

Defining versus Describing the Nature of Science: A Pragmatic Analysis for Classroom Teachers and Science Educators

MIKE U. SMITH

Department of Internal Medicine, Mercer University School of Medicine, Macon, GA, 31201, USA

LAWRENCE C. SCHARMANN

Department of Secondary Education, Kansas State University, Manhattan, KS 66506, USA

Received 28 September 1997; revised 2 July 1998; accepted 5 September 1998

ABSTRACT: There appears to be an almost universal commitment among science educators to promote the goal of student understanding of the nature of science. Recent disagreements among philosophers of science and between philosophers and other groups such as scientists and science educators about the nature of science, however, leave classroom teachers in a quandry: If experts disagree about the nature of science, how should we decide what to teach students? In this article, the authors first reconsider what level of understanding of the nature of science students should experience so that they can become both intelligent consumers of scientific information and effective local and global citizens. Second, based on an analysis of the literature, it appears that there is a general agreement among science education stakeholders regarding a set of descriptors that can be used to judge which questions or fields of study are more scientific or less scientific than others. Therefore, we propose that most precollege teachers should attempt to teach students how to use these descriptors to judge the relative merits of knowledge claims instead of teaching a set of rules that attempt to demarcate science completely from nonscience. Finally, we suggest two classroom activities based on this proposal and draw some implications for teacher preparation and future research. © 1999 John Wiley & Sons, Inc. *Sci Ed* **83**:493–509, 1999.

INTRODUCTION

Throughout this century, and especially in recent years, many science educators, curriculum development projects, and assorted study groups and government panels in various countries have called for educational practice that focuses on the goal of scientific literacy in general, and on understanding of the nature of science in particular (Aikenhead, 1997;

Correspondence to: L. C. Scharmann; e-mail: Ischarm@ksu.edu

American Association for the Advancement of Science [AAAS], 1993; Monk & Osborne, 1997; National Research Council [NRC], 1996; National Science Teachers Association [NSTA], 1993; Solomon, Scott, & Duveen, 1996). Few science educators are likely to disagree with this goal and most probably perceive (at least above the elementary school level) that they have an adequate personal understanding of the nature of science for their own instructional purposes. Many teachers would be surprised to know, however, that in recent years there has been a heated debate over the nature of science, leading to a wide diversity of opinion among philosophers of science. (For a recent review of some of these issues, see House [1991].) In addition, recent research has also shown that, as a group, philosophers of science espouse views of science that are very different from those of practicing scientists and from classroom teachers (Abd-El-Khalick, Bell, & Lederman, 1998; Alters, 1997; Pomeroy, 1993). Positivists argue with radical constructivists, who argue with empiricists, not to mention the realists, feminists, Marxists, multiculturalists, universalists, logical empiricists, radical empiricists, scientific realists, instrumentalists, idealists, and so on, ad infinitum. It seems there are no stable and immutable borders between the provinces of science and nonscience. Even if there were, Suchting (1995) presents a compelling argument that, as science grows and our understandings of the universe increase, our views of the nature of science are themselves likely to evolve. Lederman (1996) concludes that “the process [of science] . . . is more tentative than the products [of science]” (p. 12). Thus, essentially everyone agrees that we should teach the nature of science. Unfortunately, there is as general a lack of consensus about the nature of science as there is about what it means to achieve scientific literacy (Shamos, 1995).

What then is a teacher to do? Lederman (1995) is concerned that this state of affairs will result in some teachers attempting to teach “in a manner that would give balanced treatment to the varying conceptions of science” (p. 373). Both Alters (1997) and Meyling (1997) have, in fact, called for just such a “pluralistic” approach in which “several different epistemological conceptions are offered to the students” (Meyling, 1997, p. 408)—a proposal likely to strike fear in the hearts of even those teachers who are the most interested in philosophical matters. In a practical vein, even teachers who agree with this recommendation must be asking: “Where will I find the time to teach that much more stuff?” and “How can I possibly get my high school students to understand material that is so abstract?” Lederman (1995) points out that a primary dilemma in implementing such a “balanced treatment” is that most of our high school students (and lower level college students) are at a dualistic stage of intellectual development at which they are incapable of understanding one philosophical view while holding an opposing one (Perry, 1970). In effect, such instruction requires students to “psychologically travel back and forth between multiple paradigms of science” (Lederman, 1996, p. 12). A balanced treatment approach therefore seems ill-advised.

In what follows, we will sketch in broad outline an alternative approach. First, we will briefly consider reasons why an understanding of the nature of science is a worthwhile goal for all students. Second, from this analysis we will draw some implications about the level of understanding that we should encourage students to achieve. Third, we will summarize the demarcation problem and make a proposal that most teachers should *not* attempt to teach a set of rules that demarcate science and nonscience. We will argue, instead, for teaching a set of descriptors that can be used to judge which questions or fields of study are more scientific or less scientific than others, including two sample instructional activities. Finally, we will provide a reflective synthesis and draw some implications of these proposals for teacher preparation and future research. Because we are both biologists, the discussion that follows draws heavily on biology and is intended to refer to instruction in natural science (in the Western tradition). In addition, many of our examples will relate to

evolution because of our conviction that this content is an excellent example of a classroom issue that requires confronting misunderstandings about the nature of science.

WHY SHOULD AN UNDERSTANDING OF THE NATURE OF SCIENCE BE A GOAL OF SCIENCE EDUCATION?

Before we can consider how to teach the nature of science we must address two obvious questions: What is the nature of science (which will be addressed in the second section)? and Why is it important for students to understand the nature of science?

Many answers have been given to the latter question. In our opinion the most important reason students should understand the nature of science is that this understanding is crucial to responsible personal decisionmaking and effective local and global citizenship. The American Association for the Advancement of Science (AAAS) argues that knowledge of the biophysical environment is needed to develop effective solutions to its global and local problems. . . . [It] fosters the kind of intelligent respect for nature that should inform decisions on the uses of technology . . . [and it fosters] scientific habits of mind [that] can help people in every walk of life to deal sensibly with problems that often involve evidence, quantitative considerations, logical arguments, and uncertainty (Rutherford & Algren, 1990, p. xiv).

