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FOREWORD

Research on Nature of Science:

Reflections on the Past, Anticipations of the Future

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Introduction

Later this year, a new *Handbook of Research in Science Education* will be published by Lawrence Erlbaum and Associates (edited by Sandra Abell and Norman G. Lederman). As one might expect, there will be a chapter on nature of science. The chapter will represent the fourth systematic review of research on nature of science (Abd-El-Khalick & Lederman, 2000; Lederman, 1992; Meichtry, 1992). What follows is a brief review of the history of research in the field and some speculations about WHAT research the future may hold.

The construct ‘nature of science' (NOS) has been advocated as an important goal for students studying science for approximately 100 years (Central Association of Science and Mathematics Teachers, 1907). Most recently, NOS has been advocated as a critical educational outcome by various science education reform documents worldwide (e.g., Australia, Canada, South Africa, United Kingdom, United States). The observation that NOS has been a perennial goal of science education, and is now receiving increased emphasis, can be construed to mean that high school graduates, and the general citizenry, do not possess (and never have possessed) adequate views of NOS. The research clearly supports this notion. That said, has anything been lost?

Perhaps, the most concise way of answering the question of why understanding NOS is important is to consider the five arguments provided by Driver, Leach, Millar, and Scott (1996). Their arguments were as follows:

Utilitarian: understanding NOS is necessary to make sense of science and manage the technological objects and processes in everyday life

Democratic: understanding NOS is necessary for informed decision-making on socioscientific issues

Cultural: understanding NOS is necessary to appreciate the value of science as part of contemporary culture

Moral: understanding NOS helps develop an understanding of the norms of the scientific community that embody moral commitments that are of general value to society

Science learning: understanding NOS facilitates the learning of science subject matter

Certainly, these are all important and noble reasons for why science educators value NOS as an instructional outcome. However, at this point, the arguments are primarily intuitive with little empirical support. Much like the general goal of scientific literacy, until we reach a critical mass of individuals who possess adequate understandings of NOS we have no way of knowing whether achievement of the goal will accomplish what has been assumed. If we become generally more successful at teaching NOS to our students, will they become better decision-makers? Will their science achievement improve? My goal is not to contradict or cheapen my life's work. Rather, my goal is to emphasize that the jury is still out. The most important questions are still left to be answered and there are most assuredly many questions that have yet to arise. Students' and teachers' understandings of NOS remain a high priority for science education and science education research. As mentioned before it has been an objective in science education (American Association for the Advancement of Science [AAAS], 1990, 1993; Klopfer, 1969; National Research Council [NRC], 1996; National Science Teachers Association [NSTA], 1982) for almost 100 years (Central Association of Science and Mathematics Teachers, 1907; Kimball, 1967-68; Lederman, 1992). Indeed, "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).

Defining the Construct

Before summarizing the research on NOS it will be important to provide some general parameters for the meaning of the construct. What is NOS? It might help to back-up to the proverbial question, "What is Science?" The most common answer to this question in the literature is: 1) Body of Knowledge, 2) Method/Inquiry, and 3) Way of Knowing. NOS typically refers to the characteristics of scientific knowledge that are derived from how the knowledge is developed (i.e., scientific inquiry). What follows is a brief consideration of these characteristics of science and scientific knowledge related to what students should know. It is important to note that the aspects of NOS described below are not meant as a comprehensive listing. There are other aspects that some researchers include or delete (Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003; Scharmann & Smith, 1999). The primary purpose here is not to emphasize one listing versus another, but to provide a frame of reference that helps delineate NOS from scientific inquiry (and processes of science) and the resulting body of knowledge.

My research team and colleagues over the past 20 years have focused on the following characteristics of scientific knowledge in our research on nature of science:

- The distinction between observation and inference
- The relationship and distinction between scientific laws and theories
- Scientific knowledge is, at least partially, based on and/or derived from human imagination and creativity.
- Scientific knowledge necessarily is partially subjective and can never be totally objective.
- Science as a human enterprise is practiced in the context of a larger culture and its practitioners (scientists) are the product 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.
- Scientific knowledge is never absolute or certain; it is subject to change.
- Scientific knowledge is empirically based.

It is important to note that individuals often conflate NOS with science processes or scientific inquiry. Although these aspects of science overlap and interact in important ways, it is nonetheless important to distinguish the two. Scientific processes are activities related to collecting and analyzing data, and drawing conclusions (AAAS, 1990, 1993; NRC, 1996). For example, observing and inferring are scientific processes. More complex than individual processes, scientific inquiry involves various science processes used in a cyclical manner. On the other hand, NOS refers to the epistemological underpinnings of the activities of science and the characteristics of the resulting knowledge. Perhaps, the phrase "nature of science" has caused the confusion and the phrase "nature of scientific knowledge" might be more accurate. The conflation of NOS and scientific inquiry has plagued research on NOS from the beginning.

What Has the Research Shown?

