A framework for teaching the nature of science

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To help students understand the nature of science, good science teachers will infuse considerations for the nature of science throughout their instruction. While such teaching about the nature of science might be limited in scope and duration on any one day, it is generally ongoing, explicit, and in context. Poor science teaching assumes that students will learn about the nature of science implicitly through lecture, problem solving, and cookbook lab experiences. While this assumption is true to a limited extent, using an inquiry approach and teaching directly about the nature of science on a regular basis and in context will be considerably more effective. In order to successfully teach about the nature of science, teachers must be provided with essential understandings, suitable pedagogical practices, and appropriate motivation so they can maximize what their students learn in this important topic area. (Note: Sections III-V on pages 5-6 were slightly updated on 10/17/06; changes are italicized.)

As a physics teacher educator since 1994, I have seen many physics teacher candidates at Illinois State University come into my classrooms as juniors with a limited understanding of the nature of science. They generally have a good understanding of the content of physics, but only a vague understanding of what science is about and how it proceeds. When questioned about various nature-of-science topics, they frequently are unable to assemble more than one or two cogent sentences in response. This is not surprising when textbook-driven instruction gives the conclusions of scientific work and merely explains the concepts. Much introductory science teaching leaves out of the discussion the processes – the context and motivations, the twist and turns, the mistakes and dead ends, the assumptions and decisions – explaining how scientists arrived at their conclusions.

If students have taken several years of didactic physics content courses, it is understandable why they have such a limited knowledge of the nature of science. Given a traditional textbook approach, how can we expect science teacher candidates to impart a suitable understanding of the nature of science to their own students? Logically speaking, we can't. Teachers cannot effectively teach what they do not know and understand.

While there have been volumes written about the nature of science and its relationship to science literacy, very little information is provided about how to actually teach students so that they can develop the expected understanding of the nature of science. After several years of classroom experience and reflection, I feel that my colleagues and I are now in a position to help our physics teacher candidates learn what they need to know about the nature of science, and how to both value and teach it.

It would be presumptuous of any author if he thought that he could fully describe and explain everything a teacher candidate should know about the nature of science in a short essay. Only a book-length manuscript would be sufficient for this purpose. Nonetheless, it is my goal here to outline how we prepare our physics teacher candidates at Illinois State University to effectively educate their own students about the nature of science at the high school level.

To What Does "Nature of Science" Refer?

The concept of "nature of science" is complex and multifaceted. It involves aspects of philosophy, sociology, and the history of science (McComas, Clough, & Almazroa, 1998). It is surrounded by numerous issues (Alters, 1997; Labinger & Collins, 2001; Laudan, 1990), and is rather complex as the review of any relatively recent philosophy of science book will show (e.g., Bakker & Clark, 1988; Klee, 1997).

Authors variously define what constitutes the nature of science (NOS), and what students should know in order to be "NOS literate." For instance, Aldridge et al. (1997) see the processes of scientific inquiry and the certainty of scientific knowledge as being central to understanding NOS. Lederman (1992, p. 498) states, "Typically, NOS refers to the epistemology and sociology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development." Lederman et al. (2002) define NOS in part by referring to understandings about the nature of scientific knowledge. These understandings deal with science's empirical nature, its creative and imaginative nature, its theory-laden nature, its social and cultural embeddedness, and its tentative nature. They also express concern about understandings relating to "the myth of The Scientific Method."

Project 2061's *Science for All Americans* (AAAS, 1989) and *Benchmarks for Science Literacy* (AAAS, 1993) both regard understandings about scientific world view, scientific inquiry, and the scientific enterprise as being central to a comprehension of NOS. According to the Project 2061 authors, a scientific world view consists of beliefs that the world is understandable, that scientific ideas are subject to change, that scientific ideas are durable, an that science cannot provide complete answers to all questions.

In addition, individuals will understand the processes of inquiry and know that science demands evidence, is a blend of logic and imagination, and explains and predicts, but is not authoritarian. Those who are NOS literate will also be knowledgeable about the scientific enterprise. They will understand that science is a complex social activity, that science is organized into content disciplines and is conducted at various institutions, that there are generally accepted principles in the conduct of science, and that scientists participate in public affairs both as specialists and as citizens. They attempt to avoid bias.

The National Research Council in *National Science Education Standards* (NRC, 1996) sees scientific inquiry, the human aspects of science, and the role that science has played in the development of various cultures as being central to understanding the nature of science.

