suggested the idea of evolution by natural selection and it was a catalyst. It got people going along that direction. (E104, post-interview)
>
> A theory . . . kind of gives a direction to go for more study. And if you reach an end and it is a dead end, you still learn a lot on the way. I mean on the way of studying evolution we learned a lot about genetics and that changed a lot about variations and where do they come from . . . I think by studying evolution scientists learned a lot about other things. (E099, post-interview)

Five other participants had indicated on their pre-instruction questionnaires that scientific experiments are *required* for the development of scientific knowledge. As evident in their responses to the post-instruction questionnaire, these participants demonstrated better understandings of the validity of scientific claims derived from and supported by observational studies:

> No, experiments are not required. Scientific knowledge can be acquired through observation. An example are field biologists or naturalists. Observation alone with previously acquired knowledge are what led Darwin to his theory although there is no way to test evolution with an experiment. (E109, post-questionnaire)
>
> No. Observational data can be accumulated and theories can be developed without experiments. These theories can lead to other ideas that increase scientific knowledge. Darwin used observational data and developed a theory about the origin of species. (E129, post-questionnaire)

Change was evident in the views of six other participants regarding the concept of "species." At the beginning of the study, these participants had indicated that scientists are *certain* about their characterization of species. Now, these participants indicated that the concept of "species" is a human construct, an attempt to classify organisms in nature. 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:

> When I was reading the *Origin of Species* I read about varieties and species and I started thinking about that and I realized that there may be no lines. 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. And based on similar characteristics, I think we take the characteristics of animals and place them together. (E117, post-interview)
>
> As Darwin discusses in the *Origin*, there is no definite line between species and there are many varieties in between. Scientists classify those in between varieties according to what fits with their beliefs on how it evolved. (E094, post-questionnaire)

Three other participants demonstrated better understandings of the theory-laden or subjective nature of scientific knowledge. In particular, they noted that scientists' training influences their acceptance or rejection of scientific theories. Additionally, scientists' perspectives and personal beliefs may lead them to advance several theories to explain the same set of data. These participants provided specific examples discussed in the Evolution course to substantiate their views:

> It is easy to interpret the same data differently when two people are trained to think in particularly different ways. For example, people in France were trained and influenced by Cuvier who promoted the species type concept and catastrophism, so the French did not believe or accept Darwin's natural selection. (E164, post-questionnaire)
>
> I think it happens a lot in science. You have a set of data and you have different people. Like in evolution there is the same idea of evolution but there are so many different mechanisms coming from people from many different disciplines trying to explain it. You know, Paley was explaining variety in species in terms of the design concept while someone like Darwin or people in modern evolution like Huxley explain it from what they knew about genetics. The same evolution but different ideas for how it happens. (E095, post-interview)

Finally, one participant explicated more adequate views of the creative NOS. In her pre-instruction questionnaire, this participant had used "creativity and imagination in science" to refer to scientists' resourcefulness. In her post-instruction questionnaire, this participant noted that scientists, such as Darwin, use imagination and creativity to formulate theories intended to explain the observations available to them:

> Yes. Scientists must use creativity and imagination to a certain degree. For example, Darwin was very imaginative to formulate his theory that explained all his observations and the observations of others about species and geographical distribution. (E120, post-questionnaire)

The views of 15 other participants enrolled in the Evolution course were enriched. Twelve of these participants had indicated in their responses to the pre-instruction questionnaire that scientific theories do change but provided no examples or inadequate examples to support this view. All 12 participants cited the theory of evolution as an example of theory change in their post-instruction questionnaires. Additionally, without providing any examples, two other participants had noted at the beginning of the study that experiments are not required for the development of scientific knowledge and that such knowledge could be based on observations of the natural world. These participants now cited the theory of evolution as an example of a scientific theory built on observational data.

Finally, at the beginning of the study one participant had noted that "scientific theories are used to explain vast amounts of data with a fairly simple set of concepts. Laws are developed as the result of consistent results from experiments or observations" (ES01, pre-questionnaire). As such, this participant had an adequate view of the difference between scientific theories and laws. At the conclusion of the Evolution course her view on this issue had not fundamentally changed, but her response to the post-instruction questionnaire was enriched with specific examples:

> 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 that may have otherwise been unconnected. Evolution synthesizes genetics, geology, population biology, ecology, and taxonomy. (ES01, post-questionnaire)

When specifically asked during the post-instruction 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:

> At the most fundamental level my views did not change, I think what has happened is that I gained a set of vocabulary and a set of examples that help me communicate what my philosophy of science really is. For example, from an ecology point of view, evolution and especially the Neo-Darwinian interpretation of evolution is all-pervasive . . . And to have this historical perspective and to track the development of this idea gives me another level of insight into it that I did not have before. (E163, post-interview)

Four other interviewees noted that their views regarding the theory of evolution and their disposition toward scientific theories in general have changed. As evident in the following quote, these latter participants indicated that they have learned more about Darwin's theory of evolution and have come to be more critical of scientific theories:

> Yes definitely, my views changed. I think I can be a lot more constructively critical of the theories that are presented to me. The [professor] is really good about presenting a way to do that, a method by which you can look at both sides of the theory. And this is the first time the theory was actually described to me and this was pretty good but I learned about more than one side's views. Also, I got a more accurate idea of what Darwin's theory of evolution was. (E139, post-questionnaire)

Additionally, one of these latter four interviewees (6%) noted that his views about the nature of scientific theories have changed substantially. He came to realize the dynamic nature of scientific theories and to view theories as being strong or weak rather than being "true" or "false:"

> I kind of thought that theory was something that someone set out and showed. I did not know that theories were so variable and so dynamic as I do now . . . Before this class I wasn't very sure on what a theory meant. Also, now I am thinking in terms of a weak or a strong theory, it is not a true or a false theory. So, my views have changed in that sense . . . Also I am

> more skeptical now, you know, asking more why do I have to believe in this theory. So, the course kind of opened my eyes to be more critical when I read scientific books. And also the course really explained what Darwin's theory of evolution was. (E114, post-interview)

<u>Changes in the views of preservice science teachers enrolled in the Evolution course.</u>

Change was evident in the views of six preservice teachers (60%) enrolled in the Evolution course. However, the views of four preservice teachers (67%) changed with respect to one aspect of the NOS or another. The views of two others changed in regard to two and three aspects respectively. Additionally, the views of three student teachers in the focus group (30%) were enriched. One of these latter participants was among the aforementioned six preservice teachers.

At the conclusion of the Evolution course, two preservice teachers emphasized the role of scientific theories in guiding scientific investigations as evident in the following quotes:

> We bother to learn theories because . . . they 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, post-questionnaire)
>
> I would say theory would come first [when doing scientific investigations]. I mean, in everything we know a lot of things from the past. Without that background there is no direction. Theories lead our research and direct what we look for. (ME08, post-interview)

Three other preservice teachers had indicated in their pre-instruction questionnaires that scientific theories change solely due to the accumulation of new evidence and technological advances. At the end of the study, two of these participants recognized a role for new *ideas* and reinterpretation of extant data in changing scientific theories:

> Theories change as new knowledge, evidence, and also new theorization are put forth. The ability to recognize new ideas as viable is a corner stone for change in scientific theories. (ME07, post-questionnaire)
>
> Theories change through new empirical data or as people interpret the data differently. That was evident with Darwin . . . Also [Asa] Gray looked at the exact same information that Darwin had and he came to an entire different theory and tried to promote his own theory to explain geographical distribution and whatnot. (ME13, post-interview)

The third preservice teacher noted that cultural factors, such as dominant philosophies and the prioritization of "scientific problems" worthwhile investigating within certain scientific and cultural contexts, influence the acceptance of new theories and consequently the abandonment of extant ones:

> Theories change as a result of, I don't know how it comes exactly, but revolutions in thought such as, you know, Darwin and others in the 19th century . . . If you look at the reception of Darwin's theory in England, France and Germany. I mean if we look at Germany they had that nature philosophy thing and they were looking more into a mechanical view. So, they said, "Oh yes, we can assimilate Darwin's ideas into our own." Whereas the French, they were thinking about other issues and they just said, "Well, we're not dealing with this and this is not something that interests us." It was a matter of what they were concerned with in their own cultures at that time. (ME08, post-interview)

At the beginning of the study, five preservice teachers in the focus group had indicated that scientists are certain about their characterization of species. In their responses to the post-instruction questionnaire and interview questions, two of these student teachers emphasized that "species" is a human construct intended for classification purposes:

> Scientists differ in opinion as far as what defines a species. Classification of species is artificial and is constructed by scientists. (ME12, post-questionnaire)

> We think we are fairly certain but after reading the *Origin* I don't think we are certain at all. All of our classification systems are man made. There is no book that fell from the sky that said, "This is how you name the animals, this is how you mane the plants, this is how they go in groups." We made these groups, and there are different levels of putting animals in categories. It is a human idea and it could change. (ME08, post-interview)

Finally, at the conclusion of the study, two preservice teachers demonstrated better understandings of the creative and imaginative nature of scientific knowledge as evident in the following quote:

> From the development of hypotheses to the creating of tests, scientists use both imagination and creativity . . . 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, post-questionnaire)

In addition, the views of three preservice teachers were enriched. Three student teachers in the focus group did not provide any examples or provided inadequate examples of theory change in their pre-instruction questionnaires. At the conclusion of the study, two of these participants cited the theory of evolution as an example of a scientific theory that changed through time. A third participant cited evolution theory to support his view that the development of scientific knowledge does not necessarily require manipulative experimentation.

When specifically asked during the post instruction interviews, only one preservice teacher noted that her views have changed. The remaining four interviewees either noted that their views had not changed or had been elaborated:

> My views have not necessarily changed. Taking the Darwin course I was able to pick more examples to help me out, to extend my own thoughts. Like I knew that theories change but how, you know. I was able to look at more things; well this is how they change. This is an example of how theories change and also of the whole idea of different interpretations of theories. (ME13, post-interviews)

Pre-instruction Interviews and Changes in Participants' Views of the NOS

During the pre-instruction interviews, participants were asked to elaborate on their views. Moreover, several follow-up questions related to different aspects of the NOS were asked of interviewees. In this sense it can be argued that the pre-instruction interview might have served as a treatment. As such, changes in interviewees' post-instruction views of the scientific endeavor could be attributed to the pre-instruction interviews rather than to experiences in the HOS courses. To assess such a possibility, two groups of participants were compared. The first group comprised participants who were interviewed at the beginning of Fall term and whose views changed at the conclusion of the study. The second group included participants who were not interviewed at the beginning of the study and whose views have changed.

As noted earlier, change was evident in the views of 7 and 35 participants enrolled in the Survey and Evolution courses respectively. Of these participants, two (28%) and six (17%) were interviewed at the beginning of Fall term. None of the three Controversy course participants whose views have changed were interviewed at the beginning of the study. Moreover, only one (17%) of the six preservice teachers in the focus group whose views have changed was interviewed. Thus, it can be seen the percentages of participants whose views have changed and who were interviewed at the beginning of the study were either smaller or not appreciably larger than the percentage of participants in the first random sub-sample. It should be noted that the first random sub-sample comprised 20% of the participants enrolled in each of the investigated courses. Additionally, there were no trends in the specific 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 the pre-instruction interview served as a treatment and impacted the participants' post-instruction views of the NOS.