In a companion resource, *Benchmarks for Scientific Literacy* (AAAS, 1993), it is contended that:

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. [They can also] . . . follow the science adventure story as it plays out during their lifetimes. (p. 3)

Finally, understanding science prepares people to lead personally fulfilling and responsible lives:

It should help students to develop the understandings and habits of mind they need to become compassionate human beings able to think for themselves and to face life head on. It should equip them also to participate thoughtfully with fellow citizens in building and protecting a society that is open, decent, and vital. (Rutherford & Algren, 1990, p. xiii)

There is remarkable agreement between these resources (and the many others that could be cited) that understanding science and the how science works is important. Few would disagree with the desirability of some form of these outcomes, although many would find these goals rather lofty and unlikely to be attained in the real world (Shamos, 1995). What is usually not explicit and occasionally missing altogether in such discussions, however, is a recognition that our instructional commitment must be to student understanding, not to accepting or rejecting a view of science, to believing one thing and discounting another, or to adopting the philosophical position of the instructor. Matthews (1997) observes in teachers this “unfortunate tendency to judge success in teaching the nature of science by the degree to which students adopt our views on the subject” (p. 306). Although we assert most science educators would agree that such a goal is inappropriate, we are concerned that several authors have recently espoused such evangelism. Roth and Roychoudhury (1994), for example, clearly aim to “facilitate” their students’ “development” into constructivists. Even more troubling to us is the work of Lawson and Weser (1990)

whose stated goal is an outright student “rejection of non-scientific beliefs,” including beliefs in God, the soul, and so on. Even James Robinson, in his seminal work, *The Nature of Science and Science Teaching* (1968), proposed that the objective for science teaching is to have students “believe” (not merely understand) his 85 propositions on the nature of science.

We strongly oppose such goals for science education. When teaching the theory of evolution by natural selection, for example, it is our goal for students to understand the theory, to see how its various tenets fit together into a cohesive whole, to understand the evidence that supports it (and the evidence used to question its validity), and to understand why almost all biological scientists accept the basic tenets of the Darwinian view as the one theory that best explains the currently available data. It is not our goal to get students to believe in evolution or to reject creationism (except in such limited areas where creationism makes explicit claims that are clearly contradicted by evidence—e.g., the age of the earth). Our purpose in this case is also to get students to begin to question the nature of science, the kinds of questions it can and cannot answer, the kinds of evidence that can and cannot be used to support its propositions, and so on. To do otherwise is to open ourselves to accusations of evolutionism, scientism, dogmatism, and indoctrination.

Let us hasten to say that the preceding paragraphs are not to be taken to imply that evenhandedness is appropriate in all matters in the science classroom. We do not, for example, support equal time for evolution and creationism in biology classes. We should not present creationism as an alternate theory to evolution, because it is not a theory in the sense in which scientists use the term (i.e., a logically consistent explanation of a phenomenon which is well-supported by a wealth of interconnecting threads of evidence) and because it is not neutral on the existence of a supernatural being. But, in matters that lie outside the purview of science (including philosophy and religion), the science teacher—as a scientist—must remain impartial. (There are literally hundreds of books and articles that could be recommended for those interested in this issue further. Among these are Gould, 1994, 1977; Mayr, 1982, 1991; Moore, 1983, 1993; Numbers, 1992; Scott & Cole, 1985; Siegel, 1984; Skoog et al., 1997; Smith, Siegel, & McInerney, 1995.)

WHAT LEVEL OF UNDERSTANDING OF THE NATURE OF SCIENCE SHOULD WE ENCOURAGE STUDENTS TO ACHIEVE?

Exactly what kind of understanding of the nature of science is required in order to achieve the goal of responsible citizenship? When the question is asked this way a logical analysis leads to a rather surprising answer. In order to be intelligent consumers of scientific knowledge and make intelligent decisions about scientific matters, we propose that future citizens in our classrooms need a sound, but limited, understanding of the nature of science. Do citizens need to understand the difference between empiricism and radical constructivism in order to understand the claims of all sides in the debate over an ecologically related law? Do they need to understand a priorism vs. realism in order to decide whether a medical treatment they are considering is a hoax or is well supported by adequate research data? We think not. We propose, instead, that the more important learning outcome should be to get students to understand the characteristics that make something more or less scientific and to be able to judge any single claim/field by those criteria.

Achievement of this more immediate learning outcome may eventually contribute to our longer term goal—that of enhancing responsible citizenship among secondary school students, what Shamos (1995) refers to as “functional scientific literacy” (p. 88).

As scientists and science educators, of course, we want to provide the best possible

understanding of the subject we are presenting. In the name of thorough understanding, therefore, the temptation is great to provide much greater depth than is necessary for students at a given level or even to provide expositions and abstractions that students are incapable of understanding. For some science education leaders, the scales may already have tipped too far in this direction. Paul Hurd (1977), for example, questions the wisdom of our practices of attempting to teach students to “understand the theoretical and conceptual structure of various science disciplines and to become skillful in their investigative procedures . . . Is this liberal education or vocational education?” We must be careful not to become so focused on students achieving a thorough understanding of the nature of science that we lose sight of the reasons for espousing this goal.

Many philosophers of science will doubtless find the proposals in this article the equivalent of instructional malpractice. “How can you continue to teach the mythology of school science?” (Smolicz & Nunan, 1975). “How can you teach such a caricature of the rich nature of science?” they might ask. But, do we not limit the depth of our consideration of every topic raised in our classrooms? Are not decisions about the appropriate depth for a topic an everyday issue for the classroom teacher? Taking some practical examples, do not most introductory biology courses present a caricature of our understanding of inheritance when we present simple Mendelian genetics, omitting phenomena such as multifactorial and cytoplasmic inheritance? Similarly, in the introductory biology classroom, does not the typical presentation of the basic tenets of evolution present something of a caricature of the theory when it omits the controversies at the cutting edges of current evolutionary theory (e.g., punctuated evolution)?, or is not typical introductory physics a rather gross oversimplification of the physical world given our current understandings of quantum mechanics? Clearly, the answer to these questions is *yes*, and it should therefore be clear that adjusting the level of treatment of the nature of science (like that of genetics or evolution or physics) to match the level of knowledge, abilities, and intellectual development of our students is both necessary and appropriate. Our educational practice should keep clearly in mind that in the introductory science classroom our primary goal is to produce effective citizens, not scientists (in Hurd’s terms we are engaged in liberal education, not vocational education).