These characterizations of what constitutes the nature of science are incomplete. Many more things could be added to these characterizations such as an understanding that science is self-correcting, that scientists assume a naturalistic world view, that science most often advances as a result of incremental change which is just as important as if not more important than genius, and that the primary roles of science consist of explanation and prediction.

In order to achieve the goal of having students become broadly NOS literate, we must first identify essential understandings about NOS, and provide an implementation model, practical advice, and motivation for implementing appropriate NOS literacy practices in the classroom.

Essential Understandings about NOS

Statements about what it means to be NOS literate are inadequate for planning purposes to the extent that they do not provide a detailed definition. Teaching in the Illinois State University PTE program is predicated on a nominal definition of what it means to be NOS literate. Individuals with a broad understanding of the nature of science will possess knowledge of the content and history of at least one science discipline, plus knowledge of associated scientific nomenclature, intellectual process skills, rules of scientific evidence, postulates of science, scientific dispositions, and major misconceptions about NOS.

While this definition appears rather comprehensive, it takes an admittedly simple if not simplistic view of NOS. Nonetheless, judgment about what constitutes an adequate understanding of the nature of science must be based on the practicalities of teacher preparation. While it would be ideal if every teacher candidate would take a course dealing with the nature of science or the history of science, it too infrequently happens due to the lack of such courses or as a result of the prodigious number of graduation requirements placed on science education majors. As a consequence, we use a pragmatic operational definition tempered by the requirement that we must be able to address the various components of the definition in our physics content and teaching methods courses. It should be noted that a reasonably comprehensive understanding of physics content knowledge is not addressed, but is assumed.

I. Scientific Nomenclature

A common language is essential to accurately communicate ideas (Hirsch, 1987). We believe that this is true in relation to NOS. As such, we have identified twenty-four terms that we feel are most closely associated with both experimental and epistemological concepts. We believe these terms represent the minimal vocabulary and concepts with which every teacher candidate, teacher, and their students should be familiar.

The experimental terms are regularly employed in inquiry-oriented laboratory activities associated with introductory calculus-based physics courses that students take at Illinois State University. All experimental terms are fully explained in our regularly referenced *Student Laboratory Handbook* (see http://www.phy.ilstu.edu/slh/). Epistemological terms and concepts are addressed in considerable detail in two of our six required physics teaching methods courses: Physics 310 – Readings for Teaching High School Physics and Physics 312 – Physics Teaching from the Historical Perspective (for hyperlinks to all courses described in this article, visit http://www.phy.ilstu.edu/pte/). The terms that serve as the basis for our NOS-related course work appear in Table 1.

assumption	hypothesis	proof
belief	induction	pseudoscience
control	knowledge	system
deduction	law	science
empirical	model	scientific
evidence	parameter	theory
explanation	prediction	truth
fact	principle	variable

Table 1. *Essential scientific nomenclature: Twenty-four fundamental terms and concepts with which science teachers and their students should be familiar.*

II. Intellectual Process Skills

We believe that students cannot have a comprehensive understanding of the nature of science if they do not have first-hand experiences with the empirical methods of science. We have adopted a list of essential observational and experimental skills that will be learned when science is taught using inquiry-oriented teaching and laboratory methods. A listing of the some of the key intellectual process skills addressed in our inquiry-oriented labs is provided in Table 2.

- Generating principles through induction
- Explaining and predicting
- Observing and recording data
- Identifying and controlling variables
- Constructing a graph to find relationships
- Designing and conducting scientific investigations
- Using technology and math during investigations
- Drawing conclusions from evidence

Table 2. *Some of the many intellectual process skills addressed in ISU's inquiry-oriented labs in introductory physics.*

Based on the skills in Table 2, the Physics Department recently has undertaken the task of replacing its traditional cookbook labs with inquiry-oriented labs that strongly focus attention on important intellectual process skills used by scientists.

III. Rules of Scientific Evidence

The rules of scientific evidence have been a topic of considerable attention for notable scientists and philosophers ever since the "Enlightenment" of the 17th century (e.g., Pascal, Leibniz, Galileo, Newton, Bacon, Berkeley, Hume, Hobbes, Locke, and Kant to name but a few). Nonetheless, to the best of the author's knowledge, the rules of scientific evidence have never been codified in an easily accessible way. There is a need for such if treatment of this subject matter is ever to be addressed systematically through teaching. What follows is a simple compilation of such. There is no claim of completeness, and no claim that every scientist or philosopher of science would agree with all these statements. Readers are cautioned that characterizations are at best tentative. No form of hierarchy is to be inferred on the basis of order. This list is a point of departure for those who would like to talk about rules of scientific evidence with students. It again serves as one of the bases upon which NOS teaching is based at Illinois State University.