Summary

Few changes were evident in participants' views of the NOS. Change was evident in the views of seven participants (16%), three participants (20%), and 35 participants (37%) enrolled in the Survey, Controversy, and Evolution course respectively. As such, more changes were evident in the case of participants enrolled in the Evolution course. However, none of the participants' views were substantially changed. Almost all of the observed changes were *only* with regard to one aspect of the NOS or another. This localization of the observed changes should not be surprising given the aforementioned fragmented nature of participants' views of the NOS. The views of only four participants (3%) changed in regard to two or three aspects of the NOS.

The views of five participants (33%) and 18 participants (19%) respectively enrolled in the Controversy and Evolution course were enriched. These participants used specific examples discussed in these courses to support their views of one aspect of the NOS or another. By comparison, it is noteworthy that none of the participants enrolled in the Survey course used any of the examples discussed in that course to support their views of the NOS.

Moreover, compared to participants enrolled in the HOS courses, change was evident in the views of a larger percentage of preservice teachers in the focus groups. Changes were observed in the views of 6 out of 10 preservice teachers enrolled in the Evolution course. However, the views of four of these preservice teachers (67%) changed with respect to one aspect of the NOS or another. The views of two others changed in regard to two and three aspects respectively. Additionally, the views of three student teachers in the focus group (30%) were enriched. Finally, when specifically asked during the post-instruction interview, an overwhelming majority of all interviewees indicated that their views regarding the NOS had not changed.

Relationship between Changes in Participants' Views of the NOS, their Pre-Instruction Conceptions, and Specific Aspects of the HOS Courses

The present section attempts to elucidate the relationship between changes in participants' views of the NOS and their pre-instruction views. The section also relates the observed changes in participants' views of the scientific endeavor to specific aspects of the investigated HOS courses.

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

As noted earlier, eight aspects of the NOS were emphasized in the present study. These aspects included the tentative, empirical, inferential, creative, and subjective nature of scientific knowledge. The three other aspects were 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 were highlighted.

The profile of participants' pre-instruction views of the NOS revealed that a majority of participants held inadequate understandings of several aspects of the NOS. Table 11 presents the number and percentage of participants in the investigated HOS courses and the focus group who demonstrated adequate conceptions of certain subsets of the aforementioned eight aspects of the NOS. For instance, 12 participants (28%) enrolled in the Survey course demonstrated adequate views of only one aspect of the NOS or another. Three *other* participants (7%) held adequate views of two aspects of the NOS. It should be noted that Table 11 does not present cumulative numbers and percentages of participants. It rather presents the number and percentage of participants who only held adequate views of the corresponding number of aspects of the NOS.

Table 11 indicates that some participants enrolled in the HOS courses demonstrated adequate understandings of two or three aspects of the NOS. However, no discernable patterns were evident in the views of these participants. Such lack of patterns or coherence might be a consequence of the aforementioned idiosyncratic and fragmented nature of participants' NOS views.

Only one noteworthy pattern was evident in the case of preservice science teachers enrolled in the Evolution course. As indicated in Table 11, eight preservice teachers in the focus group held adequate views of four or more aspects of the NOS. A set of four NOS aspects were common to the views of seven (88%) of those preservice teachers. These aspects included an understanding of the tentativeness of science, the role of inference in science, and the functions of and relationships between scientific theories and laws.

Change in participants' views of the NOS seemed to have been compromised by their pre-instruction conceptions of the scientific endeavor. After all, participants have developed such conceptions over years of high school and college science experiences. This point was clearly communicated by several participants. When asked during the post-instruction interview whether his views *about* science have changed, one participant noted:

> I don't think my views have changed, not at all. I mean I think that I am at the point where one more class even if it is history of science and analyzing science in a historical perspective, it really wouldn't change the way I view science. I've taken so many science classes and one class over-viewing science will not change my ideas. (E083, post-interview)

The tenacity with which participants held on to some of their pre-instruction NOS views was evident in the case of a majority of participants. A few examples would suffice to demonstrate this tenacious nature of some of the participants' views. As noted earlier, 12 participants enrolled in the Evolution course had indicated at the beginning of the study that scientific theories do not change or are merely modified and elaborated.

Table 11

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

NOS	Survey		Evolution		Controversy		Focus group	
Aspects	n	P	n[a]	P[a]	n	P	n	P
1	12	28	28	33	3	20	0	0
2	3	7	12	14	1	7	0	0
3	3	7	7	8	1	7	2	20
4	0	0	0	0	1	7	6	60
5	1	2	3	3	1	7	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.

Theory change, as indicated earlier, was the major theme of the Evolution course. Moreover, the Evolution course professor made several *explicit* references to the tentative nature of scientific theories. Despite all that, 8 of these 12 participants (67%) indicated at the conclusion of the study that scientific theories do *not* change or are slightly modified and expanded as evident in the following representative quotes:

> I believe that scientific theories do *not* change [italics in original]. A theory is broad and alterations to the idea does not always affect it. (E075, post-questionnaire)

> Well, as the body of scientific knowledge gains more precision or resolution, theories do change and they get better resolution. But generally theories, by the time we call it a theory, they are kind of right on the target. My being a modern scientist, I am only learning those theories that seem to work, you know. (E135, post-interview)

> A scientific theory does not change through time . . . It can however be expanded or added on to with the development of modern science. (E133, post-questionnaire)

Another example of the tenacious nature of some of the participants' NOS views relates to their belief that scientific claims could be proven "true." As noted earlier, the Evolution course professor *explicitly* indicated at several occasions 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 weakly supported or well corroborated and not "right" or "wrong." Six participants enrolled in the Evolution course indicated in their responses to the first item on the post-instruction 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, post-questionnaire). At first, such responses are reassuring since these six 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 as evident in the following representative quotes:

> I think scientific law has so much evidence for it and no evidence against it. That must be why it is accepted. It has been proven. And if a theory has a lot of support, it eventually is proven and becomes a law. (E148, post-interview)

> A scientific law is a theory that has been proven to be correct when thousands of scientists have tested it over and over again. (E063, post-questionnaire)

Even those participants who seemed to have internalized that scientific theories cannot be "proven" still had a hard time using more accurate terminology in a consistent manner. In particular, during the post-instruction interview, one participant was almost apologetic about his recurrent use of the term "prove." This participant was struggling to make consistent use of adequate terms such as "validate" or "support" as evident in the following excerpts:

> Well, in my understanding of science, first we make hypotheses about what we believe to be true in nature. And then we gather facts and data and we try to prove, I am sorry, to make the hypothesis valid or invalid by going out in nature and finding evidence against or for it . . . . You can basically say that you have a weak or strong theory in science. A theory is more dynamic and it is true for the time being, I am sorry, valid for the time being but it can change. (E114, post-interview)

As such, inadequate pre-instruction NOS views seem to have impeded participants' learning of more adequate views of the NOS presented in the HOS courses. 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; Hewson & Hewson, 1983; Smith, Blakeslee, & Anderson, 1993; Stofflett & Stoddart, 1994; Treagust, Duit, & Fraser, 1996; Wandersee, Mintzes, & Novak, 1994).

Table 11 shows that the greater majority of participants entered the HOS courses practically lacking any views consistent with current conceptions of the NOS. Indeed, 84%, 74%, and 72% of the participants respectively enrolled in the Survey, Evolution, and Controversy course either held views that were entirely inconsistent with current conceptions of the NOS or held adequate views of *only* one of the aforementioned aspects of the NOS. Additionally, 14%, 22%, and 14% of the participants respectively enrolled the Survey, Evolution, and Controversy courses demonstrated adequate understandings of two or three NOS aspects. However, as indicated earlier, these NOS aspects lacked coherence or consistency.

These latter two groups of students comprised 90% of all participants enrolled in the HOS courses. Change was evident in the views of 26% of these participants. The overwhelming majority of these changes, it should be emphasized, were related to one aspect of the NOS or another. Moreover, the views of 12% of these participants were enriched. By comparison, 15 participants (10% of all participants) held adequate views of four or more aspects of the NOS (see Table 11). Change was evident in the views of eight of these participants (53%). Moreover, the views of seven of these participants (47%) were enriched. It should be noted that 8 of these 15 participants were preservice science teachers.

As such, change (mainly with respect to one aspect of the NOS or another) was evident in the views of *relatively* more participants who entered the HOS courses with four or more adequate views of the NOS. Indeed, the percentage of these latter participants whose views have changed is twice as large as the corresponding percentage among participants who entered the HOS courses with relatively less adequate views of the NOS. 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 science teachers in the focus group. Eight of the 10 preservice teachers enrolled in the Evolution course demonstrated adequate views of four or more aspects of the NOS at the beginning of the study. The views of all eight student teachers were changed or enriched. Change was evident in the views of six preservice teachers (75%), and the views of three others (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 views of the NOS 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 aspects of the NOS 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 aspects" of the NOS 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 four aspects of the NOS with which certain participants entered the HOS courses and the few changes that were evident in those participants' post-instruction 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' views of the NOS could be directly related to those aspects of the NOS that were *explicitly* addressed in the respective HOS courses. First, there were changes in the views of three participants enrolled in the Controversy course. Some of these changes were related to the manipulative or controlled nature of scientific experiments and the role of prior expectations in designing experiments. As previously noted, the Controversy course professor explicitly articulated these two aspects in her discussion of experiments at the outset of the course.

Another change in the views of two participants enrolled in the Controversy course was related to the influence of theoretical commitments and other personal attributes on the explanations that scientists advance to account for empirical observations. Both participants demonstrated an understanding of this aspect of the NOS when responding to the ninth item on the post-instruction NOS questionnaire. This item, it should be noted, is specifically related to the mass-extinction controversy; one of the case studies *explored* in the Controversy course. These two participants made references to geologists' indoctrinated preference for "uniformitarian" or "terrestrial" explanations as one of the factors underlying the mass-extinction controversy.

However, it can be argued that a similar change was not evident in the views of the remaining 13 participants in the Controversy course even though the extinction controversy was explored in the course. What is noteworthy, nonetheless, is that the aforementioned two participants were among the four students who chose to further explore the mass-extinction controversy in their term paper for the Controversy course. As such, even though the mass-extinction controversy was *explored* in the course, change in participants' responses to the ninth item on the NOS questionnaire was evident in the case of participants who had opportunities to further investigate and *reflect* on this specific controversy. In this regard, it is noteworthy that the Evolution course professor had discussed uniformitarian geology. However, as indicated earlier, he made no explicit references to the relationship between theoretical commitments and preferred explanations in *this* context, such as the relationship between the implicit assumptions of uniformitarianism and geologists' "preference" for "terrestrial" explanations. Such a specific relationship was not relevant to the story of evolution. None of the participants in the Evolution course made a connection between the discussion of uniformitarianism and the mass-extinction controversy addressed in the ninth item on the NOS questionnaire.

Second, the changes evident in the views of participants enrolled in the Evolution course, including preservice science teachers, were almost all related to aspects of the nature of scientific theories that were explicitly addressed in the course. As previously stated, many of the observed changes in participants' views were related to the notion that scientific theories are tentative and change through time, serve as frameworks for guiding research, and change *partly* due to new ideas, theories, or social and cultural factors. All these aspects of scientific theories were explicitly emphasized at one point or another in the Evolution course.