The irony in Hurd’s words should not be missed. Scientists, when they have paid any attention at all to the debates of philosophers of science, have often found the arguments irrelevant at best and nonsensical at worst. Philosophers have responded that they are not surprised that scientists have little understanding of the philosophical underpinnings of their practice because they are so deeply involved in the day-to-day business of doing science and because the knowledge and understandings of modern scientists are so limited by the specialization required in 20th century research (Pitt, 1990). In other words, being a scientist today does not require a thorough understanding of the nature of science, and, according to many philosophers, the only people who understand the nature of science well are the philosophers of science! Is a philosopher’s understanding the level we want our students to achieve? Should we focus our instruction on philosophical understandings that scientists themselves do not find necessary? (In Hurd’s terms, are we in the business of producing graduates to become not just scientists but philosophers as well?) Again, we think not.

THE DEMARCATION PROBLEM: ARE THERE ABSOLUTE BORDERS THAT DISTINGUISH SCIENCE FROM NONSCIENCE?

There is an extensive and often bewildering body of literature addressing this issue, which it is not our purpose to review here. Many readers, however, may be surprised to

know that there is such widespread disagreement over the nature of science. In recent years, in fact, the so-called demarcation question has “tied philosophers of science in knots” (Ruse, 1983, p. 168). One has only to consider the never-ending controversy over whether “creation science” is or is not a science, however, to see that the question of what distinguishes science from nonscience continues to be a perplexing issue.

On the horns of this dilemma, we propose a rather radical solution. We believe the time has come for science educators to give up attempting to achieve consensus on the exact boundaries between science and nonscience, conceding the field to the philosophers. The demarcation problem is, in fact, largely avoided if one asks, not “Is this field of study a science or not?” or “What characteristics must typify (or conversely must not be essential components of) a field of study for us to recognize the field as being a science or not,” but rather “What are the characteristics of the field that make it more scientific or less scientific?” or “To what extent is the field scientific?”^{1,2} In other words, we can avoid much of the difficulty if we set aside the philosophical assumption that there is an absolute dichotomy between science and nonscience, as well as the more troubling desires to see that our students adopt that assumption, use the same criteria that we apply in making distinctions between science and nonscience, and come to the same conclusions (e.g., about creationism) that we do.

At first blush, this continuous view of science and nonscience may seem only a modest proposal that is unlikely to lead to avoiding the demarcation dilemma. Perhaps a few examples will demonstrate the utility of taking this different tack. First, scientists have long claimed that a basic distinction between science and nonscience is that science does not depend on authority, that the validity of a conclusion rests entirely on the quality of the experiment (appropriateness of design, etc.). In rebuttal, other authors have accurately noted that the work and claims of esteemed scientists are clearly given more serious consideration than are those of less well-established researchers (e.g., consider the attention received by Linus Pauling’s proposals that megadoses of vitamin C prevent the common cold). Thus, respect for authority can no longer be considered a candidate for an absolute line of demarcation between science and nonscience. Taking a more continuous view of science, however, few if any would argue that fields whose conclusions depend heavily on the positions of authorities make them less scientific than fields that do not. Thus, although stating that creationism is not a science would clearly lead to a heated debate in many circles, it seems much less arguable that creationism is less scientific than evolution because creationists measure the acceptability of their tenets (at least in large part) by coherence with the Bible. Evolutionists clearly appreciate (or even revere) the work of Darwin, but they do not measure the adequacy of current explanations by reference to his unchanging and unchangeable writings. Therefore, although science is sometimes guilty of not being blind to authority, the relative difference between adherents of evolution and creationism lies in their degree of dependence on authority.

Second, objectivity has been widely recognized as a hallmark of science, but sociologists who study the scientific enterprise have clearly demonstrated that scientists are often not objective. Scientists often have a very deep personal commitment to a given theory or position on a question. They may, in fact, have a great deal of time, research dollars, and

¹ We owe the genesis of this idea to a reading of Somerville (1941).

² Surprising support for this approach comes from Suchting (1995): “In fact, in all or at least a great number of cases there will be no single set of marks the applicability of which, conjointly, is necessary and sufficient for the correct use of the term [science]. Rather, the term in question will be held to correctly apply so long as just a sufficient number of them conjointly apply in a particular case. Thus, we have to do with a cluster concept” (p. 4). See also Kitcher (1982, 1985).

personal prestige invested in a certain question being resolved in a certain way. Such vested interest can clearly impact the selection of research questions and other components of the research enterprise. Among unscrupulous scientists, this lack of objectivity even results in biased reporting or interpretation of data! Therefore, objectivity is a poor candidate for an absolute criterion distinguishing science from nonscience. On the other hand, few educated individuals would argue that scientists who seek to increase their objectivity and decrease their subjective biases are not being more scientific than scientists who do not.³

A third criterion used by many to distinguish science from nonscience has been falsifiability/testability (Popper, 1972). Although a discussion of this philosophical literature is beyond the scope of this article, one of the reasons this characteristic fails as an absolute criterion is the fact that science is based on a set of assumptions that, at least on the surface, appear to be nonfalsifiable or testable.⁴ Thomas Huxley (1893/1968, p. 601) identified these assumptions as the postulates of “the objective existence of a material world, . . . the universality of the law of causation [uniformitarianism—every event has a cause, and] . . . that any of the rules, the so-called ‘laws of Nature,’ . . . is true for all time.” (Huxley himself recognized, in fact, that these postulates “are neither self-evident nor are they, strictly speaking, demonstrable.”) (For a further discussion of this issue, see Suchting [1995]). Under our qualitative continuum, however, we suspect that few if any philosophers (and no scientists or science teachers) would refute the proposition that any claim that is potentially falsifiable (e.g., “HIV causes AIDS”) makes that question more scientific than a claim that cannot be falsified (e.g., “There is a God”).

Let us hasten to make an important point: Just because a field of study is deemed more scientific than another does not mean that the former is somehow better than the latter. Science is a way of knowing; it is not the *only* way of knowing or even the *best* way of knowing in many cases (see later). Yes, science is recognized by many as the best way of answering certain types of questions about the natural world, but that does not mean that it is the best way to answer other types of questions (e.g., Is there a God? Is this beautiful? How can I find meaning in life?) We must admit that scientists have too often been guilty of taking this erroneous imperialist position (Duschl, 1988) and that we are ethically bound to avoid the temptation.