- In order for a claim to be scientific, it must be testable (Popper's principle of falsifiability); by this definition a claim need not be accurate to be scientific.
- The ultimate authority in science is empirical evidence based on observation or experimentation.
- Scientific conclusions must be based on *public* evidence; it is improper to accept any claim without sufficient supporting evidence.
- Correlation should not be confused with cause and effect; scientists do not accept coincidence or unlinked or unsupportable correlations as proofs.
- Scientific claims, to be acceptable, must not conflict with what is known with relative certainty; nonetheless, it should be kept in mind that scientific creativity sometimes contradicts conventional understanding.
- Scientists should be skeptical of claims that conflict *with accepted views of* reality; they should avoid bias and be particularly objective in their treatment of claims of which they are skeptical.
- Scientists should test and independently verify all significant and apparently justifiable claims, especially those that appear to contradict conventional thinking and/or prior evidence.
- The more unconventional a claim, the greater the requirement for supporting evidence; anecdotal evidence is insufficient proof of any scientific claim.
- Scientists must not make selective use of evidence; they must not promote a particular belief by suppressing evidence or fail to seek evidence by avoiding investigation.
- Only one positive instance is required to refute a negative claim.
- Multiple positive instances alone cannot prove a positive claim unless all cases are examined.
- *One should not assume as certain that which one is attempting to demonstrate; this can lead to false conclusions.*
- If several explanations account for the same phenomenon, the *more elegant* explanation is preferred (parsimony or Ockham's razor); a single comprehensive proposition is to be valued over a number of ad hoc propositions.

IV. Postulates of Science

Postulates of science are the assumptions upon which science operates. They serve as the basis for scientific work and thought, and to some extent determine what is admissible or inadmissible under the rules of scientific evidence. The postulates of science are often referred to, but they – like the rules of scientific evidence – appear not to have been codified to the best of the author's knowledge. Nonetheless, for the sake of educating Illinois State's teacher education majors about NOS, we have adopted the following statements as representative of the postulates of science. Again, as with the rules of scientific evidence, there is no guarantee that this list is comprehensive or that all scientists or philosophers of science would agree with these postulates and their characterizations. Indeed, in the light of quantum physics some philosophers of science have argued that several of the postulates are mutually exclusive. We have adopted a pragmatic view for the sake of our teacher candidates studying and teaching classical physics during their student teaching practicum.

- All laws of science are universal and not merely local.
- There is a consistency in the way that nature operates in both time and space; the natural processes in operation today can explain physical events – past, present, and future.
- No observed effect exists without a natural cause, but sequence – no matter how frequently repeated – does not necessarily infer cause and effect.
- Scientists do not accept any kind of explanation for which no test is available; while objective scientists will preclude theological explanations, this must not be taken to imply that they are necessarily atheistic.
- Science admits, in addition to observable, repeatable observations, natural entities that might not be directly observed but whose existence can be theoretically inferred through reason.

- Scientific knowledge is durable but tentative, and is subject to revision; science does not *provide us with absolute certainty.*

- *While science does not provide for absolute certainty, proofs beyond a reasonable doubt are possible.*

- Science is not a private matter that concerns the individual scientist alone; rather, science is a social compact, and scientific knowledge represents the consensus opinion of the scientific community.

V. Scientific Dispositions

Science for All Americans (AAAS, 1989) identifies several general characterizations that describe suitable dispositions for scientists. *Benchmarks for Science Literacy* (AAAS, 1993) similarly addresses *desirable* "habits of mind" – the values and attitudes – *looked for in* scientists. We have encapsulated the major points of these two works in the following listing.

Desirable characteristics of scientists are:
- curious and skeptical – they are on the lookout to discover new things and demand suitable evidence for claims; they avoid unwarranted closure.
- objective and not dogmatic – they demonstrate intellectual integrity and avoid personal bias; they are open to revision in the face of incontrovertible evidence.
- creative and logical – they attempt to provide rational explanations on the basis of what is already accepted as established fact.
- intellectually honest and trustworthy – they realize that science is a social compact, and abide by the ethical principles of the science community.