Another change in the views of a few participants enrolled in the Evolution course was related to the validity of observationally based disciplines and/or scientific theories. These participants specifically cited evolution theory as an example of scientific theories that are substantiated through observational data. The Evolution course professor, it was noted, 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 evolutionary 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 the discussion of species and varieties in the Evolution course. Finally, at the conclusion of the study, 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 aspect of the NOS in the specific context of the reception of Darwin's theory of evolution in France and Germany that was discussed at some length in the Evolution course.

Third, the changes evident in the views of participants enrolled in the Survey course 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 aspect of the NOS was the major theme that was explicitly discussed of the Survey course. Only one of the changes evident in the views of participants enrolled in the Survey course could not be related to the specific aspects of the NOS explicitly addressed in the course. At the conclusion of the study, a few participants demonstrated adequate understandings of the arbitrary nature of the notion of "species." This aspect of the NOS was not discussed in the Survey course.

It was previously mentioned that relatively few changes were evident in the views of participants enrolled in the HOS courses. However, change was evident in the case of a relatively larger percentage of participants enrolled in the Evolution course (37%) as compared to the corresponding percentages in the Survey (16%) and Controversy (20%) courses. Among the attributes of the participant HOS courses that could account for this observation, besides explicit attention given to the NOS, the most likely ones are course objectives and instructor priorities. During the interview, the Evolution course professor articulated an explicit commitment to helping students develop adequate views of the NOS in general and of a *few specific* attributes of the nature of scientific theories in particular. The Evolution course professor noted that helping students develop adequate conceptions of the NOS is a major concern of his. He indicated that an understanding of the NOS is relevant to students' everyday life decision making. The Survey and Controversy course professors did not explicitly express similar commitments or concerns.

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 a few participants enrolled in the Survey course changed with respect to this aspect of the NOS. Participants enrolled in the Survey course might have perceived the works and examples presented in the course to be "non-scientific" 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.

This inference is corroborated by two other observations. First, during the interview, the Survey course professor indicated that most of the participants were judging the course materials from within current conceptions of science and scientific practice as was evident in their responses to the short in-class quizzes. Second, with one exception, none of the participants enrolled in the Survey course used any of the examples discussed in the course to support their views at the conclusion of the study. By comparison, 33% and 19% of the participants respectively enrolled in the Controversy and Evolution course used specific examples from these two courses to support or defend their views. Even the two participants simultaneously enrolled in the Survey and Evolution courses (ES01) and Survey and Controversy courses (CS03) did not use any examples from the Survey course in their responses to the post-instruction questionnaire despite the fact that they provided such examples from the Evolution and Controversy courses. Unlike the Survey course, the Evolution and Controversy courses dealt with examples, such as evolutionary theory, relativity theory, and radioactivity, which are relatively recent episodes in the development of scientific disciplines. While participants might have perceived these latter examples as relevant to their views of science, they failed to perceive the relevance of examples discussed in the Survey course, such as Ptolemy's astronomical system or Galen's humorial theory.

Summary

Change in participants' views of the NOS seemed to have been compromised by their inadequate pre-instruction conceptions of the scientific endeavor. Ninety percent of all participants entered the HOS courses lacking any views consistent with current conceptions of the NOS or having adequate views of a few aspects of the NOS that lacked coherence or consistency. Change was evident in the views of 26% of these participants and the views of 12% were enriched. Such change, it should be emphasized, was with respect to *only* one aspect of the NOS or another.

By comparison, at the beginning of the study, 10% of all participants held adequate views of four or more aspects of the NOS. Change was evident in the views of 53% of these participants and the views of 47% were enriched. This pattern was even more pronounced in the case of preservice science teachers in the focus group. Change was evident in the views of 75% of the preservice teachers enrolled in the Evolution course who demonstrated adequate views of four or more aspects of the NOS at the beginning of the study.

This pattern in the data *is consistent* with the notion that students who enter HOS courses with a framework consistent with current views of the NOS are more likely to leave such courses with more adequate and enriched views. The significance of this finding, however, is *limited* by two factors. First, the number of participants who entered the HOS courses with adequate views of four or more aspects of the NOS was relatively small. The second factor was that the cut-off number of "four aspects" of the NOS was arbitrary. There were no substantial or coherent relationships between the particular sets of four aspects of the NOS with which certain participants entered the HOS courses and the few changes that were evident in those participants' post-instruction views.

Additionally, almost all the changes that were evident in participants' views of the NOS could be directly related to those aspects of the NOS that were *explicitly* addressed in the respective HOS courses. Moreover, compared to the Survey and Controversy courses, change was evident in a relatively larger percentage of participants enrolled in the Evolution course. Besides explicit attention given to the NOS, course objectives and instructor priorities were the most likely attributes of the participant HOS courses to account for this finding.

Chapter V

Discussion and Implications

Introduction

The present study assessed the influence of three history of science (HOS) courses on college students' conceptions of the nature of science (NOS). Among the student participants, a group of particular interest consisted of preservice secondary science teachers enrolled in one of the investigated HOS courses. The study also examined whether students who entered the participant HOS courses with a conceptual framework consistent with current views of the scientific enterprise achieved more elaborate and enriched understandings of the NOS. Additionally, the study explored the aspects of the participant HOS courses that rendered the courses more effective in influencing students' conceptions.

This chapter interprets the findings reported in Chapter IV in relation to the conceptual framework that guided the present investigation. Moreover, the chapter situates these findings within the larger context of the research literature on teaching and learning in general, and on the NOS in particular. The present chapter is divided into six sections. The first section explores participants' NOS views with a focus on the views of preservice science teachers. The second section examines the relatively small influence of the participant HOS courses on students' views of the NOS. The third section explores the relationship between participants' pre-instruction NOS views and the changes that were evident in those views. The limitations of the present study are explicated in the fourth section. The fifth section elucidates the practical implications of the present investigation for the role of HOS courses in enhancing students' conceptions of the NOS in general, and of prospective science teachers in particular. The sixth section presents recommendations for future research.

Participants' Views of the NOS

As far as participants' NOS views are concerned, the results of the present study are consistent with a relatively extended line of research that indicates that "students typically have *not* acquired a valid understanding of what is meant by the nature of science [italics in original]" (Kimball, 1967-68, p. 110). As explicated in Chapter IV, almost all participants in the present study held inadequate views of many aspects of the NOS. Many of the participants' misconceptions are consistent with those reported in studies that assessed high school and college students' views of the NOS over the past 45 years.

An overwhelming majority of participants held inadequate views of the tentativeness of scientific knowledge (e.g., Abd-El-Khalick & BouJaoude, 1997; Lederman, 1986; Rubba, 1977; Rubba & Anderson, 1978; Rubba, Horner, & Smith 1981; Wilson, 1954), the empirical NOS, the general structure and/or goal of scientific experiments (e.g., Aikenhead, 1972, 1973; Broadhurst, 1970; Mackay, 1971), and the role of new ideas, and social and cultural factors in theory change (e.g., Abd-El-Khalick & BouJaoude, 1997). Moreover, almost all participants ascribed to a hierarchical view of the relationship between scientific theories and laws (e.g., Abd-El-Khalick & BouJaoude, 1997; Aikenhead, 1972, 1973; Lederman, 1986; Rubba, 1977; Horner & Rubba, 1978, 1979; Rubba, Horner, & Smith, 1981).

The greater majority of participants did not demonstrate adequate understandings of the nature of scientific theories. These participants held inadequate views of the well-supported nature and explanatory function of scientific theories, the role of theories in guiding research (e.g., Abd-El-Khalick & BouJaoude, 1997; Aikenhead, 1972, 1973; Broadhurst, 1970), and the nature of theory testing (e.g., Bady, 1979).

A sizable majority of participants believed that science is characterized by the use of "The Scientific Method" or other sets of logical and orderly steps (e.g., Abd-El-Khalick & BouJaoude, 1997). Moreover, a majority of participants did not demonstrate an understanding of the role of prior expectations in designing and conducting experiments, and held inadequate views of the subjective nature of scientific knowledge and of the validity of observationally-based (as opposed to experimentally-based) scientific disciplines. Finally, a majority of participants did not demonstrate adequate conceptions of the role of inference and the use of models in science (e.g., Broadhurst, 1970; Gilbert, 1991; Mackay, 1971), and of the creative aspects of the nature of scientific knowledge (e.g., Abd-El-Khalick & BouJaoude, 1997; Aikenhead, 1972, 1973; Broadhurst, 1970; Cotham & Smith, 1981; Mackay, 1971).

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

Other attributes also characterized participants' views of the NOS. First, participants seemed to ascribe a variety of meanings to terms, such as "theory," "creativity," and "prove," that are crucial to assessing their views of the NOS. The use of an open-ended NOS questionnaire in conjunction with individual interviews in the present study was pivotal in accessing these various meanings and the contexts within which they were used, and relating them to participants' NOS views. The multiplicity of meanings attached to such key terms is likely to be masked when forced choice item paper-and-pencil instruments are solely used to assess learners' views of the nature of scientific knowledge.

For example, as indicated in Chapter IV, many participants used the term "theory" in the vernacular sense to refer to "someone's idea about what had happened" instead of a well-substantiated, internally-consistent web of concepts intended to explain a set of natural phenomena. Participants also ascribed different meanings to the term "creativity" in science. The majority of participants did not use the term to indicate that science involves the invention of explanations, theories or conceptual models. Rather, these participants used the term "creativity" in science to refer to other connotations, such as being resourceful, skillful, open-minded, curious, and not copying other scientists' designs and experimental procedures. Moreover, participants ascribed different meanings to the term "prove" and explicated various ways in which they thought scientists go about "proving" claims. This finding is consistent with conclusions reported by Lederman and

O'Malley (1990). The confusion about the meaning of the term "prove" left many participants struggling with what was dubbed in the present study as the *proving dilemma*: attempting to reconcile the acclaimed certainty of science with its well-documented tentativeness.

The variety of meanings that participants attach to key terms, such as "law," "theory" or "prove," which often hold more technical meanings for historians and philosophers of science indicates, at best, inaccurate use of these terms. However, such use of terms might also reflect more entrenched misconceptions about certain aspects of the NOS. As such, researchers attempting to assess learners' conceptions of the NOS need to clarify the meanings of terms that learners frequently use to explicate their views of the scientific endeavor. Ambiguities might result from assuming that students ascribe to key words or statements the same meanings as researchers (Aikenhead et al., 1989).

Second, the NOS views of a majority of participants were fragmented and lacked any coherent framework. As elucidated in Chapter IV, many participants explicated compartmentalized conceptions with few or no connections to bridge these, sometimes disparate, conceptions. This finding is inconsistent with results reported by some studies, such as Dibbs (1982) and Hodson (1993), that assessed learners' views of the NOS. In these studies, participants' NOS views were assigned labels, such as inductivist, verificationist or hypothetico-deductivist that indicated that participants held coherent and consistent philosophic stances of the NOS. Such findings were more likely an artifact of the instruments used in the aforementioned studies than a faithful representation of participants' conceptions of the NOS. These instruments, it should be noted, were of the forced-choice type with items often designed with various philosophical stances in mind.

As such, irrespective of the choices the respondents made, they often ended up being stamped with one "coherent" philosophical position or another.

Not only were participants' NOS views fragmented and inconsistent, these views were often not associated or reconciled with scientific knowledge or practice or, at least, with adequate conceptions of scientific knowledge and practice. As indicated in Chapter IV, many participants either did not provide any examples or provided inadequate examples from the history or practice of science to support or defend their NOS views, especially when discussing experiments, theories and theory change, scientific laws, and the creative nature of scientific knowledge.