WHAT ARE THE QUALITATIVE DISTINCTIONS THAT MAKE A QUESTION OR FIELD OF STUDY MORE SCIENTIFIC OR LESS SCIENTIFIC?

Here now is the most difficult question—which we will not avoid. The list of descriptors we propose in what follows has been drawn from a wide range of the science education and philosophy of science literature, including Abimbola (1983), Blois (1988), Butterfield (1965), Duschl (1990; 1985), Feyerabend (1975), Giere (1988), Hyers (1984), Jegede (1989), Kitcher (1982, 1985), Kuhn (1970), Lakatos (1970), Laudan (1977), Mayr (1988),

³ We recognize that many recent feminists in sociology, education, and related fields are staunch advocates of the value of the subjective voice in research, but we are aware of no feminists who advocate that increasing subjectivity in the study of the natural sciences is desirable. Following our argument, this would, or course, mark such feminist research as less scientific. Barbara McClintock’s description of her approach to scientific research, however, is a well-known example of an eminent scientist who reports the utility of having a “feeling for the organism” (Keller, 1983).

⁴ Siegel (personal communication, March 1996) argues that the validity of these assumptions can be measured inductively; that is, we can collect empirical evidence in the physical world that supports some of these assumptions, and that whether or not science even makes such assumptions is some cases (e.g., quantum mechanics).

Nieman and Siegel (1993), Popper (1972), Root-Bernstein (1984), Ruse (1983), Siegel (1981), Sonleitner (1986), and Wilson (1983). Wherever possible, we have selected characteristics for which there is empirical survey data to suggest that a majority of scientists and/or philosophers accept the proposition. Otherwise, the inclusion or exclusion of an item is based solely on our perception of the general agreement among science educators and/or scientists.

Many will likely disagree with the inclusion or omission of one or another descriptor, which is as it should be. It is our hope, in fact, not that the proposed list will be adopted en masse by the science education community (much less by the philosophy-of-science community), but that this proposal will engender a lively, ongoing discussion (perhaps even in the *Comments* section of this journal). For reasons of space, only a brief description of each characteristic is provided.

Characteristics that Make a Question or Field of Study More Scientific

The Objects and Processes of Study. (a) *Science is empirical.* It is based on observation (direct and/or indirect); it seeks to find out about the natural world. Scientific claims are based on sensory data or what Hume called “sense-experience” (quoted in Suchting, 1995). Science deals with things that can be measured and/or counted, things that can be perceived with the five senses, with or without the assistance of various instruments. Or, as Suchting has so well said, science studies “the material world, or its collective objects or phenomena.”

(b) *Scientific claims are testable/falsifiable.* Data can be obtained that support or refute each claim. “Evidence is the arbiter for cognitive justification in science” (Mahner & Bunge, 1996, p. 113).

(c) *Scientific tests or observations are repeatable.* Science values replication studies and eschews claims based on experiences that are not repeatable (e.g., revelation). Experiments or observations can be repeated by other investigators. Conclusions can be confirmed by repeated investigations by many researchers in a variety of settings.

(d) *Science is tentative/fallible.* Science is not a rigid, unchanging body of “right” answers. Scientific knowledge evolves over time; old theories are modified or discarded in the light of new evidence.

(e) *Science is self-correcting.* The recognition that science is fallible and that replication of crucial studies is important, leads to the elimination of error.

Values of Science. (a) *Science places a high value on theories that have the largest explanatory power.* The greater the number of diverse observations that can be explained by a theory, the more likely it is to be accepted by the scientific community.

(b) *Science values predictive power.* Science privileges theories that can be used to make accurate predictions about future events or the outcomes of studies not yet performed.

(c) *Science values fecundity.* Scientists value theories that raise new questions that have not been asked before or that facilitate new ways of looking at the world.

(d) *Science values open-mindedness.* Although we acknowledge that observation is not theory-free, good science seeks to be unbiased and objective.

(e) *Science values parsimony.* Accurate explanations may, of course, be quite complex, but scientists prefer theories that are relatively simple, with few exceptions or apparently tangential assumptions. Scientists often speak of such theories as elegant.

(f) *Scientists demand logical coherence in their explanations.* Scientific explanations must be able to withstand careful scrutiny of their logic and employ sound argumentation.

(g) *Scientists value skepticism.* No conclusions are accepted on face value, without careful analysis of the evidence supporting and refuting the claim.

Characteristics That Make a Question or Field of Study Less Scientific

Espousing a Theological Position. Science is theologically neutral. It takes no position on the existence of a supernatural being (that God does or does not exist), much less on the possible actions of such a being (e.g., that God did or did not create the Earth).⁵

Valuing Authority over Evidence. The words or opinions of no person or text (e.g., the Bible) can be accepted in spite of a clear and compelling body of evidence to the contrary (e.g., belief in a “young Earth” in spite of geological dating).

Fideism. Fideism is the reliance on faith rather than reason, where faith is defined as a belief in the absence of supporting evidence. As described earlier, science is based on a group of assumptions (e.g., universalism) that are not empirically verifiable in the same sense that scientific claims are, but this does not mean that there is no difference between science and nonscience in the relative status of faith and evidence.

In addition, there are several characteristics that science education stakeholders seem to generally recognize as important for a basic understanding of the nature of science, although these attributes do not necessarily distinguish between things that are more or less scientific. Some of these issues have already been discussed and many are well addressed in documents such as the *AAAS Benchmarks for Scientific Literacy* (AAAS, 1993) and the *National Science Education Standards* (NRC, 1996). The characteristics of the nature of science raised in these documents seem to be appropriate goals for high school graduates. Examples of these characteristics include the following:

- Science is a way of knowing, not the only way of knowing.
- Science is built on a set of functional assumptions (e.g., order and predictability in the universe).
- Curiosity, creativity, and chance play important roles in science.
- In practice, absolute objectivity is a goal of science that is rarely, if ever, achieved (including the social/cultural embeddedness of science and observational/interpretational biases).
- Persuasive communication of scientific findings and theories is crucial in science if the interpretation of those findings and/or theories are to be accepted by the scientific community.

Finally, student citizens need certain competencies in this area. They should, for example, be able to distinguish between observation and inference, hypothesis and theory, etc. Students must also understand the nature of valid scientific investigation (including understanding of variables, controls, etc.) so as to be able to evaluate the validity of scientific propositions.