VI. Major Misconceptions about Science

McComas (1996) has identified what he feels are the major misconceptions about science held by many non-scientists (and even some scientists). These myths are listed in Table 3. Readers are referred to the McComas article for explanations.

An Implementation Model for Achieving NOS Literacy

In addition to possessing an understanding about the nature of science, teachers need to have appropriate models and activities to help their students acquire an adequate understanding of NOS (Abd-El-Khalick, et al., 1998; Bell, Lederman & Abd-El-Khalick, 2000).

How, then, can teachers successfully promote student understanding in relation to NOS? What pedagogical practices should teachers use in an effort to effectively promote NOS literacy among their students? When does a teacher deal with the subject matter of NOS?

Figure 1 depicts the model that guides the work of the Illinois State University Physics Teacher Education program. Our model consists of six pedagogical practices geared toward helping students attain the required understanding: background readings that describe NOS, case study discussions that incorporate NOS, inquiry lessons that model NOS, inquiry labs that reflect NOS, historical studies that involve NOS, and multiple assessments that address NOS.

1. There exists a scientific method that is general and universal.
2. Hypotheses are really only educated guesses.
3. Hypotheses turn into theories that eventually become enshrined as laws.
4. Scientific knowledge is based mainly on experiment.
5. High objectivity is the hallmark of science.
6. Scientists always review and check the work of their colleagues.
7. Certainty results when facts are accumulated and analyzed.
8. Science is less creative than it is procedural.
9. The scientific method leads to absolute truth.
10. All questions posed by the universe can be answered via the scientific method.

Table 3. *Ten major myths about science. (After McComas, 1996)*

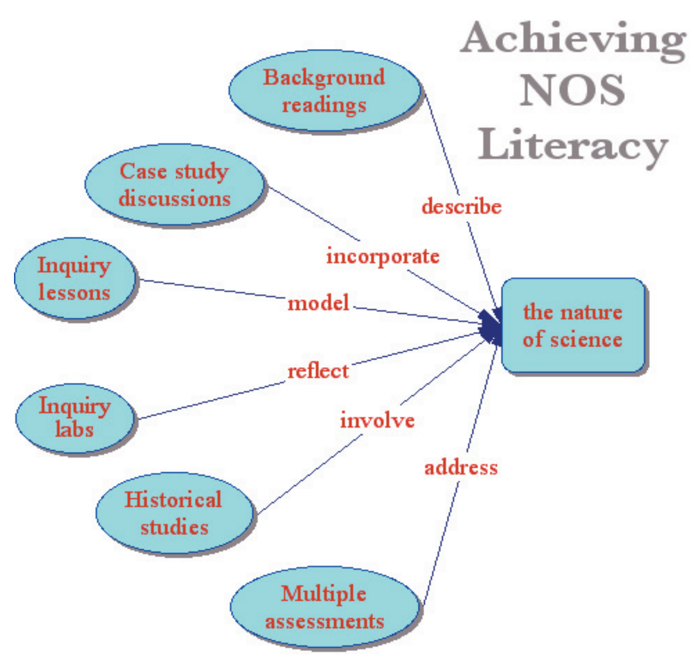

Figure 1. *ISU NOS implementation model. Pedagogical practices we believe are most suited to helping students achieve nature-of-science literacy.*

We believe that this approach helps our candidates gain a relatively comprehensive understanding of the nature of science. It is a model that we promote among our high school physics teacher candidates to help them achieve NOS literacy among their own students.

Background readings from books and articles that deal with the nature of science can have a very significant impact upon a student's understanding of the nature of science. Such readings can also heighten appreciation for science itself. Many books are available that deal reasonably well with the nature of science theme. Reading these books, and writing book reports or book reviews, can provide substantial background that can readily be brought to bear on classroom discussions. In the PTE program at Illinois State University, physics education majors are required to complete and discuss a number of readings in relation to NOS in Physics 310 – Readings for Teaching High School Physics. They are also required to read and write a review about one of the books listed in Table 4.

Case study discussions (Herreid, 2005) are excellent forums for helping students develop an understanding of NOS. Case studies typically present a dilemma or an issue, and students are asked to help resolve the problem. At ISU we have integrated 17 case studies (see sample) over two courses that help PTE majors learn about NOS through what is often very spirited discussion.