That the participants in the present study held many inadequate views of several important aspects of the NOS, though disconcerting, should not be surprising. During their years of high school and college science experiences, participants were, at best, not informed about adequate conceptions of the NOS. As noted in Chapter IV, many participants indicated that they had not thought or were not given opportunities to think about many of the issues asked of them in the present study. Indeed, as noted by one participant who demonstrated adequate views of several aspects of the NOS, students often need to "go out of their way" to learn about the nature of the scientific enterprise. When asked about the experiences that helped him develop his views of the NOS, this participant noted:

> Right now I am actually taking a course . . . in the philosophy of science . . . And when I was an undergraduate . . . I took a philosophy of physics class. And I have been doing reading on my own. That seems to be the *only way*, unless *you go out of your way* to do this type of thing [italics added] you never learn anything about the nature of science. (E163, post-interview)

Not only were participants not informed about the NOS in their high school and college years, they more likely had been misinformed. The present study revealed several substantial patterns in participants' misconceptions of the NOS. These patterns seem to be persistent among high school and college students. As indicated earlier, the patterns evident in the present study were consistent with those reported in many empirical studies that assessed students' NOS views over the past 45 years. It is highly unlikely that such patterns could be attributed to chance or to what students have inadvertently generalized from their experiences with science at the high school and college levels. It is more likely that students have been *explicitly taught* certain misconceptions about the NOS.

For example, students are 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 the existence of "The 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). In fact, as one participant noted, "The Scientific Method" is often "drilled" into students' heads. When this participant was asked whether she thought scientists follow a certain set of orderly steps in their investigations, she replied:

> No. Well, yes. I think yes, maybe. But at the same time, I mean, that is like how the science textbook goes about it. I don't think that everybody would go about it that way . . . I mean you might stumble across something that you did not think is going to happen and from that, I mean you might go from there. So, I don't think that that is the only way you can go about it but that's what has been *drilled* into my head [italics added], the scientific

> method, this is how the scientists work. You know, this is how we do it.
> (C171, pre-interview)

The notion of the "absolute" status of scientific knowledge is also bolstered through traditional evaluation practices often presented in science textbooks and laboratory manuals or used by science teachers. Learners are lead to believe that for every question posed about the natural world, scientists will eventually find the "correct and final" answer. This belief is not *implicitly* conveyed to learners. Rather, students are *explicitly* asked and expected to come up with "the" correct answer to end-of-chapter textbook exercises, choose the "one" correct answer on multiple choice tests, and arrive at "the" right conclusion to "cook-book" laboratory activities.

As such, patterns in participants' misconceptions of the NOS are likely to be the result of the aforementioned and other similar commonalties in their science education experiences. Such commonalties were among the reasons that invited the recent efforts to reform science teaching and learning at the primary and secondary levels (AAAS, 1990, 1993; NRC, 1996). Indeed, despite their varying pedagogical and curricular emphases, agreement between these major reform efforts in science education is centered on the aim of providing learners with experiences that would help them develop more adequate understandings of the NOS.

However, science teachers are the main intermediaries of the reform efforts (Brown & Clarke, 1960; Lederman, 1992). To be able to convey adequate conceptions of the NOS to their students, science teachers should themselves possess adequate views of the scientific enterprise. And, as was argued in Chapter I, even though possessing adequate views of the NOS might not be *sufficient* to teaching the NOS in the classroom, it is nonetheless, *necessary*. Teachers are not likely to teach what they do not understand themselves. A question that follows from this discussion is: Did the prospective science teachers who participated in the present study *sufficiently* meet this *necessary* condition?

Preservice Teachers' Views of the NOS

Participant student teachers held adequate views of some aspects of the NOS emphasized in the present study. The overwhelming majority of preservice science teachers demonstrated adequate understandings of the tentativeness of scientific knowledge, the function of scientific laws, and the relationship between theories and laws. Moreover, a sizable majority held adequate views of the empirical and subjective NOS, recognized the explanatory function of scientific theories, and indicated that scientists do not use a single recipe-like method in their investigations.

That the participant preservice teachers held adequate views of the aforementioned NOS aspects was anticipated. These aspects of the scientific enterprise were explicitly addressed during the Summer science methods course in which preservice teachers were enrolled prior to their participation in the present study. Nonetheless, it seems that the preservice teachers' NOS views were different from those of other participants *only* with respect to the aspects of the NOS explicitly included in the science methods course. After all, it is highly likely that these preservice teachers had shared similar high school and undergraduate science experiences with other participants in the present study. As such, participant preservice teachers still held inadequate views of some aspects of the NOS emphasized in the present study.

The greater majority of participant student teachers did not demonstrate adequate views of the well-supported nature of scientific theories, the role of theories in guiding future research, the nature of theory testing, and the role of new ideas, and social and cultural factors in theory change. Moreover, many preservice teachers held inadequate views of the creative aspects of the NOS, the structure and/or goal of scientific experiments, the role of prior expectations in designing and conducting experiments, and the validity of observationally based scientific claims. It is noteworthy that these latter aspects of the scientific endeavor, with the exception of the creative, and social and cultural NOS, were not explicitly addressed during the Summer science methods course.

Moreover, like other participants in the present study, preservice teachers' NOS views lacked coherence or a consistent conceptual framework. As noted in Chapter IV, many preservice teachers articulated inconsistent or compartmentalized views of the NOS. For instance, in their responses to the sixth item on the NOS questionnaire that was related to the structure of the atom, the majority of preservice teachers demonstrated adequate understandings of the use of conceptual or theoretical models in science. However, the majority of preservice teachers did not demonstrate similar understandings in their responses to the seventh item on the questionnaire that asked about the concept of species. It is noteworthy that, unlike the model of the atom, the concept of species was not among the several examples discussed in the Summer science methods course to illustrate the use of conceptual models in science. Preservice teachers, it follows, were not able to generalize the NOS understandings they derived from the explicit NOS instruction in the Summer science methods course across scientific examples or disciplines. Rather, their understandings were situated within the contexts and examples discussed in the Summer methods course.

As such, participant preservice teachers did not seem to possess clearly articulated and integrated understandings of the NOS. Moreover, their NOS conceptions were not well substantiated with knowledge of relevant examples from the history or practice of science. As noted in Chapter IV, the majority of student teachers did not provide any examples or provided inadequate examples from the history or practice of science to support their views regarding experiments, and the subjective, imaginative and creative nature of scientific knowledge.

As was argued in Chapters I and II, teaching students about the NOS requires science teachers to have *more* than rudimentary or superficial knowledge and understandings of various NOS aspects. An enriched knowledge of the NOS is especially important for teaching secondary students about this valued aspect of science. Secondary science teachers are faced with the challenge of making the aspects of the NOS emphasized in the recent reform efforts in science education (AAAS, 1990, 1993; NRC, 1996) *accessible* and *understandable* to students. To meet this challenge, teachers need to be able to devise and organize alternative ways of representing the emphasized NOS aspects and to adapt those aspects to the diverse interests and abilities of learners (Shulman, 1986, 1987). Teachers should be able to discourse about the NOS, lead discussions regarding various aspects of the NOS, design science-based activities that would help students comprehend those aspects, and contextualize their teaching about the NOS with some examples or "stories" from the HOS. For instance, it is not enough for teachers to "know" that scientific knowledge is theory-laden. They should be able to use examples and/or simplified case histories from scientific practice to present and substantiate this claim.

As noted earlier, participant preservice science teachers held adequate views of some aspects of the NOS. However, compared to the understandings of the NOS explicated above, it is safe to conclude that these student teachers did not demonstrate understandings that are deemed *necessary* for them to be able to teach the NOS to secondary students. This lack of understanding should not be surprising given that these student teachers received less than 10 hours of specific instruction on the NOS within the context of a science methods course. Indeed, as indicated in Chapter II, attempts undertaken to enhance science teachers' conceptions of the NOS within the context of teacher preparation programs in general and science methods courses in particular, were characteristically short in duration and ranged from a few hours to a few days (e.g., Akindehin, 1988; Billeh & Hasan, 1975; Scharmann, 1990; Trembath, 1972). The relative ineffectiveness of these attempts could be partly attributed to their limited duration. It is highly unlikely that science teachers' views of the scientific enterprise, views that have developed over years of high school and college science, could be effectively changed or elaborated during a few hours, days or weeks for that matter. However, the realities of teacher education programs and science methods courses impose limitations on the time that can be dedicated within these contexts to improve science teachers' conceptions of the NOS. The agendas of teacher education programs are already extensive and overly long and so are the lists of objectives that science methods courses often aim to achieve.

As such, the efforts undertaken within science teacher education programs to enhance prospective teachers' conceptions of the scientific endeavor need to be augmented with relevant coursework in other disciplinary departments (Bork, 1967; Brush, 1969; Matthews, 1994). During the past 70 years, many science educators have argued that coursework in the HOS can help learners in general and science teachers in particular develop more adequate conceptions of the NOS (e.g., Brush, 1969, 1989; Conant, 1947; Duschl, 1989, 1990; Haywood, 1927; Klopfer, 1964, 1969; Klopfer & Watson, 1957; Matthews, 1994; Monk & Osborne, 1997; Robinson, 1969; Rutherford, 1964; Scheffler, 1973; Wandersee, 1992). However, despite their longevity, these arguments are based solely on intuitive assumptions, anecdotal evidence, and virtually no supportive empirical literature. A crucial question follows: Do college level HOS courses influence students' views of the NOS?

The Influence of HOS Courses on Students' Views of the NOS

The results of the present study do *not lend empirical support* to the assertion that coursework in the HOS would improve students' views of the NOS. 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 discernible way. As indicated in Chapter IV, change was evident in the views of a relatively small minority of students enrolled in the three participant HOS courses regarding the aspects of the NOS emphasized in the present study. Moreover, almost all the changes in individual participant's conceptions were related to *only* one aspect of the NOS or another. The post-instruction responses of *none* of the participants revealed substantial change with regard to several NOS views.

That the participant HOS courses had only a small influence on students' NOS views is probably the most significant finding of the present study. This finding, nonetheless, *seems* counterintuitive. After all, HOS is the study of science and its aim is to understand the scientific enterprise, and HOS courses deal with the development of scientific knowledge and disciplines. Thus, it has been *intuitively* appealing for science educators to *assume* that coursework in the HOS would help students develop more adequate views of the NOS. The results of the present study, however, were not totally unanticipated. These results are explicable on several conceptual and empirical bases.

First, as was argued in Chapter I, there seems to be some difficulty inherent to using HOS to help learners acquire an understanding of the NOS. Even though historical research could "teach" the *historian* about the nature of the scientific endeavor, such "lessons" often vanish from "finished" historical narratives (Kuhn, 1977). 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 the NOS, students need to put "on a different kind of thinking cap" (Butterfield, 1965, p. 1). Students need, or are *expected*, to view and interpret the historical materials with which they are presented in a HOS course from within a conceptual framework that is sometimes radically different from their own, and more congruent with the worldview or paradigm 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. In this latter case, students are less likely to perceive the historical narrative as a portrait of the active attempts of earlier "scientists" to understand the natural world from within a certain, and most likely different, set of "scientific," social, cultural, and cosmological conceptual tools.