Doubtless, many science educators, philosophers, and scientists will argue that science/nonscience is not a continuum, that the characteristics in the preceding lists are hallmarks that clearly distinguish science from nonscience, not descriptors that should be used to identify questions as more or less scientific. In most of the cases just listed, we

⁵ Note that this proposition necessarily eschews teleology.

would in fact agree with this position. But there are four important points to be made in this respect. First, this dichotomist position is a philosophical one; students may need to understand that it is the position widely held by scientists, but science educators are not bound to force students to espouse this position. Second, in practice, decisions about the applicability of each criterion are not always so clear cut (see the discussion of umbrellaology in what follows). Third, the instructional recommendation to discuss qualitative distinctions that make a question or field of study more scientific or less scientific should not be confused with the relativist view that there is in fact no distinction between science and nonscience, that one answer is just as good as another in any given situation. Fourth, and perhaps most important, using the philosophically more unbiased instructional approach recommended here seems to lend itself to more fruitful classroom discussions instead of heated and unproductive arguments. It does not divide the students into camps, each with a vested interest and a worldview that the other cannot understand; instead, it focuses the learning on the foundational issues in the nature of science that are necessary for effective citizenship. In the biology classroom, for example, it does not set believers in creation against believers in evolution but makes possible a fruitful discussion of the characteristics of each way of knowing that make it more scientific or less scientific. Stated another way, it allows the beginning student (and his/her teacher) to avoid unproductive discussions/arguments over whether or not a claim or an area of study is or is not science—especially topics such as creationism that exhibit some of the characteristics of science but are questionable in others—until such time as students are academically and developmentally prepared to address the thornier issues. The following section suggests a classroom activity that might be used in this way.

UMBRELLAOLGY

Various authors have suggested having students or visiting experts debate whether evolution and creationism are sciences or not (e.g., Kurvink, 1995). Many educators find such exchanges stimulating and instructive about our students, but in our experience such lessons are also usually very frustrating to both the teacher and the students. There may be lots of vociferous arguing, but nothing is ever resolved, few if any opinions are changed, and there appears to be little or no advancement of student learning about the nature of science. For readers who have had similar experiences and for readers who only see science/nonscience as a stark dichotomy, we recommend the following exercise that can be used once a group of students has some basic introduction to the nature of science or, with slight modification, as a first session on the topic.

Somerville (1941) presented an interesting hypothetical letter from a colleague who claimed to have begun a new science called “umbrellaology.” For 18 years, this individual had been collecting door-to-door interviews in which he “ascertained 1) the number of umbrellas possessed, 2) their size, 3) their weight, 4) their color” (p. 557). The findings of this work were published in nine volumes, he continues. He employs hypotheses which he tests, leading to the discovery of a number of theories and laws, such as the Law of Color Variation Relative to Ownership by Sex (umbrellas owned by women tend to great variety of color, whereas those owned by men are almost all black). “To this law I have given exact statistical formulation,” he further asserts (p. 559). Somerville’s imaginary correspondent notes the power of umbrellaology to predict umbrella ownership, its empirical and statistical base, and so on. The writer of the letter has a friend, however, who cannot be convinced that umbrellaology is a science, and he asks Somerville to settle the dispute.

This exercise, which is well known in the philosophy community but not in the science

education community, can lead to a very animated and fruitful classroom discussion. Assign students to read the “letter” before class. When class begins, ask: “Is umbrellalogy a science or not?” Lead the discussion to focus on the writer’s question of “to what extent is it a science . . . [what makes it] more [or less] scientific?” Focus the discussion on the characteristics identified by the author as characteristics that umbrellalogy shares with science. Are there other characteristics to consider (such as the 14 listed previously)? Make sure to ask students to explain what they mean when they use terms such as hypothesis, theory, law, empirical, and so on.

Be sure to make the goal of the discussion clear to the students. The goal is not to decide whether or not umbrellalogy is indeed a science. There is no clearly accepted right answer to that question (philosophers of science in fact disagree on this point!). The suggested goals are (1) to identify the characteristics of umbrellalogy that make it more scientific or less scientific; (2) to identify the characteristics of any claim, field of study, question, or approach to a problem that make it more or less scientific; (3) to learn what is meant by the terms people use in such discussions; (4) to learn what scientists tend to believe about how accurately these descriptors characterize science; and (5) to come to view science as one, among many, ways of knowing. Students will, of course, want to know the right answer, or at least to try to achieve agreement among themselves. One must not be led down this path to taking a vote. As Clough (1994) so clearly noted, “Science is not a democracy!” (p. 412). In fact, it can be valuable to point out that an individual’s opinion about umbrellalogy is irrelevant to whether it is or is not a science. It is also important to point out that even if a thing is judged to be nonscientific, that does not mean it is untrue but that science cannot test the truth value of some statements (e.g., “There is a god” or “God created the heavens and the earth”).

Although we have described this activity only in outline, it should be readily apparent that it has advantages over the typical creationism/evolution debates. First and foremost, there are no vested interests. No one’s personal beliefs about umbrellalogy are likely to be attacked. No one has preconceptions that will cloud the issues except those preconceptions about the nature of science itself. Second, it is much easier to focus the discussion on the characteristics of science and nonscience without becoming embroiled in heated debates over theological issues. Once students become knowledgeable and adept at using the relevant terms, we recommend challenging them to test their understanding of the nature of science on nonhypothetical issues such as astrology or even creation science. (Note: Further reading concerning instructional approaches to evolution/creation science can be found in Scharmann [1993].)

WHAT QUESTIONS ARE SCIENTIFIC?

Although it is sometimes important to be able to judge how scientific an entire field such as creation science or umbrellalogy is, as citizens and consumers of information in a democracy, our graduates are much more likely to encounter questions that require that they be able to determine whether the question should best be answered using the methods of science, or religion, or politics, and so on, or even a combination of these methods. Having made that assessment, a consumer can then decide what kinds of evidence are relevant (and what is irrelevant) and how to evaluate such evidence.

To give students practice at this very important skill, we suggest a second activity. Give the students a set of questions such as the following and ask, “Which of these questions is scientific? Which are not? Which have some parts that are related to science and others

that are not? Are some of the questions more scientific than others?" Examples might include⁶:

- Is it wrong to keep dolphins in captivity?
- How was the Earth made?
- Is the Earth's atmosphere heating up?
- Do ghosts haunt old houses at night?
- How old is the Earth?
- Should I ask a certain person to go out with me?
- Am I in love?
- Is there a god?
- Is premarital sex wrong?
- What kind of birth control should my spouse and I use?
- Should I follow the advice of my daily horoscope?
- Do species change over long periods of time?