Doubt and Certainty. Rothman, T. & Sudarshan, G. (1999) New York, NY: Perseus Printers.
Fact, Fraud and Fantasy. Goran, M. (1979) Cranbury NJ: A.S. Barnes and Co., Inc.
Fads and Fallacies in the Name of Science. Gardner, M. (1957) Dover Publications.
Great Feuds in Science. Hellman, H. (1998) New York, NY: John Wiley & Sons, Inc.
Science and Its Ways of Knowing. Hatton, J. & Plouffe, P.B. (1997) Upper Saddle River, NJ: Prentice Hall.
Scientific Literacy and the Myth of the Scientific Method. Bauer, H.H. (1994) Urbana, IL: University of Illinois Press.
The Borderlands of Science: Where Sense Meets Nonsense. Shermer, M. (2001) Cambridge: Oxford University Press.
The Demon Haunted Word: Science as a Candle in the Dark. Sagan, C. (1996) New York, NY: Ballantine Books.
The Game of Science. McCain, G. & Segal, E.M. (1989) Belmont, CA: Brooks/Cole Publishing Co.
The Structure of Scientific Revolutions. Kuhn, T. (1962) Chicago, IL: University of Chicago Press.
Uncommon Sense: The Heretical Nature of Science. Cromer, A. (1993) New York, NY: Oxford University Press.
Voodoo Science: The Road from Foolishness to Fraud. Park, R. (2000) Cambridge: Oxford University Press.
Why People Believe Weird Things. Shermer, M. (1997) New York: W. H. Freeman and Co.

Table 4. *A list of books from which ISU physics teacher education majors must select to write a book review. Additional selections are also available.*

Sample Case Study: A Haunting Experience!

Fourteen-year-old Akimbo is afraid to enter the upper rooms of his 4-level mansion home. The mansion is a former plantation house that has been around since about 1850; the plantation was the site of a bloody 1863 Civil War battle. Many say that the mansion is haunted. Akimbo has been told by house workers that "spirits of dead soldiers" inhabit the upper rooms. According to these house workers, restless spirits move things around the rooms, and at night foot falls and even clashing swords can sometimes be heard from beneath each of the rooms. No one has ever seen these spirits. Still, those who visit the rooms often report having a "creepy" sensation, and feel as though someone is watching.

Are the various claims made by the house workers to be believed? Why or why not?

What might explain the "creepy" sensations and the feeling that someone is watching that visitors to the rooms report?

What other explanations might account for the reports?

Which is the best explanation for these supposed phenomena?

On what basis to do you accept some explanations and reject others?

These case studies cover most of the topics addressed in this article. (These cases can be found online at http://www.phy.ilstu.edu/pte/ by following the hyperlinks to Physics 311 and Physics 312.) Case studies need not be of long duration; it's amazing what insights students can gain in relation to NOS with just a 5-minute discussion. Case studies can be used intermittently as "problem of the day," during pre- and post-lab discussions, and as fillers when extra instructional time presents itself at the end of a class period.

Inquiry lessons, as one of the levels of the "inquiry spectrum" (Wenning, 2005a), provide an excellent forum for student learning in relation to NOS. Inquiry lessons by their very nature are predisposed to modeling science processes. As teachers conduct inquiry lessons, they can use think aloud protocols to provide insights about the workings of science; they can guide student thinking through focusing questions; they can talk explicitly about procedures being employed; they can give explicit instruction while modeling scientific inquiry practices. Inquiry lessons are a great way to teach NOS explicitly. Great care is taken during Physics 310 – Readings for Teaching High School Physics to model inquiry through appropriate inquiry lessons, and in Physics 311 – Teaching High School Physics – through "Lesson Study" (Stigler & Hiebert, 1999). This helps our physics teaching majors understand the comprehensive nature of the inquiry lesson planning approach. They can also come to understand the value of including it in their planning considerations for NOS literacy, and learn about the various barriers that exist in relation to its implementation (Abd-El-Khalick, Bell & Lederman, 1998; Wenning, 2005b; Wenning, 2005c).