Science educators who have assumed that coursework in the HOS would automatically result in enhancing students' views of the NOS did not seem to recognize or appreciate the difficulty inherent to helping students make the prerequisite conceptual shift. The HOS course professors in the present study, nonetheless, recognized the importance of this crucial conceptual shift and attempted to address it. All three professors situated the materials presented in their courses within certain historical contexts. In particular, the Evolution course featured an active attempt to help students perceive the course materials from within an alternative perspective. The Evolution course professor specifically aimed to help students "pull themselves out of the contemporary setting . . . 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" (Evolution course professor, interview). As indicated in Chapter IV, many of the Evolution course activities were structured with this aim in mind. For instance, the midterm exam asked students to evaluate *The Origin of Species* as *if* they were living in 1860, and as *if* their knowledge of "natural history" was only limited to the works of Linneaus, Buffon, Paley, and Cuvier.

However, a genuine effort and extended commitment 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, including student teachers, enrolled in HOS courses to achieve such a conceptual shift as a result of their rather *limited* exposure to historical materials and active engagement in historical research. After all, the experiences of students and preservice teachers with HOS are often limited to one or, at best, a few courses.

Indeed, consistent with constructivist arguments (e.g., von Glasersfeld, 1979,1989) and the premises of cognitive psychology (e.g., Anderson, 1990; Ausubel, 1968), students are highly likely to perceive and interpret their educational experiences from within their extant conceptual frameworks and prior knowledge. In the context of the present study, participants seemed to have interpreted the historical narratives from within their current scientific knowledge and conceptions of the NOS rather than from within any other alternative framework with which they were presented. Interpreting the historical narrative from within current frameworks was particularly evident in the case of the Survey course. The Survey course professor indicated that most of the participants were judging the course materials from within current conceptions of science and scientific practice as was evident in their responses to the short in-class quizzes. Moreover, as indicated in Chapter IV, almost none of the participants enrolled in the Survey course used any of the examples discussed in the course to support their views at the conclusion of the study. Participants enrolled in the Survey course seemed to have judged the examples presented in the course, such as Ptolemy's astronomical system or Galen's humorial theory, to be "non-scientific" by "modern" standards. These participants thus failed to perceive the relevance of such examples to their views of science.

As such, within the historical approach, students are expected to "put on a different kind of thinking cap" while going through the historical materials. However, adopting an "out-of-date" alternative framework is not enough. To be able to perceive the associated "lessons" about the NOS, students are then expected to "step-back" to the present and discern the relevance of the historical narrative to understanding 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, the research literature on learning indicates that students' cognition is primarily situated within the specific contexts in which learning has occurred and that students' ability to apply the acquired understandings is usually limited to such contexts. Learners are often not successful in transferring and applying the knowledge and understandings they acquire within one context to other *similar* contexts (Brown, Collins, & Duguid, 1989; Gage & Berliner, 1992; Lanier & Little, 1986). The failure to "transfer" NOS understandings was evident, for instance, in the case of participant preservice science 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 this regard. These student teachers, however, failed to apply their understandings to a similar concept from the biological sciences, namely the concept of species. Indeed, Gage and Berliner (1992) 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. In the context of the present study, if students are expected to discern "lessons" about the NOS from the historical narrative, then students should be helped to recognize the similarities between such narrative and current scientific knowledge and practice.

It follows from the above discussion 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" (Russell, 1981, p. 56). It seems that exposure to HOS might not be sufficient to improve learners' views of the nature of the scientific endeavor. *If* HOS courses *aim to* help students develop adequate conceptions of certain aspects of the NOS, then those aspects need to be given *explicit* attention.

The need to explicitly address certain NOS aspects within HOS courses brings to light the second factor that may explain the relatively limited influence that participant HOS courses had on students' views of the NOS. This aspect relates to the extent to which various elements of the NOS were *explicitly* addressed in the participant HOS courses. As noted in Chapter IV, explicit attention accorded to the NOS in these courses was limited. 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 the NOS, namely the social and cultural embeddedness of science. By comparison, the Evolution course professor made more explicit, but brief, references to some aspects of the NOS. Notably, the Evolution course professor also presented two explicit and relatively extended discussions about the NOS and scientific theories on two separate occasions in the course. The NOS aspects explicitly addressed in the Evolution course were related to the tentativeness of science, the explanatory function of scientific theories and their role in guiding research, the nature of theory testing, the social and cultural embeddedness of science, and the considerations associated with the use of the term "prove."

As indicated earlier, some science educators (e.g., Duschl, 1989, 1990; Matthews, 1994; Monk & Osborne, 1997; Wandersee, 1992) seem to have assumed that students and student teachers would automatically acquire adequate views of the NOS by exposure to historical narratives. The results of the present study do not lend support to this assumption. Indeed, these results lend credence to the notion that explicitly addressing certain aspects of the NOS within the context of HOS courses could be more effective than an implicit approach to enhancing students' views of the NOS. This conclusion is corroborated by two observations. First, as indicated in Chapter IV, almost all of the changes that were evident in participants' views of the NOS 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 participants enrolled in the Evolution course. This difference could be attributed to the fact that the Evolution course professor accorded more explicit attention to the NOS.

However, it might be argued that the results of the present study are not altogether congruent with the claim that explicitly addressing certain NOS aspects in the investigated HOS courses was effective in enhancing participants' views of those aspects. This argument could be based on the fact that a few aspects of the 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 explicitly articulated NOS aspects in the respective HOS courses. As such, the claimed effectiveness of an explicit approach lacks strong empirical support.

Two elements serve to ameliorate concerns regarding the validity of this latter claim. First, it should be noted that the claim regarding the effectiveness of an explicit approach was made *relative* to the purported effectiveness of an implicit approach. In particular, it was claimed above that explicitly addressing certain aspects of the NOS within the context of HOS courses could be *more effective than* an implicit approach in enhancing students' NOS views. This claim is corroborated by the fact that while the few changes evident in participants' views could be directly related to the 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. Indeed, none of the participants explicated any of these implicit "lessons" about the NOS in their responses to the NOS questionnaire or interview questions at the conclusion of the study. 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 the 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 (Hewson & Hewson, 1983; Treagust, Duit, & Fraser, 1996).

This latter discussion brings to light the third factor that might explain the relatively limited influence that the participant HOS courses had on students' views even with regard to those NOS aspects that were explicitly addressed in these courses. This third aspect relates to the fact that prior to HOS instruction, the greater majority of participants held several misconceptions of many of the NOS aspects emphasized in the present study. Moreover, as explicated in Chapter IV, these pre-instruction NOS views were held tenaciously by the majority of participants. After all, participants, including preservice science teachers, have developed such conceptions over years of high school and college science experiences. As such, participants' inadequate pre-instruction views seem to have impeded their learning of more adequate views of the NOS presented in the HOS courses. Indeed, as noted earlier, the interaction between learners' misconceptions of content and learning more accurate content is well documented in the science education literature (e.g., Anderson et al., 1990; Bishop & Anderson, 1990; Hewson & Hewson, 1983; Smith et al., 1993; Stofflett & Stoddart, 1994; Treagust et al., 1996; Wandersee et al., 1994).

A fourth factor that might explain the relatively limited influence of the participant HOS courses on the NOS views of students, including student teachers, relates to the goals and objectives of these courses. The aim of enhancing students' views of the NOS might not always be accorded priority in HOS courses. Science educators' suggestion that coursework in the HOS would improve science teachers' NOS views seems to be based on the implicit assumption that the goals and objectives of HOS courses are comparable with science educators' vision of the role of HOS in the preparation of science teachers and the vision of recent reforms regarding the centrality of the NOS to achieving scientific literacy (AAAS, 1990, 1993; NRC, 1996). This assumption might not always be valid. HOS is an established discipline with its own legitimate agendas and concerns (Kuhn, 1977). These agendas and concerns will not always be consistent with the needs of prospective science teachers or their educators. For instance, in HOS courses, learning about the history of scientific disciplines and knowledge might be viewed as an end rather than a means to achieve other goals. Moreover, if HOS is viewed as a vehicle for achieving other objectives, teaching about the NOS might be only one among several other objectives deemed important within the discipline of HOS.

As indicated in Chapter IV, in the present study, only the Evolution course professor articulated an explicit commitment to helping students develop adequate views of the NOS in general and of *specific* aspects of the nature of scientific theories in particular. He explicitly noted that helping students develop an understanding of the NOS ranks high among his objectives because such an understanding is relevant to students' everyday lives. By comparison, the Survey and Controversy course professors did not *explicitly* express similar commitments or concerns. Indeed, as was argued earlier, besides explicit attention given to the NOS, course objectives and instructor priorities were the most likely attributes of the participant HOS courses to account for the fact that, among these courses, the Evolution course was relatively more effective in improving students' views of the NOS.

As such, it can be seen that several factors might impede the effectiveness of the historical approach in enhancing the NOS views of students in general and student teachers in particular. It was argued in Chapter I that one possible way to ameliorate the aforementioned "obstacles" to enhancing prospective science teachers' NOS views is to provide those teachers with a conceptual framework consistent with current views of the

NOS *prior* to their enrollment in HOS courses. As was indicated in Chapter II, such a framework could be developed, and has indeed been developed with *some* success, within science methods courses through the use of an explicit approach that utilizes *elements* from the history and philosophy of science. And since learners tend to interpret and make sense of new experiences from within their extant conceptual frameworks (Anderson, 1990; von Glasersfeld, 1979,1989), such framework might help student teachers to interpret the historical narrative from within an alternative mind-set, one that is more consistent with current views of the nature of scientific knowledge and practice. As such, this framework coupled with coursework in the HOS could serve to reinforce, elaborate, and deepen student teachers' understandings of various aspects of the NOS and to enrich these understandings with examples, analogies, metaphors, and stories. These understandings, it should be noted, were deemed necessary to enable science teachers to successfully teach the NOS to secondary students. The question that follows from this discussion is: Do the results of the present study lend empirical support to the suggestion that entering HOS courses with a framework consistent with current views of the NOS is likely to help students and students teachers develop more adequate and elaborate views of the NOS?

The Relationship between Participants' Pre-instruction NOS Views and Changes in Their Views

Data analyses revealed a pattern *consistent* with the suggestion that students who enter HOS courses with a framework consistent with current views of the NOS are more likely to leave such courses with more adequate and enriched views. As noted earlier, eight aspects of the NOS were emphasized in the present study. These aspects included the tentative, empirical, inferential, creative, and subjective nature of scientific knowledge. The three other aspects were 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 were highlighted. Change, mostly with respect to one aspect of the NOS or another, was evident in the views of *relatively* more participants who entered the investigated HOS courses with adequate views of *four* or more of the eight NOS aspects emphasized in the present study. Indeed, the percentage of these latter participants whose views have changed (53%) was twice as large as the corresponding percentage (26%) among participants who entered the HOS courses with relatively less adequate views of the NOS. Moreover, the percentage of participants whose views were enriched among students who entered the HOS courses with adequate views of four or more NOS aspects (47%) was four times as large as the corresponding percentage (12%) among participants who entered the HOS courses with less adequate views of the NOS. It should be noted that participants' views of an aspect of the NOS were considered enriched if those participants provided in post-instruction questionnaires specific examples discussed in a HOS course to support or defend their views regarding the target NOS aspect.

