

Teaching the Nature of Science: Three Critical Questions

By Randy L. Bell

CURRENT REFORMS IN SCIENCE EDUCATION emphasize teaching science for all, with the ultimate goal of developing scientific literacy. In this view, science instruction must go beyond simply teaching science as a body of knowledge. Today's teachers are challenged to engage students in a broader view of science—one that addresses the development of scientific knowledge and the very nature of the knowledge itself (National Research Council, 1996). In other words, Science teachers are increasingly being encouraged (and, according to many state standards, required) to teach about the nature of science.

Unfortunately, decades of research have demonstrated that teachers and students alike do not possess appropriate understandings of the nature of science (Lederman, 2007). This lack of understanding negatively impacts what teachers teach about science, and in turn, what students learn. Too often, science is taught as a subject with little connection to the real world. Students view scientists as strictly adhering to "The Scientific Method," and in so doing, producing "true" knowledge that is untarnished by human limitations. In this caricature of science, hypotheses are educated guesses, theories have yet to be proven, and laws are absolute and infallible. It is no wonder that so many students fail to see any connection between what they learn in science class and what they know about the "real world," where science controversies abound and scientists often disagree about the results of their investigations.

Why Teach about the Nature of Science?

Science educators have promoted a variety of justifications for teaching about the nature of science. For example, Matthews (1997) argued that the nature of science is inherent to many critical issues in science education. These include the evolution/creationism debate, the relationship between

science and religion, and delineation of the boundaries between science and non-science. Others have related teaching about the nature of science to increased student interest (Lederman, 1999; Meyling, 1997), as well as developing awareness of the impacts of science in society (Driver, Leach, Millar, & Scott, 1996). Perhaps the most basic justification for teaching the nature of science is simply to help students develop accurate views of what science is, including the types of questions science can answer, how science differs from other disciplines, and the strengths and limitations of scientific knowledge (Bell, 2008).

What is the Nature of Science?

The nature of science is a multifaceted concept that defies simple definition. It includes aspects of history, sociology, and philosophy of science, and has variously been defined as science epistemology, the characteristics of scientific knowledge, and science as a way of knowing. Perhaps the best way to understand the nature of science is to first think about scientific literacy. Current science education reform efforts emphasize scientific literacy as the principal goal of science education (American Association for the Advancement of Science, 1989; 1993). Reform documents describe scientific literacy as the ability to understand media accounts of science, to recognize and appreciate the contributions of science, and to be able to use science in decision-making on both everyday and socio-scientific issues.

Science educators have identified three domains of science critical to developing scientific literacy (Figure 1). The first of these is the body of scientific knowledge. Of the three, this is the most familiar and concrete domain, and includes the scientific facts, concepts, theories, and laws typically presented in science textbooks.