Add questions as you like to take advantage of current issues, local controversies, and student interests. Provide lots of feedback to the students during the discussion, and keep it focused on the characteristics of science previously listed (e.g., Are all the issues involved empirical? How testable are the individual claims being made? Are explanations logically coherent?). (Note: This activity is also an excellent response to the perennial question of "Why do we need to know this stuff anyway?")

SCIENCE AS A WAY OF KNOWING (SCIENCE-AAWOK): A REFLECTIVE SYNTHESIS

Throughout this article we have acknowledged that science is but one way of knowing. Although it is an important way, science is neither the only nor always the best way of knowing. It is important to recognize and to help our students realize that some questions are best answered by the methods of science, and some by the methods of theology, aesthetics, and so on. The methods of science are, in fact, inappropriate for addressing some questions. Many times, in fact, making informed decisions about how to act involves considering the scientific merit of certain claims in conjunction with claims, principles, and imperatives that lie outside of science (e.g., whether or not to vote for a nuclear energy plant or a new welfare law). When participating as an individual within a society, it is appropriate for members of the scientific community to criticize individuals or groups who attempt to apply nonscientific methods to scientific questions (e.g., those who maintain that the authority of a literal translation of the Bible takes precedence over empirical evidence regarding the age of the Earth or the origin of species). In our role as science educators, however, we must be careful not to fall into the trap of promoting the preeminence of science in all issues. To repeat an old cliché, science tells us how the heavens go; religion tells us how to go to heaven. When science teachers encourage students to reject ideas in areas that lie outside the purview of science (cf. Lawson & Weser [1990], who encourage students to reject a belief in the existence of the human soul), the public is likely to feel threatened and even antagonistic. It is in exactly such situations that students

⁶ Note: Some of the questions appearing in this section are drawn from Driver, Leach, Millar, and Scott (1996).

perceive that scientists are promoting science-AAWOK as “truth” and the only truth. It is then that we can be aptly accused of being “secular humanists”—people who believe there is nothing outside ourselves and our physical world. Science teachers should not exacerbate public mistrust or student anxiety; instead we must provide students with the knowledge and the tools to find their own reasoned place to stand in relation to what students sometimes perceive as a dichotomous choice between science and religion.

In their daily work, scientists must, out of necessity, employ empirical methods to answer questions about the natural world rather than assume the intervention of a supernatural being (i.e., they employ methodological naturalism, also known as “hueristic” naturalism). Critics such as creation scientists sometimes attempt to confuse the public by painting both philosophical naturalism and methodological naturalism as being one and the same (Gilkey, 1986; Nelson, 1986), but they are not equivalents! Philosophical naturalism maintains that the natural world is all that is knowable (such a philosophy can be considered a humanistic religion); alternately, methodological naturalism simply describes the essence of scientific inquiry—the way science is done. Where the former consciously denies that a deity is knowable, the latter remains steadfastly neutral regarding any question concerning a deity. In other words, although scientists must be methodological naturalists, it does not of necessity follow that they also be philosophical naturalists. To play the game of science, one must wear blinders to other ways of knowing, but when the game ends and the blinders are removed, scientists (like nonscientists) are free to frame their personal worldviews using a full range of human experiences and interpretations.

In recent years the compatibility but incommensurability of science and religion have been accepted by a wide range of leaders from both communities.⁷ Pope Pius XII adopted such a position in his 1950 encyclical entitled *Humani Generis*, a position also endorsed recently by Pope John Paul II (October 2, 1996). According to Gould (1997), both of these papal essays accept that no conflict should exist between science-AAWOK and theology-AAWOK “because each subject has a legitimate magisterium, or domain of teaching authority—and these magisteria do not overlap” (p. 16).

To illustrate multiple ways of knowing in a less controversial setting, consider a painting by Picasso. Using aesthetics-AAWOK, one can make decisions about the quality of the work on the basis of whether the painting is more aesthetically appealing than others. Alternately, using science-AAWOK, one can delineate and operationally define empirical criteria by which to judge the painting (e.g., symmetry, perspective, color, brush stroke marks, etc.) Is one of these ways of knowing superior to the other, or as we are suggesting, might the two methods be used in conjunction to provide a broader understanding of the work? This is essentially the same argument made by Pope John Paul II when he recognized that individuals need not choose one way of knowing as an exclusive representation of their worldview. Individual worldviews, instead, are framed using multiple, simultaneous ways of knowing the world that inform and enrich each other. This is what Albert Einstein meant when he said that “Science without religion is lame, religion without science is blind” (Aicken, 1991, p. 90).

Science and religion, in fact, often use the phrase “to know” with very different meanings which are apparent in a definition given in *Webster’s Seventh New Collegiate Dictionary* (1971): “know: to be aware of the truth or factuality of; be convinced or certain of.” But scientists use the terms “fact” and “truth” very carefully, as in the facts that the sun

⁷ This position is, of course, not universal among scientists or religious leaders. In fact, a recent study (Mahner & Bunge, 1996), arguing for the incompatibility of science and religion, has generated considerable debate.

came up this morning and that there are millions of different living species. Truth in a religious sense, however, is not that understanding of reality/factuality that is best supported by empirical evidence, but is a matter of conviction, a:

personal truth, that is, truth for persons in contrast to truth about things . . . It is that truth in which . . . their experiences find coherence and unity. Personal truth is not content but action . . . This is the kind of truth proclaimed by "For I 'know' that my Redeemer lives," in contrast to a neutral demonstration that the redeemer is alive instead of dead. (Shideler, 1966, p. 39)

In science, of course, there is no such subjective "knowledge," and if this is the kind of knowledge a person is seeking, religion and not science is the "way of knowing" to follow.