What is noteworthy is that this pattern was even more pronounced in the case of the 10 preservice science teachers enrolled in the Evolution course. Eight of these 10 preservice teachers demonstrated adequate views of four or more aspects of the NOS at the beginning of the study. The views of *all* eight student teachers were changed or enriched. Change was evident in the views of six of these eight preservice teachers (75%)

and the views of three (38%) were enriched. It should be emphasized, nonetheless, that those changes were mostly with respect to one aspect of the NOS or another.

However, as indicated earlier, the significance of this pattern is *limited* by two factors. First, the number of participants who entered the HOS courses with adequate views of four or more aspects of the NOS was relatively small. Ninety percent of all participants entered the HOS courses lacking any views consistent with current conceptions of the NOS or having adequate views of a few aspects of the NOS that lacked coherence or consistency. Only 15 participants (10% of all participants) held adequate views of four or more aspects of the NOS. Eight of these participants were preservice science teachers. As such, the aforementioned pattern might be an artifact of idiosyncratic attributes of a few participants rather than a reflection of a more general trend. The second factor was that the cut-off number of "four aspects" of the NOS was arbitrary. There were no substantial or coherent relationships between the particular sets of four aspects of the NOS with which certain participants entered the HOS courses and the few changes that were evident in those participants' post-instruction views.

Nonetheless, it should be noted that the aforementioned pattern was particularly pronounced in the case of the few participant preservice teachers. In general, to the extent that participant student teachers are representative of preservice science teachers, the results of the present study indicate that providing prospective science teachers with a framework consistent with current views of the NOS prior to their enrollment in HOS courses *is likely* to help them develop more adequate and elaborate views of the NOS.

Limitations of the Study

As with all research studies, the present study has limitations. First, the results of the present study are not necessarily generalizable beyond the participant students, student teachers, and HOS courses. Indeed, in the present study, it is not claimed that participant students and student teachers are representative of any larger population of college undergraduates or graduates and preservice science teachers respectively. Similarly, it is not claimed that the participant HOS courses are representative of introductory or general HOS college courses. Rather, extensive profiles of participant students, student teachers, and HOS courses were provided in Chapter IV. The student profiles delineated the participants' gender, age, and education with a special focus on their HOS, philosophy of science, and science backgrounds. The course profiles presented overviews of the three participant HOS courses including course objectives, instructor priorities, topics covered, teaching approach, classroom dynamics, assignments and assessment strategies, and any explicit attention accorded to the NOS. It is hoped that these profiles would help readers, science educators or historians of science, judge for themselves the relevance and applicability of the results of the present study to their particular contexts.

Second, some generalizations concerning participants' views of the NOS were derived from analyses of the interviews conducted with students in the two random sub-samples. While there was no evidence to indicate that participants in these sub-samples were different from all participants in any systematic manner, the richness and validity of these reported generalizations could have been enhanced if all participants were interviewed. However, as noted earlier, the decision to interview a sample of all participants was largely dictated by practical considerations. Given the relatively large number of participants, it was not possible within the timeframe of the present study that spanned 12 weeks to interview all or even half of the participants at the beginning of the study and all or the other half at the end and still manage to adequately regard these interviews to be pre- and post-instruction respectively. However, as noted above, this concern is somewhat mitigated by the fact that there were no systematic differences between participants in the random sub-samples and all participants. Moreover, Chapter IV clearly delineates the data source(s), such as responses to the NOS questionnaires, responses to interview questions or both, used to derive each generalization reported in the present study.

Third, the researcher was the main instrument of data analysis. As such, the results of the present study are no doubt infused with elements from the researcher's background, experiences, and biases. These elements might have focused the researcher's attention on certain aspects of the data at the expense of others. This concern is somewhat ameliorated, though by no means eliminated, by two factors. First, as was detailed in Chapter III, the generalizations reported in the present study were based on several rounds of pattern generation, confirmation, and modification. Second, it is hoped that the section "About the researcher" presented in Chapter III would provide readers with an overview of the researchers' background, priorities, and probably biases that might help them to better judge the validity of the reported results.

Fourth, the pattern concerning the relationship between preservice teachers' pre-instruction conceptions of the NOS and the changes that were evident in their conceptions should be viewed with caution given the relatively small number of preservice teachers enrolled in the Evolution course. Finally, the aspects of the NOS emphasized in the present study, though consistent with the NOS understandings emphasized in the recent reforms in science education (AAAS, 1990, 1993; NRC, 1996), are by no means privileged or exhaustive. These aspects represent only a subset of a multifaceted and complex enterprise that is given the *seemingly* unifying label "the NOS." However, as was argued in Chapter I, the NOS aspects emphasized in the present study were those judged by the researcher to be accessible and meaningful to K-12 students. For instance, the present study did not explore participants' views of the nature of reality, such as their beliefs regarding the existence of an ontological reality versus a socially constructed one. Similarly, the present study did not explore the issue of whether the notion of a single "Science" or "Scientific enterprise" with a capital "S" is an actuality unified in its essence or whether there exists a set of "unique" scientific disciplines each with its idiosyncratic set of attributes, such as cannons of evidence, validity, and instrumentation. As such, the reported results should by viewed and interpreted only from within the few NOS aspects that were emphasized in the present study.

Implications of the Study

The present 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 the nature of the scientific enterprise. These implications are specifically related to the instructional approach utilized in HOS courses to improve students' NOS views and sequencing coursework related to the NOS in the preparation of prospective science teachers.

First, as was argued earlier, some conceptual difficulties might impede the effectiveness of the historical approach in enhancing students' NOS views. Briefly, in HOS courses, students are expected to interpret the historical narrative from within a conceptual framework that is different from their own. Students are then expected to "step-back" to the present and discern the relevance of the historical narrative to understanding the nature of *current* scientific knowledge and practice. The difficulty of such conceptual shifts is especially pronounced in the case of students, including prospective science teachers, whose experiences with HOS are mostly limited to one or a few courses. The present study indicates that *if* historians of science *specifically aim* to enhance students' views of the NOS, then an explicit instructional approach that targets certain NOS aspects can be *more* effective than an implicit approach. As noted earlier, an implicit approach assumes that learners would discern the NOS "lessons" embedded in the HOS course narratives on their own. Historians of science need to explicitly guide students in the process of interpreting historical narratives from within alternative perspectives. Additionally, students should be explicitly helped to discern the 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 the NOS based on their exposure to historical narratives.

However, a counter argument would be that certain views of the NOS have *already* been imposed on students. As was argued earlier, it is highly unlikely that students have come to harbor the well documented and persistent NOS misconceptions merely by internalizing implicit messages about the NOS embedded in their high school and college science experiences. It is more likely that those students were explicitly taught certain inadequate conceptions of the nature of scientific knowledge and practice. As such, explicitly communicating to students more adequate views of the NOS should not be viewed as an episode of formal indoctrination. Rather, helping students acquire a basic understanding of a complex intellectual endeavor labeled "the NOS" might empower them to further pursue this endeavor that aims to make sense of a yet more complex, rich, and interesting intellectual enterprise, the scientific endeavor.

Second, as indicated earlier, an explicit approach might not suffice to substantially change students' entrenched misconceptions of the NOS. In this regard, many research studies have indicated that a conceptual change approach might be effective in helping college students replace their misconceptions of certain scientific concepts with current scientific understandings (e.g., Anderson et al., 1990; Bishop & Anderson, 1990). As such, a conceptual change approach (Hewson & Hewson, 1983; Posner, Srike, Hewson, & Gertzog, 1982) could be more effective than direct instruction in helping students develop more adequate NOS views.

In the context of HOS courses, a conceptual change approach entails several stages. Students' views of certain aspects of the NOS are first elicited. Next, specific historical examples are used to help students discern the inadequacy of some of their views and raise their dissatisfaction with their current conceptions of the NOS. 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. For example, students could first be asked to articulate their views of the term "prove," the tentativeness of science, and the relationship between scientific theories and laws. If students harbor misconceptions about these NOS aspects similar to those explicated in the present study, then historical examples could be used to help students recognize the inadequacy of their views. More adequate views of these NOS aspects could then be explicitly presented and reinforced through the historical narrative. Students could then be guided to discern how adopting adequate views of these aspects might help them resolve some conceptual difficulties, such as the *proving dilemma* explicated in Chapter IV: students' struggle to reconcile the purported certainty or absoluteness of scientific laws and facts with the well-documented tentativeness of science. 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 the NOS probably at the expense of other instructional objectives.

Third, as far as helping student teachers develop more adequate views of the NOS is concerned, the present study has implications for sequencing coursework related to the NOS in teacher preparation programs. The results of the present study suggest that science educators can *not* simply assume that coursework in the HOS by itself might suffice to help prospective science teachers develop desired understandings of the 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 the NOS *prior* to their enrollment in HOS courses. Such a course sequence might help preservice teachers develop more adequate and enriched views of the NOS.

Within the context of science teacher preparation programs, science methods courses could play a role in providing student teachers with a conceptual framework consistent with more current conceptions of the NOS before enrolling in HOS courses. In the context of science methods courses, an explicit approach that utilizes elements from the history and philosophy of science might be more effective than implicit approaches that utilize science process-skill instruction or "doing" science, such as involving prospective teachers in hands-on inquiry based science activities, in enhancing science teachers' NOS views.

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 taken on the part of science educators to initiate a discourse with historians of science interested in enhancing students' views of the NOS. Such discourse could help make historians of science more cogent 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.

It should be noted that such collaboration would not be an easy undertaking. Various disciplinary commitments and institutional constraints might impede the aforementioned discourse and collaborative efforts. For instance, science educators and historians of science might not share common views regarding the basic components of constructs, such as scientific literacy or the NOS for that matter, that are crucial to the fruitfulness of any future collaboration. Nonetheless, HOS remains a valuable and indispensable resource that is crucial to helping prospective science teachers develop pedagogical content knowledge (PCK) in the specific context of the NOS. Such knowledge might "prove" essential in enabling those teachers to address the NOS instructionally in their classrooms.

Recommendations for Future Research

First, to the best of the author's knowledge, the present study is the first in the science education literature to investigate the influence of HOS courses on college students and preservice science teachers' views of the NOS. Further research is needed to establish the validity of the findings of the present study 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' views of the NOS reported in the present 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' views of the NOS. However, there might be some critical mass of HOS coursework that would substantially influence students' views of the nature of scientific knowledge. Future research studies could investigate the influence of completing multiple courses in the HOS on students' NOS views. Such research can shed light on the practicality of recommending HOS coursework for the *purpose of improving* preservice science teachers' NOS views. In this regard, as indicated earlier, during their years in teacher preparation programs, prospective science teachers are required to complete extensive coursework in a variety of disciplines in addition to their relatively extended student teaching experiences. Recommendations to add HOS coursework to an already extensive list of courses might not be practical if it were found that a relatively large number of HOS courses is needed to substantially improve those prospective teachers' views of the NOS. Alternative approaches might be sought to achieve that end. 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 views of the NOS. Moreover, the views of relatively more of these latter participants were enriched compared to participants who entered the HOS courses with less adequate views of the NOS. This finding was particularly pronounced in the case of participant student teachers and indicates that exposing preservice teachers to explicit NOS instruction prior to their enrollment in HOS courses might increase the likelihood that their NOS views would be changed or enriched as a result of their experiences with HOS. However, as was indicated earlier, this finding should be viewed with caution given the relatively small number of preservice science teachers that were enrolled in the Evolution course. This pattern, it was argued, might be an artifact of idiosyncratic attributes of a few participants rather than a reflection of a more general trend. Nonetheless, the possibility remains that the present finding reflects a more generalized pattern. It should be fruitful to assess the generalizability of this pattern in future research studies.