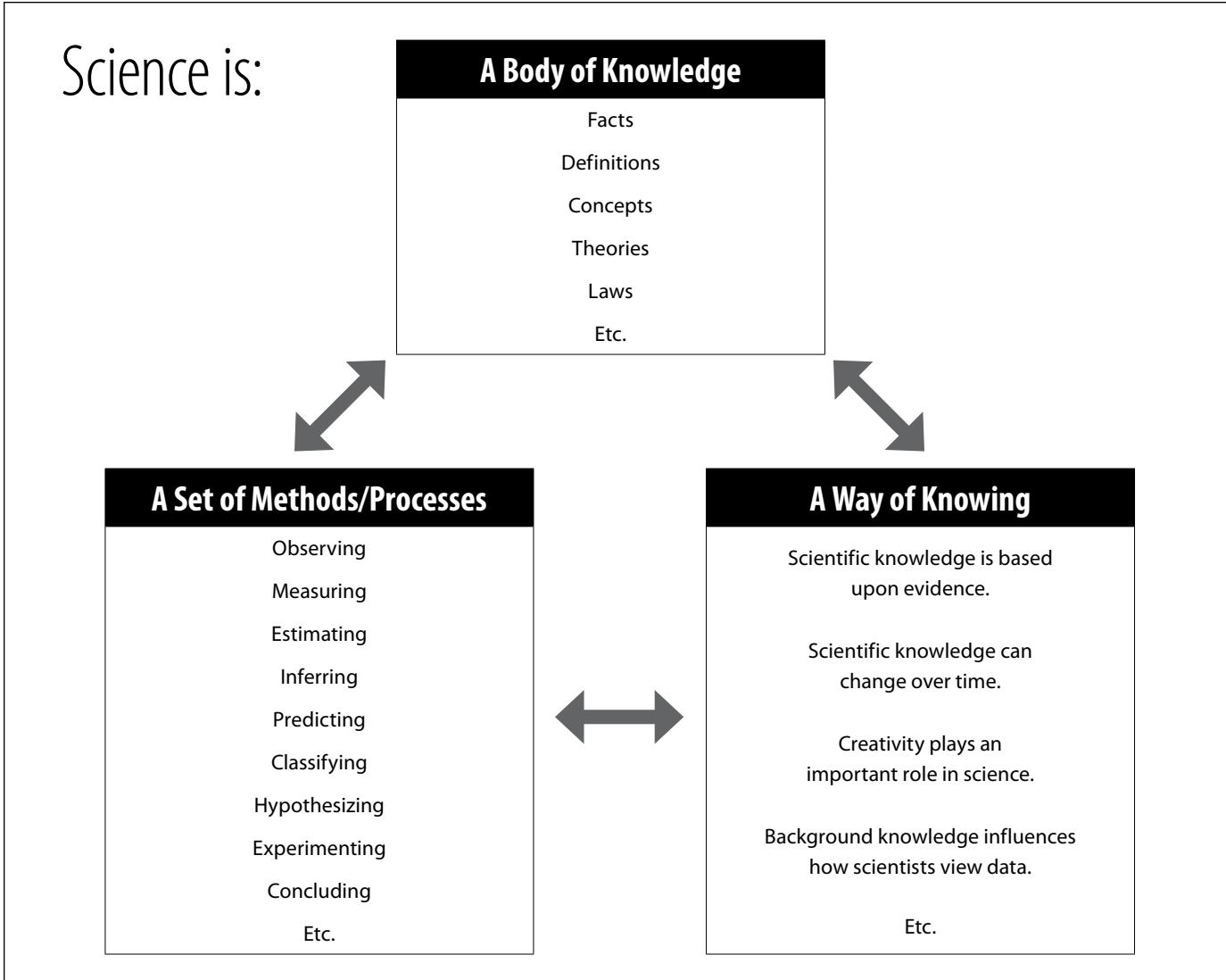


Figure 1. Three Domains of Science

Scientific methods and processes comprise the second domain, which describes the wide variety of methods that scientists use to generate the knowledge contained in the first domain. Science curricula delve into this domain when they address process skills and scientific methodology.

The nature of science constitutes the third domain and is by far the most abstract and least familiar of the three. This domain seeks to describe the nature of the scientific enterprise and the characteristics of the knowledge it generates. This domain of science is poorly addressed in the majority of curricular materials, and when it is addressed, it is often misrepresented. The myth of a single "Scientific Method" and the idea that scientific theories may be promoted into laws when proven are two examples of misconceptions directly taught in science textbooks (Abd-El-Khalick, Waters, & An-Phong, 2008; Bell, 2004).

Key Concepts

When describing the nature of science, science educators have converged on a key set of ideas viewed as most practical in the school setting and potentially most useful in developing scientific literacy (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003). These include the following concepts:

1. Tentativeness. All scientific knowledge is subject to change in light of new evidence and new ways of thinking—even scientific laws change. New ideas in science are often received with a degree of skepticism, especially if they are contrary to well-established scientific concepts. On the other hand, scientific knowledge, once generally accepted, can be robust and durable. Many ideas in science have survived repeated challenges and have remained largely unchanged for

hundreds of years. Thus, it is reasonable to have confidence in scientific knowledge, even while realizing that such knowledge may change in the future.