Inquiry labs, as opposed to traditional cookbook labs (Wenning, 2005a), help students learn and understand the intellectual processes and skills of scientists, and the nature of scientific inquiry. Inquiry labs are driven by questions requiring ongoing intellectual engagement, require the use higher-order thinking skills, focus students' attention on collecting and interpreting data, and help them discover new concepts, principles, or laws through the creation and control their own experiments. With the use of inquiry labs, students employ procedures that are much more consistent with the authentic nature of scientific practice. With inquiry labs, students learn such things as nomenclature and process skills, and do so implicitly. Pre- and post-labs provide opportunities for explicit instruction about NOS. The ISU Physics Department has recently undertaken great strides to convert our traditional labs into inquiry labs (Wenning & Wenning, 2006) through which all native physics teacher education majors progress. In addition, inquiry labs are a central focus in the physics teaching methods courses Physics 302 – Computer Applications in High School Physics and Physics 312 – Physics Teaching from the Historical Perspective. At the conclusion of five semesters of inquiry-oriented labs in the area of classical physics, our teacher candidates have a fairly good grasp of the nature of scientific inquiry in the areas where they will focus their attention during the teaching of high school physics. A required two-semester sequence of Physics 270 – Experimental Physics provides teacher candidates with additional experiences in more modern aspects of physics research.

Historical studies can prove to be a powerful tool for not only teaching about NOS, but for putting a human face on physics and increasing student interest in the subject. The *National Science Education Standards* suggest the use of history "to elaborate various aspects of scientific inquiry, the nature of science, and science in different historical and cultural perspectives" (NRC, 1996, p. 200). The components of *NSES* dealing with history and the nature of science are closely aligned with similar standards described in Project 2061's *Benchmarks for Science Literacy. Benchmarks* notes, "There are two principal reasons for including some knowledge of history among the recommendations. One reason is that generalizations about how the scientific enterprise operates would be empty without concrete examples. A second reason is that some episodes in the history of scientific endeavor are of surpassing significance to our cultural heritage" (AAAS, 1993, p. 237).

Each of the sciences has at least one "great idea" that can be used to incorporate the historical perspective: Physics – models of the atom; Chemistry – periodic table of elements; Biology – evolution; Earth Science – plate tectonics; and Space Science – nature of the solar system and/or Big Bang. Historical research findings can be presented in a class presentation, in a paper, or by any other means. In Physics 312 – Teaching Physics from the Historical Perspective – we include approximately 30 vignettes to help make our students more aware of the historical background of physics.

Multiple assessments, alternative as well as more traditional, are important components in helping students to develop a deeper understanding of the nature of science. Alternative assessments such as presentations, written or oral reports dealing with historical subject matter, and periodic reflective journaling can be good ways to heighten student understanding of NOS. Test items such as multiple-choice and free-response questions on traditional exams can get students to focus attention and study time on the nature of science. Students tend to study those things that are addressed during assessment, and for which they are held accountable. A set of student performance objectives should be developed in relation to NOS goals, and students should be made aware of them. Lessons and assessments then should be aligned with these objectives. In Physics 310 – Readings for Teaching High School Physics and Physics 353 – Student Teaching Seminar – students complete a 30-item NOS literacy test dealing with the six elements addressed in this article. They subsequently use this assessment instrument as a pre- and post-test during student teaching to see what impact, if any, they are having on their own students' understanding of the nature of science (Wenning, in preparation).

Practical Advice for Implementing NOS Instruction

Based on a review of the literature, our experiences, and philosophical reflections, we offer the following advice for implementing instruction in relation to NOS: (1) The nature of science is best taught explicitly to both teacher candidates and students of science. Research has shown that students fail to develop many of the expected understandings of NOS concepts from traditional classroom instruction where it is assumed that students will learn about the nature of science by "osmosis" (Duschl, 1990; Lederman, 1992; Ryan & Aikenhead, 1992). NOS, therefore, should be taught explicitly when possible to develop the desired understandings (Bell, Blair, Crawford & Lederman, 2003; Khishfe & Abd-El-Khalick, 2002; Moss, Abrams & Robb, 2001; Abd-El-Khalick & Lederman, 2000; Akerson, Abd-El-Khalick & Lederman, 2000). Without directly addressing scientific nomenclature, intellectual process skills, rules of scientific evidence, postulates of science, scientific dispositions, and major misconceptions about science, it is highly unlikely that students will extract all these concepts on their own. Indeed, our own internal testing (Wenning, in preparation) shows that after several years of didactic science instruction, many science majors end up with only a vague and fragmented understanding of the nature of science. (2) The nature of science is best taught contextually. Students can develop a functional understanding of the nature of science only when they are taught in the context of scientific inquiry. NOS should not be treated as subject matter apart from the content of science, be it physics, chemistry, biology, earth and space science, or environmental science. (3) The nature of science is best taught experientially. Teaching science through inquiry helps student understand the nature of the scientific endeavor that simply cannot be meaningfully obtained in any other fashion. (4) The nature of science is best taught regularly. Addressing the nature of science once or twice, even if is dealt with as part of a discrete unit, is inadequate to the task of teaching students about NOS. Only repeated treatment of the subject matter of NOS covering a wide variety of situations will imbue students with a proper understanding. (5) The nature of science is best taught systematically. Teachers ought to know what should be taught in relation to this topic, and address the whole range of information about NOS with their students. To teach the subject haphazardly will result in substantial gaps in student understanding. (6) Only by helping teachers focus on the nature of science as an important goal in their instructional practice will result in more explicit science instruction (Lederman, Schwartz, Abd-El-Khalick & Bell, 2001).