Fourth, should any collaborative efforts between science educators and historians of science to enhance science teachers' views of the NOS 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 the NOS aspects explicitly taught in the context of science education courses with those explored in depth in the context of HOS courses on enhancing preservice teachers' NOS views.

Finally, it was argued in the present study, that a form of NOS PCK might be needed to enable teachers to address the 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 the 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 avenue for future research.

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APPENDICES

Appendix A

Biographical Data Questionnaire

1. Gender: (please circle one) Female Male
2. Age: _________
3. Class: (please circle one)
   a. Freshman
   b. Sophomore
   c. Junior
   d. Senior
   e. Graduate
   e. Other. Please specify: ____________________
4. Undergraduate studies:
   Major: ______________________________________
   Minor (if any): ________________________________
5. Graduate studies:
   Undergraduate degree: BS BA Other. Please specify: ____________
   Graduate major: _________________________________
   Graduate minor (if any): ____________________________
6. Did you take (or are currently taking) other history of science classes? Yes No
   Did you take (or are currently taking) any philosophy of science classes? Yes No
   If yes, please list the course titles (or numbers) and credit hours

OSU				Other institutions			
Course Title	*	Course #	Credit hours	Course Title	*	Course #	Credit hours

* Please check if you are currently enrolled in this course.

7. Please list the total number of credit hours that you have completed in each of the following science areas:

Undergraduate courses:

Area	Number of credit hours
Biological sciences (biology, botany, cellular biology, entomology, fisheries and wildlife, forest science, microbiology, molecular biology, nutrition, plant pathology, plant physiology, toxicology, zoology)	
Physical sciences (biochemistry, chemistry, physics)	
Agricultural sciences (general, agricultural chemistry, crop science, soil science)	
Geo- and space sciences (including oceanography)	

Graduate courses:

Area	Number of credit hours
Biological sciences (biology, botany, cellular biology, entomology, fisheries and wildlife, forest science, microbiology, molecular biology, nutrition, plant pathology, plant physiology, toxicology, zoology)	
Physical sciences (biochemistry, chemistry, physics)	
Agricultural sciences (general, agricultural chemistry, crop science, soil science)	
Geo- and space sciences (including oceanography)	

8. Have you had other relevant experiences in science (independent research, fieldwork, teaching high school science, teaching college level science, etc.)? Please, elaborate.

Appendix B

Course Handout: Overview of the Research Project

My name is Fouad Abd-El-Khalick. I am a doctoral student in Science Education at OSU. I am beginning my dissertation research this Fall term and would like to ask for your help in my investigation.

I have a particular interest in the nature of the scientific enterprise and the history of science. My research project is an attempt to examine how your views of, and thinking *about* science might change as a result of enrolling in this course. I should note that I am not interested in your knowledge of the subject matter of science, but rather in your views about what science is, how it is practiced, the characteristics that typify the scientific enterprise and its various disciplines, and the characteristics of scientific knowledge.

In this course you are required to respond to an open-ended questionnaire that will ask for your views on some issues about science. You will answer this questionnaire twice, once at the beginning of the term and once toward the end of the term. The questionnaire has 9 open-ended items. There are no "right" or "wrong" answers to these items. I am simply interested in *your* views about some aspects of science.

In addition to the 9 items, the first questionnaire asks for some biographical information like your class standing and history of science background. The first questionnaire is due in class on (day, month, and year).

The second questionnaire is due in class on (day, month, and year).

In addition to the questionnaire, I will ask to interview *some* of you once. The interview will typically last for about 30 minutes. In the interview, I will ask you about what you have written in your questionnaire. The interview will be audio-taped. **I should note that participation in these interviews is *voluntary*. Unlike the questionnaire, the interview is *not* part of this course.**

Confidentiality will be maintained through the use of coding. The results of my investigation will be reported in aggregate from to maintain anonymity. The audio-tapes and questionnaires will be kept in a locked location at all times.

The information that you will provide me will be extremely valuable to my study. I would like to thank you in advance for taking the time to help me in this investigation.

For any questions please do not hesitate to contact me at my office (737-4031 or 737-1824) or home (713-6706). My e-mail address is abdelkhf@ucs.orst.edu

Appendix C

Informed Consent Form

Dear _________________,

My name is Fouad Abd-El-Khalick. I am a doctoral student in science education at OSU. I am beginning my dissertation research and would like to ask for your help in my investigation. My research is concerned with the influence of college history of science courses on students' conceptions of the nature of science.

Participation will be in Fall term, 1997. I will interview you once during my investigation. The interview will typically last for about 30 minutes. In the interview, I will ask you about your views regarding the nature of science.

The interview will be audio-taped and transcribed for analysis. My major professor and myself will be the only persons with access to the data. Confidentiality will be maintained through the use of coding. The results of the proposed study will be reported in aggregate form to maintain anonymity. In case reference to individual participants is in order, pseudonyms will be used. The audio-tapes and interview transcripts will be kept in a locked location at all times.

Participation is voluntary. You may discontinue your participation at any time.

Questions about the research or personal rights should be directed to Prof. Norman Lederman, 737-1819.

Thank you for taking the time to participate in this research project.

Fouad Abd-El-Khalick, 713-6706 or 737-1824

I agree to participate in this research project and understand the general intent of the study, the types of data to be collected, and the time commitments in the study.

_________________________ Signature

_______________ Date

Appendix D

NOS Questionnaire

Name: ______________________________

Date: / / 1997

Instructions

- Please answer each of the following questions. You can use the back of a page if you need more space.
- **There are no "right" or "wrong" answers to the following questions. We are only interested in your views on a number of issues about science.**

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)?

[This question attempted to assess respondents' views regarding the role that empirical play evidence in science, the notion that the aim of science is to answer questions about the natural world and to provide "natural" explanations, etc. In responding to this question, students usually express the misconception that the use of "the" scientific method or any other set of logical and orderly steps differentiates science from other disciplines of inquiry.]

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.

[Questions #2 and #3 were used in combination in the attempt to assess whether respondents equate scientific investigation with experimentation or equate science with the use of "the" scientific method or any other set of logical and orderly steps. In order to avoid any confusion in interpreting answers to question #3—confusion that might follow from the fact that different students might define experiments differently, respondents were asked to express their conceptions of scientific experiments in question #2.]

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.

[This question aimed to assess respondents' understanding of the tentative nature of scientific theories/claims and why these theories/claims change. Students mostly attribute such change solely to the accumulation of new facts and/or the development of new technologies. Additionally, the question aimed to assess respondents' understanding of the theory-laden nature of scientific investigations and the crucial role that scientific theories play in science.]

5. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.

[This question aimed to get at a common misconception about the relationship between the products of science. Most students believe in a hierarchical relationship between the two whereby theories become laws if and when enough evidence has been accumulated in their favor. Moreover, several ideas are often expressed by respondents as they attempt to delineate the difference between scientific theories and laws.]

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?

   [This question referred respondents to a concept from the physical sciences to assess their understandings of the role of human inference and creativity in science, the role of models in science, and the notion that scientific models are not copies of reality.]

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?

   [This question referred respondents to a concept from the biological sciences to assess their understandings of the role of human inference and creativity in science, the role of models in science, and the notion that scientific models are not copies of reality.]

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

[This question aimed to assess respondents' understandings of the role of human creativity and imagination in science, and the phases of scientific investigations at which students believed that these aspects play a role. Usually, students indicate that creativity plays a role in designing experiments. Creativity in this sense turns out to be "resourcefulness" or "skillfulness." Students are less likely to indicate that creativity is used in data analysis in the sense that scientists are, for instance, "creating" patterns rather than "discovering" them.]

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?

   [By posing a scientific controversy and stressing the fact that scientists are using the same set of data to come up with radically different conclusions, students are invited to think about the factors that affect the work of scientists. This question aimed to assess respondents' beliefs about such factors that might range from personal preferences and bias to differing theoretical commitments to social and cultural factors.]

Appendix E

Syllabi for the Investigated HOS Courses

HSTS 411/511 **History of Science** Fall 1997

The Beginning

[Professor's name]
[Office and office hours]

History Dept. [Phone]
[Office]

Texts:
- H. Frankfort, *Intellectual adventure of ancient man* (or *Before philosophy*). This is REQUIRED.
- M. Clagett, *Greek science in Antiquity*, optional; old but OK.
- D. Lindberg, *The beginnings of Western science*, optional but very BEST survey of the whole period.
- G. Lloyd, *Early Greek science, Thales to Aristotle*, optional, but very GOOD for the early period which is confusing.
- E. Grant, *Physical science in the Middle Ages*, optional but BEST on what happens after Rome.

DATE	**PROBABLE TOPIC**	**SUGGESTED READING**
U 30 Sept	Before the Greeks	Frankfort (required), Clagett, Lindberg (Neugebauer)
H 2 Oct	Egypt	
U 7 Oct	Mesopotamia	
H 9	Comparison	
U 14 Oct	Hellenic Greeks	Lloyd, Clagett, Lindberg (Hussey, Kirk & Raven)
H 16	Pre-Socratics	
U 21 Oct	Socrates	
H 23	Plato	
U 28 Oct	Aristotle	
H 30	More Aristotle	
U 4 Nov	Hellenistic Greeks	Clagett, Lindberg
H 6	Anatomy & Galen	
U 11 Nov	Math, pure & applied	
H 13	Astronomy	
U 18 Nov	Ptolemy	Grant, Clagett, Lindberg (Stahl, White)
H 20	The Latin-speaking West	
U 25 Nov	Romans and Christians	
H 27	**THANKSGIVING HOLIDAY**	
U 2 Dec	East & Islam	
H 4	Revival	
M 9 Dec	**** TAKE-HOME FINAL DUE only if you are required to write one ****	

Background and Reference :

Ed. Hussey, *Pre-Socratics*.
G. Kirk & J. Raven, *Pre-Socratic philosophers*; the standard reference.
O. Neugebauer, *Exact sciences in Antiquity*; on math and astronomy, mostly pre-Greek.
W. Stahl, *Roman science*; excellent, the best on the subject.
L. White, *Medieval technology and social change*; classic on social effects of new tech.

GRADING

Your grade is based on short take-home essays (if any) and in-class quizzes and summaries. Some of the in-class work will be open notes and some will be closed notes. There will be no formal midterm. A final is required only if your average score at the last tally is less than 70% (C-). If your average is 70% or greater, the final is optional. The final will be handed out the last week of class, probably on Tuesday and will be due the following Tuesday.

Work done outside class, if there is any, will be due on the date announced. You can turn it in the class period following the due date, but you will loose 10%. Later work will **NOT** be accepted. Missed in-class quizzes cannot be made up unless you are in a body cast (i.e., you must have **a very good excuse**; enrollment and the number of quizzes makes it impossible to give you much leeway on this).

Letter grades are assigned strictly on percent-**no curve**. A=90-100%, B=80-<90, C=70-<80, D=60-<70, and F=<60. Pluses and minuses are given. Grades for all work done outside of class and quizzes over Frankfort will be counted. Your lowest grade on **in-class** work (Except the Frankfort quiz) will be dropped. To earn a full A, however, you must average 95% or better on **all** your work (no grade dropped).