Although nature of science has been recognized as an important instructional objective since the early 1900s, systematic research really did not begin until the late 1950s/early 1960s. Generally, the research was pursued with the following sequence of foci:

- Research on students' conceptions
- Research on curriculum
- Research on teachers' conceptions
- Research on attempts to improve teachers' conceptions
- Research on the relative effectiveness of various instructional practices

The initial research was quite descriptive and simply tried to assess whether science instruction had been successful with respect to improving students' conceptions. The results were disappointing and lead to the conclusion that students' poor understandings must be the result of a lack of curricular attention to nature of science. Hence, much effort was placed on the development of curriculum. The results were mixed, some curricula worked for some teachers and not for others. Many conjectured that the teacher was a critical factor and so much descriptive research was completed to assess teachers' understandings. The assumption was that a teacher could not be expected to teach what he/she did not understand. Unfortunately, the focus on the teacher initially did not consider what the teacher did instructionally as opposed to what the teacher knew about nature of science. It was assumed that there was a direct relationship between teachers' and students' understandings of nature of science and between a teacher's understandings and his/her instructional behavior. These assumptions guided research nature of science throughout the 1970s and early 1980s. Both assumptions were found to be invalid (Lederman, 1986) and the current view is that teachers' knowledge is necessary, but not sufficient for improving students' conceptions of nature of science.

Initially, research that focused on teachers' instructional behaviors assumed that if students were engaged in scientific activities (e.g., inquiry) they would come to understand nature of science implicitly. This third assumption did not prove to be valid as the research in the 1990s and early 2000s clearly indicates that students and teachers best learn nature of science if it is presented in a reflective, explicit manner. That is, nature of science needs to be taught in the same manner as other more traditional cognitive outcomes. It is important to note that “explicit” is not synonymous with “direct” instruction. In this sense, “explicit” refers to instructional approaches that make aspects of nature of science visible in the classroom. That is, students are engaged in discussions that ask them to reflect on what they did during investigations and what implications these activities have for the resulting knowledge and conclusions. Obviously, engaging students in scientific investigations in a very fruitful context for improving students' conceptions of nature of science, but simply having them do investigations without explicit reflections is not effective.

The review of research in the new *Handbook* presents a detailed summary of individual research investigations. In summary, however, after approximately 50 years of research on nature of science, the following generalizations can be made:

- K-12 students do not typically possess “adequate” conceptions of NOS.
- K-12 teachers do not typically possess “adequate” conceptions of NOS.
- Conceptions of NOS are best learned through explicit, reflective instruction as opposed to implicitly through experiences with simply “doing” science.
- Teachers' conceptions of NOS are not automatically and necessarily translated into classroom practice.
- Teachers do not regard NOS as an instructional outcome of equal status with that of “traditional” subject matter outcomes.

Where We Should Be Headed?

Regardless of the “holes” that one can find in the existing research literature, the past 50 or so years of research on NOS does provide us with some clear direction in terms of future research and teaching. What follows are just a few of the critical lines of research that need to be pursued.

How do teachers' conceptions of NOS develop over time? What factors are important and are certain factors more related to certain aspects of nature of science than others?

We need more in-depth knowledge of how views on NOS change over time. Certainly, change in such views must be similar to the change that one sees with other science concepts. Shifts in viewpoints are most likely gradual and certain aspects of NOS may be more easily altered than others. It is just as likely that those factors of importance have a differential influence on the various aspects of NOS. To date, the available research simply identifies whether an individual's views have changed from “naïve” to “adequate.”

What is the influence of one's worldview on conceptions of nature of science?

Although much research on individuals' worldviews has been pursued, such research has rarely been directly and systematically related to views on NOS. One notable exception has been Cobern's work (2000). It seems that NOS may be a subset of one's worldview or is at least impacted by one's worldview. Of primary importance is the relevance of this line of research for the teaching of NOS across cultures. What happens when there is a clash between one's cultural views and the views expressed in western-influenced depictions of science and NOS?

What is the relative effectiveness of the various interventions designed to improve teachers' and students' conceptions? Is one better than another or is a combination needed?

Although there is strong emerging evidence that an explicit approach to the teaching of NOS is more effective than implicit approaches, there has been virtually no research that compares the relative effectiveness of the various explicit approaches. Are the various approaches equally effective? For example, is explicit instruction in the context of a laboratory investigation more or less effective than explicit reflection within the context of an historical case study? Is a combination of the two approaches more effective than either approach alone?

Is nature of science learned better by students and teachers if it is embedded within traditional subject matter or as a separate "pull out" topic? Should nature of science be addressed as both a separate "pull out" as well as embedded?

Similar to the issue of the relative effectiveness of various instructional approaches, is the issue of the curriculum context of NOS instruction. There is an existing assumption that when NOS is embedded within the context of lessons on other aspects of subject matter, that student learning is enhanced. There is little published research specifically related to this issue. Even the most superficial perusal of the recent research on explicit instruction, however, shows that explicit teaching of NOS has supporters for embedded and non-embedded approaches. Systematic research that compares the relative effectiveness of these instructional approaches alone and in combination is needed.