Valuing NOS Literacy

Understanding the nature of science - its goals, assumptions, and processes inherent in the development of knowledge - has been one of the major goals of science education since the beginning of the twentieth century (Central Association of Science and Mathematics Teachers, 1907). Contemporary literature of the science reform movement also regards understanding the nature of science as one of the main components of science literacy (AAAS, 1993; NRC, 1996).

While a teacher's understanding of the nature of science and an implementation model are necessary prerequisites for teaching about the nature of science (Lederman, 1992), it is not sufficient. Teachers must also value an understanding of the nature of science before they will teach it (Lederman, 1999; Schwartz & Lederman, 2002).

Few individuals will question the value of studying the key concepts of science; however, there are many who might question why we should understand the nature of the scientific process. *Benchmarks for Science Literacy* brings up the following key point about why NOS should be valued, "When people know how scientists go about their work and reach scientific conclusions, and what the limitations of such conclusions are, they are more likely to react thoughtfully to scientific claims and less likely to reject them out of hand or accept them uncritically" (AAAS, 1993, p. 3).

In addition, NOS literacy is important in helping students of science confront the "new age of intellectual barbarism" that seems to be encroaching upon modern society. It helps them to make informed decisions relating to science-based issues, develop in-depth understandings of science subject matter, and help them to distinguish science from other ways of knowing. (NSTA, 2003) NOS literacy helps student defend themselves against unquestioning acceptance of pseudoscience and reported research (Park, 2000; Sagan, 1996).

The media are filled with hucksters making all sorts of unsubstantiated and unsupportable pseudoscientific claims about fad diets, supposed medical cures, herbal remedies, ghosts, alien abductions, psychics, channelers, astrology, intelligent design, mind reading, past life regression therapy, and so on. Students who have a good understanding of the content and nature of science as well as healthy scientific perspectives (e.g., skepticism) will not likely fall prey to flimflam artists who promote technological gadgets of dubious worth, dogmatists who promote beliefs of doubtful credibility, or purveyors of simple solutions to complex problems. NOS literate students will be able to, in Paul DeHart Hurd's words, "distinguish evidence from propaganda, probability from certainty, rational beliefs from superstitions, data from assertions, science from folklore, credibility from incredibility, theory from dogma" (Gibbs & Fox, 1999).

The valuing of NOS literacy by teacher candidates appears to come from experiencing a curriculum that includes essential elements pertinent to the learning and teaching of the nature of science. Throughout the sequence of the aforementioned physics teaching methods courses, we have seen among our physics teacher candidates a growing philosophical bent and fascination with the nature of science. Class discussions, especially case studies, result in many impassioned conversations that continue long after class. This alone is enough to suggest that our students do, indeed, find NOS literacy of considerable value and interest. To further encourage our teacher candidates to include considerations for NOS literacy in their own teaching, we have created a nature of science literacy assessment instrument that student teachers use as pre- and post-tests during student teaching. This assessment, currently in piloting phase, will be the subject of a future article.

Belief Statements Relative to Achieving NOS Literacy

A series of belief statements undergird NOS-related teaching practices within the Physics Teacher Education program at Illinois State University:

We believe that teachers can pass on to their students only what they themselves possess. Teachers must therefore possess an understanding of the nature of science if they are to impart that understanding to their students.

We believe that teachers must value NOS literacy before they will impart that understanding to their students. An understanding of NOS alone is not enough to make teachers to value or teach it.

We believe that teachers must be provided with an effective and practical means of achieving NOS literacy among their students before they will make the attempt to do so. To this end we deploy the implementation model described in this article.

We believe that teachers tend to teach the way in which they themselves were taught. It is only reasonable, therefore, that we should teach in the way that we expect our candidates to teach, and this includes considerations for the nature of science.

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