Grading is straight forward and some what mechanical. Problems come from at-home work not turned in or not turned in by the deadline, or from in-class work missed or bad grades on in-class quizzes on material from a class you missed. You build your grade as the term progresses and although the final will count more than a single assignment, it does not count enough to compensate for an otherwise low average. Thus **it is not possible to recoup at the end for an accumulation of missed work or quizzes—remember this.** If you are taking this pass-fail, you must average 70% (C-) or better to pass.

Come to class, listen and take notes. Mentally prepare yourself each day to summarize the subject discussed. Read. Understand (if you do not understand, ask questions!). If you miss a class read about the topic. Turn in work on time. That's it. I will expect you to remember (in your head, not in your notes) the major figures (there are not very many), why each is "major," and even how to spell their names! I will give you some identification quizzes as we go along.

Remember academic honesty. Talk things over with your friends but **do your own work.**

For HSTS 512: In addition to Frankfort, read all of Lloyd and the appropriate part of Lindberg. I will expect your writings to reflect a more thorough and more sophisticated understanding of the material.

Read a biography of your favorite scientist and one of his (her) works (or another book on the period—check with me) and write a five-to-six-page (of text) paper (use the standard format for research papers). It should include a summary of the life and work with special emphasis on the contemporary **importance (significance)**. Significance depends on the contemporary context. Check with me on an appropriate subject and book. Start on this early. As with your other work. Your paper should reflect your understanding of the science of the period and the role of your person in changing it.

You will also write the take-home final exam.

Hsts 415/515 Fall, 1997

The History of the theory of Evolution

[Professor's name]
[Office and phone number]
[e-mail]

Date		Lecture	Reading
Week I	9/29	Intro., Pre-D. Biology	Voyage of the B.
	10/1	Pre-Darwinian Biology	
	10/3	Natural Theology	“
			“
Week II	10/6	Geology	“
	10/8	Pre-D. Theories of Evol.	“
	10/10	Darwin, Beagle	“
Week III	10/13	Beagle and After	Origin
	10/15	Early Theory	“
	10/17	Barnacles	“
Week IV	10/20	Wallace	“
	10/22	Origin	“
	10/24	**MIDTERM**	
Week V	10/27	Reception of Theory (Sc.)	Projects
	10/29	Reception: US, Britain	“
	10/31	Reception: US, Britain	“
Week VI	11/3	“	
	11/5	Reception: France, Germany	“
	11/7	NO CLASS	“

Week VII	11/10	Reception: France, Germany	"
	11/12	Reception: Religion, Soc. Sc.	"
	11/14	"	
Week VIII	11/17	Reception: Religion, Soc. Sc.	"
	11/19	"	"
	11/21	Modern Interpretations	
Week IX	11/24	"	
	11/26	"	
	11/28	**THANKSGIVING**	
Week X	12/1	Modern Interpretations	
	12/3	"	
	12/5	Recap	

Assignments
HSTS 415\515

1. Darrin's Voyage of the Beagle is the first assigned reading (Wks 1&2). It is long, but engaging. You should attempt to skim it rather than read it word for word. Look for the following: what is it that Darwin finds interesting in his journey, i.e., what are the questions he seems to be asking, what are the observations he feels are most significant. You will not be expected to master the details of his trip, but you will be expected to have a sense of the trip's importance for Darwin.

2. Darwin's Origin of Species is the second assigned reading (Wks 3&4). It is a long, difficult book to read, but it is well worth the effort. This packet contains a Reading Guide that will guide you through it, point out the central arguments, and suggest major issues to consider. IF POSSIBLE BEGIN REDAING THIS BEFORE October 13!!!!! It will take you longer than you think. Use the first edition (available in the bookstore). If you have a copy (there are

many available in a variety of forms) and are not sure if it is the first edition, bring it to me and I will tell you which edition it is. Most of the editions on the web are 6th edition (longer and more confusing).

3. After the midterm (10/24), your major assignment (aside from attending lectures and the Final) is to write a short research paper (approximately 5-7 pages for those in HSTS 415, 10-15 pages for those in HSTS 515). You are to select a person who is alive, or whose major work was done in the twentieth century and who wrote on evolution (either as a biologist, philosopher, theologian, etc.). Your paper should BRIEFLY describe the person's life and work, and then compare and evaluate that person's conception of evolution with that of Darwin's. The papers should contain a bibliography and have footnotes to cite information and sources. The aim of the paper is to have you compare a twentieth-century evolutionary position to that of Darwin's. Although most of you will probably choose biologists to read, you should feel free to look at philosophers, social thinkers, etc.

4. First Drafts of research papers are due on Nov. 21. They will be graded and returned to you. The Final Drafts will be due Dec. 5.

GRDAING

Grades are evaluations. Your grade will be based largely on the following:

Midterm 40%
First Draft of Research Paper 15%
Final Draft of Research Paper 15%
Final Exam 30%

Additional points:

This course has weekly in-class writing assignments. These are corrected and points are recorded. Although they are not directly calculated into the grade, if your are on the borderline (e.g., between D+ and C-, or a B+ and an A-) I will take the points into consideration.

There are no "extra" assignments or projects for additional points. If you are disappointed in your midterm (or any other) grade, please come and discuss it. There are usually a variety of options possible.

HSTS 419/519 / Fall, 1997 / [Professor's name]
Studies in Scientific Controversy: The Method and Practice of Science

Class Meetings: [Hall, room and time]
[Office and office hours]

This course focuses on accounts of scientific discoveries which have been controversial, with the aim of understanding the rational, psychological, and social characteristics which have defined the meanings and procedures of the natural sciences. Case studies are used from the seventeenth through twentieth centuries.

Our readings during the first two weeks will emphasize the logical and psychological structure of scientific investigation. These readings include many examples, which should be read for general lines of argument, rather than detail. Detailed case studies which provide insights into the social as well as the logical and psychological structure of scientific work, will follow during weeks 3-9, focusing on debates about the motion of the earth; mesmerism and electricity as medical cures in the eighteenth century; radiations and radioactivity in the 1890s and early 1900s; human origins and "Piltdown man;" geological and cosmological theories of the extinction of the dinosaurs; cold fusion; and relativity.

Class meetings will focus on discussion of required readings, following introduction of the subject by [Professor's name]. There will be three twenty-five minute short-essay examinations in class. A term paper is due at the last class meeting. Two additional assignments are completion of questionnaires at the beginning and end of the term. There will be no final, comprehensive examination.

419 students are expected to write a term paper of approximately ten to twelve pages on one of the detailed cases (Weeks 3-9) that figures in our reading and discussion. 519 students are expected to write a longer term paper of approximately twenty pages. All papers should make use of some primary documents, i.e., publications by scientists or other contemporaries who figure in the case history, as well as some of our required reading. The aim of all papers should be to explain the origins and significance of a scientific controversy, as well as the balance of logical, psychological, and social factors in its outcome. Topics for term papers should be discussed with [Professor's name] before the mid-term, and a one-page proposal for the paper is due to [Professor's name] no later than the mid-term (October 30).

Term papers will be evaluated on the basis of conceptualization, technical organization and execution, and originality. Note that no wording from another author that is longer than ten words is to be incorporated into the paper without the use of quotation marks and attribution by citation. Endnotes, footnotes, or parenthetical citations must be used in the paper. A bibliography should be included of all sources consulted, including individuals and websites, if any.

519 students (but not 419 students) may choose as a topic for the term paper a case study that has not been discussed in class during Weeks 3-9. Possible subjects include controversies over phlogiston and oxygen theories, parapsychology, creationism, Kammerer's or Lysenko's genetics, continental drift, polywater, extraterrestrial life, intelligence measures, or spontaneous generation. Discoveries and theories verified, unverified, mistaken, or fraudulent may be chosen for analysis, insofar as their analysis help us understand the method and practice of scientific investigation.

The term grade will be determined as follows:
419 students: each exam: 20%; term paper 40%
519 students: each exam: 15%; term paper 55%

Students are expected to attend class, complete two questionnaires, and to participate in class discussion. Failure to do so may result in a penalty of up to two points in the term grade.

HSTS 419 meets the requirements for a Baccalaureate Core course and a writing intensive course.

Required Textbooks, available in bookstore and on reserve:

1. Rom Harre'. Great Scientific Experiments. Oxford University Press. 0-19-286036-4. $10.95
2. Harry Collins and Trevor Pinch. The Golem: What Everyone Should Know about Science. Cambridge University Press. 0-521-47736-0. $9.95
3. Albert van Helden. Siderius Nuncius. University of Chicago Press. 0-226-27903-0. $8.95
4. Robert Darton. Mesmerism and the End of the Enlightenment in France. Harvard University Press. 0-674-56951-2. $14.50
5. David Raup. The Nemesis Affair: A Story of the Death of Dinosaurs and the Ways of Science. Norton. 0-383-30409-4. $8.95

Required Readings in Reader and on reserve:

Geoffrey Sutton, "Electric Medicine and Mesmerism," Isis, 72 (1981), 375-392.

Abraham Pais, "Radioactivity's Two Early Puzzles," Reviews of Modern Physics, 49 (October 1977), 925-938.

Mary Jo Nye, "N-Rays: An Episode in the History and Psychology of Science," Historical Studies in the Physical Sciences, 11 (1980), 125-156.

John Hathaway Winslow and Alfred Meyer, "The Perpetrator at Piltdown," Science 83, September 1983, 33-43.

Ron Westrum, "Science and the Social Intelligence about Anomalies: The Case of Meteorites," Social Studies of Science, 8 (1978), 461-493.

Bruce Lewenstein, "Cold Fusion and Hot History," Osiris, 2nd series, 7, Science after '40 (1992), 135-163.

John Earman and Clark Glymour, "Relativity and Eclipses: The British Eclipse Expedition of 1919 and Their Predecessors," Historical Studies in the Physical Sciences, 11 (1980), 49-85.

Preliminary schedule, with readings:

1. Week 1 (Sept. 30, Oct. 2): Organizational Meeting and Introduction; Begin reading Harre', pp. 1-104

2. Week 2 (Oct. 7, 9): The logical and Psychological Structure of Scientific Knowledge: Compete Harre', 1-104, 125-206

3. Week 3 (Oct. 14, 16): The Seventeenth-Century Debate on the Motion of the Earth: Read all of van Helden (25 minute exam)

4. Week 4 (Oct. 21, 23): The Eighteenth-Century Controversy over Mesmerism and Electricity in Popular Medicine: Read Darton; Sutton

5. Week 5 (Oct. 29, 30): Radiations around 1900: X-Rays, Becquerel Rays, N-Rays: Read Harre', pp. 105-113; Pais, Nye

October 30: Term-Paper Proposal due

6. Week 6 (Nov. 4, 6): The Question of Human Origin and the Place of Piltdown Man in Human Evolution: Read Winslow & Meyer (25 minute exam)

7. Week 7 (Nov. 11, 13): Extraterrestrial Causes of the Extinction of the Dinosaurs: Read Westrum; Raup

(over)

8. Week 8 (Nov. 18, 20): Cold Fusion and Hot Controversy: Read Collins & Pinch, Chpt. 3; Lewenstein

9. Week 9 (Nov. 25): Tests of Relativity Theory: Read Harre', pp. 114-124; Collins & Pinch, Chpts. 2, 5; Earman & Glymour (25 minute-exam)

10. Week 10 (Dec. 2, 4): Conclusion and Discussion of Term Papers

December 4: Term Paper Due