It might be useful to consider an additional analogy. Different ways of knowing may be thought of as different versions of a screwdriver: Science might be thought of as a flat head, theology as a Phillips head, and aesthetics as a hex head. They are all screwdrivers, but each tool fits one particular set of problems and not another. When we offer science as a tool, we must make it abundantly clear that we are neither trying to remove nor asking for an exchange of any tool because all the tools are needed at different times. The different tools are not equal, but they can be equally useful under different circumstances. Problems nearer one extreme of the more scientific/less scientific continuum require the use of one kind of screwdriver, in contrast to the analysis of issues nearer to the middle of the more scientific/less scientific continuum that may require the use of two or more screwdrivers and maybe even a hammer or a hacksaw! When assisting students as they build a personal worldview and become wise consumers of scientific information, we maintain that the science teacher should help individuals learn how to decide when the "science tool" is appropriate and what the results of using that tool mean.

IMPLICATIONS FOR TEACHER EDUCATION

As with all instruction, the task falls to the teacher to design learning experiences such as the activities above that are likely to enhance student understanding of the nature of science. Research over the past 45 years, however, has consistently shown that many American science teachers have a grossly inadequate understanding of the nature of science (see Lederman [1992] for a review). Two excerpts from letters from classroom science teachers published in *NSTA Reports!* (Anonymous, 1995/1996) suggest that this lack of understanding persists. An African teacher writes:

With a theory so unproven and full of holes as evolution from the beginning of the universe till now, anyone who says "we have *proven* how it all got here and there was no supernatural event involved" has got to have a fairly small-minded approach. (p. 3, emphasis added)

A teacher from Alabama writes:

In my opinion, both the theory of evolution and creation should be taught as *theories* or neither should be taught at all . . . I do believe that both evolution and creation are theories as to how the universe began, and that neither will be *conclusively, scientifically proven* until time does not exist. (p. 10, emphasis added)

This confusion, over the nature of science in general and the scientific meaning of the

term theory in particular, is so widespread in some areas that the state of Alabama, for example, recently adopted a policy requiring that evolution be taught “as theory and not as fact.” Given the almost universal commitment to the goal of understanding the nature of science, this is a scathing indictment of science education programs (at least in the schools attended by these legislators).

Assuming that one cannot teach what one does not know, the implication is clear that science teacher educators must redouble our efforts to help future teachers understand of the nature of science. According to Lederman (1992), however, efforts reported to date to improve teachers’ conceptions of the nature of science have been “equivocal and the specific variables contributing to improved conceptions of the nature of science remained unknown” (p. 350). The time has clearly come that the science education community must consider these issues squarely. Future research should focus on questions such as the following: How can we adequately prepare classroom teachers with an understanding of the nature of science that they can use to design effective classroom activities? How can we help teachers design such activities? How can we encourage teachers to view teaching the nature of science as important in their own classrooms? How can we enhance their self-efficacy in this area? It is hoped that the analysis and the activities presented above will be useful both to teacher educators and to classroom teachers in beginning to address these issues.

The authors thank Norman G. Lederman for his thoughtful review of an earlier version of this manuscript.

REFERENCES

- Abd-El-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education*, 82, 417–436.
- Abimbola, I. O. (1983). The relevance of the “new” philosophy of science for the science curriculum. *School Science and Mathematics*, 83, 181–193.
- Aicken, F. (1991). *The nature of science*, 2nd ed. Portsmouth, NH: Heinemann.
- Aikenhead, G. S. (1997). Toward a first nations cross-cultural science and technology curriculum. *Science Education*, 81, 217–238.
- Alters, B. J. (1997). Whose nature of science? *Journal of Research in Science Teaching*, 34, 39–55.
- American Association for the Advancement of Science (1993). *Benchmarks for science literacy*. New York: Oxford University Press.
- Anonymous (1995/1996). Letters [letters to the editor]. *NSTA Reports!*, pp. 3, 10.
- Blois, M. S. (1988). Medicine and the nature of vertical reasoning. *New England Journal of Medicine*, 318, 847–851.
- Butterfield, H. (1965). *The origins of modern science, 1300–1800*, rev. New York: Free Press.
- Clough, M. (1994). Diminish students resistance to biological evolution. *The American Biology Teacher*, 56, 409–415.
- Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young people’s images of science*. Philadelphia: Open University Press.
- Duschl, R. A. (1988). Abandoning the scientific legacy of science education. *Science Education*, 72, 51–62.
- Duschl, R. A. (1990). *Restructuring science education*. New York: Teachers College Press.
- Duschl, R. A. (1985). Science education and the philosophy of science: Twenty-five years of mutually exclusive development. *School Science and Mathematics*, 87, 541–555.
- Feyerabend, P. (1975). *Against method*. London: Verso.
- Giere, R. N. (1988). *Explaining science*. Chicago: University of Chicago Press.
- Gilkey, L. (1986). The creationism issue: A theologian’s view. In R. W. Hanson (Ed.), *Science and creation* (pp. 174–188). New York: Macmillan.