How do teachers develop PCK for nature of science? Is it related to their knowledge structures for traditional science content?

The relationship between one's views of NOS, subject matter, and pedagogy remains uncertain. If we are to assume that NOS is analogous to other aspects of subject matter that teachers teach and students hopefully learn, it also stands to reason that teachers can and should develop PCK for NOS. Virtually no research has used the PCK perspective, that was so heavily researched during the 1990s, as a lens for research on the teaching of NOS. Such research would provide critical information for the planning and quality of professional development activities that focus on NOS. After all, it is one thing to teach teachers about NOS, it is a totally different endeavor to teach them how to teach NOS to their students.

How are teachers' conceptions of nature of science affected during translation into classroom practice? How much of an independent variable is the act of teaching?

Anyone who has ever attempted to enhance teachers' understandings of NOS is aware that the “newly developed” views resulting from a methods course or professional development workshop are fragile at best. Given what is known about how science is typically presented in various curriculum materials, there is the possibility that the curriculum may influence a teacher's views of NOS. Within the literature on PCK, there is some recognition that how one uses his/her subject matter (e.g., teaching) can influence the individual's subject matter structure (Hauslein, Good, & Cummins, 1992). Consequently, it is quite possible that the teaching of science may have an impact on how a teacher views the epistemology of science.

Does the difficulty of the subject matter within which nature of science is embedded influence student learning?

Unless NOS is taught independently of other science subject matter, it represents an additional outcome that students are expected to learn during science instruction. That is, for example, students would be expected to learn that scientific knowledge is tentative while at the same time learning the details of the model of the atom. It is quite possible that the difficulty level of the subject matter may interfere with the learning of NOS. Should NOS be withheld for situations in which relatively concrete science topics are being addressed?

Does knowledge of nature of science improve students' learning of other science subject matter?

One of the original rationales for teaching NOS has been the belief that an understanding of NOS will enhance students' subsequent learning of science subject matter. This assumption, as is true with other assumptions related to the purported value of NOS as an instructional outcome, has yet to be systematically tested. Should students learn to view the subject matter they are being asked to learn through a lens of NOS? This line of research would inform the placement and role of NOS within the science curriculum.

Does understanding of nature of science significantly influence the nature and quality of decisions students make regarding scientifically-based personal and social issues?

A second rationale for the teaching of NOS has been that such understandings would enhance decision-making on scientifically-based personal and social issues. Other than Bell and Lederman's (2003) investigation of university faculty members (scientists and non-scientists), this assumption has remained untested. The results of that investigation did not support the long-held assumption about the value of NOS as an instructional outcome. In general, the assumptions that have been used as advocacies for the teaching of NOS need to be systematically tested. It may very well be that the only value in teaching NOS is that it gives students a better understanding of science as a discipline.

Are nature of science and scientific inquiry universal, or are conceptions influenced by the particular scientific discipline?

Although NOS has been treated in the research literature as “generic” across all scientific disciplines, there appears to be a growing belief in the view that different disciplines may have different “definitions” of NOS. For example, is NOS in biology the same as it is in physics? Intuitively, it seems that there would be differences. Indeed, the phrase “natures of science” is starting to be heard in the halls of professional meetings. The published research literature, however, does not contain a test of this assumption. At this point, all that exists is the unpublished work of Schwartz (2004) and the results, as usual, do not support our intuitive assumptions. The implications this line of research has for teaching NOS in schools are clearly significant. Should NOS be characterized differently in the different science classes? Clearly, we need much more research that compares the views of nature of science (and scientific inquiry) of individuals viewed to have strong understandings of each. It can not be over emphasized that researchers should carefully consider the developmental appropriateness of conceptions of inquiry and NOS they consider for use with K-12 students.

How do teachers come to value NOS as having equal or greater status than "traditional" subject matter?

The last bulleted item at the beginning of this section noted that teachers do not value NOS at a level equal to that of "traditional" subject matter. The existing research clearly indicates that teachers can be taught NOS and it clearly shows that teachers can be taught how to teach NOS to students. However, the research is lacking when it comes to providing guidance for how to develop teachers' valuing of NOS as an important instructional outcome. Few would argue with the notion that teachers spend less time teaching what they don't value or value less than other material. Even teachers who understand NOS and how to teach it, may not actually attempt to teach NOS to students. This was illustrated in Lederman's (1999) case study of five biology teachers quite knowledgeable about NOS. One reason teachers may not teach NOS, even though they are capable, is that NOS is typically not assessed on local, national, or international tests. However, if we hope to improve teachers' instructional attention to NOS in a more creative way than just putting it on the test, a concerted effort must be made to unearth what it takes to get teachers to value NOS relative to other instructional outcomes

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