- Gould, S. (1977). *Ever since Darwin: Reflections in natural history*. New York: W. W. Norton & Co.
- Gould, S. J. (1997). Nonoverlapping magisteria. *Natural History*, 106, 16–20, 60–62.
- Gould, S. (1994). The evolution of life on earth. *Scientific American*, 271, 85–91.
- House, E. R. (1991). Realism in research. *Educational Researcher*, 20, 2–9.
- Hurd, P. D. (1977). Reflections and the quest for perspective. In R. L. Steiner (Ed.), *Science education: Past or prologue: 1978 AETS yearbook* (pp. 106–117). Columbus, OH: Association for the Education of Science Teachers.
- Huxley, T. H. (1893/1968). *Collected papers*, 4 vols. New York: Greenwood Press.
- Hyers, C. (1984). *The meaning of creation: Genesis and modern science*. Atlanta, GA: John Knox Press.
- Jegede, O. J. (1989). Toward a philosophical basis for science education of the 1990's: An African view-point. In D. E. Herget (Ed.), *The history and philosophy of science in science teaching* (pp. 185–198). Tallahassee, FL: Science Education and Department of Philosophy, Florida State University.
- Keller, E. F. (1983). *A feeling for the organism*. New York: W. H. Freeman & Co.
- Kitcher, P. (1982). *Abusing science: The case against creationism*. Cambridge, MA: MIT Press.
- Kitcher, P. (1985). Good science, bad science, dreadful science, and pseudoscience. *Journal of College Science Teaching*, 14, 168–173.
- Kuhn, T. S. (1970). *The structure of scientific revolutions*, 2nd ed. Chicago: University of Chicago Press.
- Kurvink, K. (1995). What do you think? A classroom approach to teaching evolution. *Journal of College Science Teaching*, 24, 270273.
- Lakatos, I. (1970). Falsification and the methodology of scientific research programs. In I. Lakatos & A. Musgrave (Eds.), *Criticism and the growth of knowledge*. Cambridge, UK: Cambridge University Press.
- Laudan, L. (1977). *Progress and its problems*. Berkeley, CA: University of California Press.
- Lawson, A. E., & Weser, J. (1990). The rejection of nonscientific beliefs about life: Effects of instruction and reasoning skills. *Journal of Research in Science Teaching*, 27, 589–606.
- Lederman, N. G. (1992). Students and teachers conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching*, 29, 331–359.
- Lederman, N. G. (1995). Suchting on the nature of scientific thought: Are we anchoring curricula in quicksand? *Science & Education*, 4, 371–377.
- Lederman, N. G. (1996, April). The nature of science: Instructional implications for a process more tentative than its products. Paper presented at the meeting of the National Association for Research in Science Teaching, St. Louis, MO.
- Mahner, M., & Bunge, M. (1996). Is religious education compatible with science education? *Science & Education*, 5, 101–123.
- Matthews, M. R. (1997). James T. Robinson's account of philosophy of science and science teaching: Some lessons for today from the 1960s. *Science Education*, 81, 295–315.
- Mayr, E. (1982). *The growth of biological thought: Diversity, evolution, and inheritance*. Cambridge, MA: Harvard University Press.
- Mayr, E. (1988). *Toward a new philosophy of biology: Observations of an evolutionist*. Cambridge, MA: Harvard University Press.
- Mayr, E. (1991). *One long argument: Charles Darwin and the genesis of modern evolutionary thought*. Cambridge, MA: Harvard University Press.
- Meyling, H. (1997). How to change students' conceptions of the epistemology of science. *Science and Education*, 6, 397–416.
- Monk, M., & Osborne, J. (1997). Placing the history and philosophy of science on the curriculum. *Science Education*, 81, 403–424.
- Moore, J. A. (1983). Why are there creationists? *Journal of Geological Education*, 31, 95–104.
- Moore, J. (1993). *Science as a way of knowing — The foundations of modern biology*. Cambridge, MA: Harvard University Press.
- National Research Council (1996). *National science education standards*. Washington, DC: National Academy Press.

- National Science Teachers Association (1993). *Scope, sequence, and coordination of secondary school science: The content core*. Washington, DC: National Science Teachers Association.
- Neiman, A., & Siegel, H. (1993). Objectivity and rationality in epistemology and education: Schefler's middle road. *Synthese* 94, 55–84.
- Nelson, C. E. (1986). Creation, evolution, or both? A multiple model approach. In R. W. Hanson (Ed.), *Science and creation* (pp. 128–159). New York: Macmillan.
- Numbers, R. (1992). *The creationists: The evolution of scientific creationism*. Berkeley, CA: University of California Press.
- Perry, W. (1970). *Forms of intellectual and ethical development in the college years: A scheme*. New York: Holt, Rinehart and Winston.
- Pitt, J. C. (1990). The myth of science education. *Studies in Philosophy and Education*, 10, 7–17.
- Pomeroy, D. (1993). Implications of teachers beliefs about the nature of science: Comparison of the beliefs of scientists, secondary science, teachers, and elementary teachers. *Science Education*, 77, 261–278.
- Popper, K. R. (1972). *The logic of scientific discovery*, 3rd ed. London: Hutchinson.
- Robinson, J. T. (1968). *The nature of science and science teaching*. Belmont, CA: Wadsworth.
- Root-Bernstein, R. (1984). On defining scientific theory: Creationism considered. In A. Montagu (Ed.), *Science and creationism* (pp. 64–94). New York: Oxford University Press.
- Roth, W.-M., & Roychoudhury, A. (1994). Physics students epistemologies and views about knowing and learning. *Journal of Research in Science Teaching*, 31, 5–30.
- Ruse, M. (1983). Creation-science is not science. In M. C. LaFollette (Ed.), *Creationism, science, and the law: The Arkansas case* (pp. 150–160). Cambridge: MA.
- Rutherford, F. J., & Ahlgren, A. (1990). *Science for all Americans*. New York: Oxford University Press.
- Scharmann, L. C. (1993). Teaching evolution: Designing successful instruction. *American Biology Teacher*, 55, 481–486.
- Scott, E. C., & Cole, H. P. (1985). The elusive scientific basis of creations science. *Quarterly Review of Biology*, 60, 21–30.
- Shamos, M. H. (1995). *The myth of scientific literacy*. New Brunswick, NJ: Rutgers University Press.
- Shideler, E. W. (1966). *Believing and knowing: The meaning of truth in biblical religion and in science*. Ames, IA: Iowa State University Press.
- Siegel, H. (1981). Creationism, evolution, and education: The California fiasco. *Phi Delta Kappan*, 63, 95–101.
- Siegel, H. (1984). The response to creationism. *Educational Studies*, 15, 349–364.
- Skog, G., Cielen, R., Jordan, L., Lavriviere, J., Scharmann, L., & Scott, E. (1997). NSTA position statement on the teaching of evolution. *Journal of College Science Teaching*, 27, 7–8.
- Smith, M. U., Siegel, H., & McInerney, J. D. (1995). Foundational issues in evolution education. *Science & Education*, 4, 23–46.
- Smolicz, J. J., & Nunan, E. E. (1975). The philosophical and sociological foundations of science education: The demythologizing of school science. *Studies in Science Education*, 2, 101–143.
- Solomon, J., Scott, L., & Duveen, J. (1996). Large-scale exploration of pupils' understanding of the nature of science. *Science Education*, 80, 493–508.
- Somerville, J. (1941). Umbrellaology. *Philosophy of Science*, 8, 557–566.
- Sonleitner, F. J. (1986). What did Karl Popper really say about evolution? *Creation/Evolution*, 18, 9–14.
- Suchting, W. A. (1995). The nature of scientific thought. *Science & Education*, 4, 1–22.
- Webster's seventh new collegiate dictionary (1971). Springfield, MA: Merriam Co.
- Wilson, D. B. (1983). *Did the devil make Darwin do it? Modern perspectives on the creation evolution controversy*. Ames, IA: Iowa State University Press.