2. Empirical evidence. Scientific knowledge relies heavily upon empirical evidence. Empirical refers to both quantitative and qualitative data. While some scientific concepts are highly theoretical in that they are derived primarily from logic and reasoning, ultimately, all scientific ideas must conform to observational or experimental data to be considered valid.

3. Observation and inference. Science involves more than the accumulation of countless observations—rather, it is derived from a combination of observation and inference. Observation refers to using the five senses to gather information, often augmented with technology. Inference involves developing explanations from observations and often involves entities not directly observable.

4. Scientific laws and theories. In science, a law is a succinct description of relationships or patterns in nature consistently observed in nature. Laws are often expressed in mathematical terms. A scientific theory is a well-supported explanation of natural phenomena. Thus, theories and laws constitute two distinct types of knowledge. One can never change into the other. On the other hand, they are similar in that they both have substantial supporting evidence and are widely accepted by scientists. Either can change in light of new evidence.

5. Scientific methods. There is no single universal scientific method. Scientists employ a wide variety of approaches to generate scientific knowledge, including observation, inference, experimentation, and even chance discovery.

6. Creativity. Creativity is a source of innovation and inspiration in science. Scientists use creativity and imagination throughout their investigations.

7. Objectivity and subjectivity. Scientists tend to be skeptical and apply self-checking mechanisms such as peer review in order to improve objectivity. On the other hand, intuition, personal beliefs, and societal values all play significant roles in the development of scientific knowledge. Thus, subjectivity can never be (nor should it be) completely eliminated from the scientific enterprise.

The concepts listed above may seem disconnected at first. However, closer consideration reveals they all fall under the

umbrella of tentativeness: There are no ideas in science so cherished or privileged as to be outside the possibility of revision, or even rejection, in light of new evidence and new ways of thinking about existing evidence. In fact, one way to look at concepts #2 through #7 is that together they provide the rationale for why scientific knowledge is tentative.

The absence of absolutes in science should not be seen as a weakness. Rather, the tentative nature of science is actually one of its greatest strengths—for progress toward legitimate claims and away from erroneous ones would never be possible without skepticism and scrutiny of new and existing claims, along with the possibility of revising or rejecting those that fall short (Sagan, 1996). One need only look at the advances in such diverse fields as medicine, agriculture, engineering, and transportation (all fields that make extensive use of the body of knowledge produced by science) for verification that science works. History has shown no other means of inquiry to be more successful or trustworthy. Change, then, is at the heart of science as a way of knowing and one of the key characteristics that distinguishes it from other ways of experiencing and understanding the universe.

What Constitutes Effective Nature of Science Instruction?

At first glance, teaching about the nature of science can appear esoteric and far removed from students' daily experiences. Decades of research on teaching and learning about the nature of science points to some specific approaches that can make instruction about the nature of science both more effective and engaging.

Be Explicit

First, it is important to realize that doing hands-on activities is not the same as teaching about the nature of science. Having students "do science" does not equate to teaching about the nature of science, even if these activities involve students in high levels of inquiry and experimentation. Several researchers have addressed this very issue (e.g., Bell, Blair, Crawford, & Lederman, 2003; Khishfe, & Abd-El-Khalick, 2002) and all have found explicit instruction to be central to effective nature of science instruction. Learning about the nature of science requires discussion and reflection on the characteristics of scientific knowledge and the scientific enterprise—activities students are not apt to engage in on their own, even when

Process Skill	Relevant Nature of Science Concepts
Observing	<p>Scientific knowledge is based upon evidence. Scientific knowledge changes as new evidence becomes available.</p> <p>Scientific laws are generalizations-based that summarize vast amounts of observational data.</p>
Inferring	<p>Scientific knowledge involves observation and inference (not just observation alone).</p> <p>Scientific theories are based partly on entities and effects that cannot be observed directly, and hence are inferential.</p>
Classifying	<p>There is often no single “right” answer in science.</p>
Predicting/Hypothesizing	<p>Scientific theories provide the foundation on which predictions and hypotheses are built.</p>
Investigating	<p>There are many ways to do science. There is no single scientific method that all scientists follow.</p>
Concluding	<p>Scientific conclusions can be influenced by scientists’ background knowledge.</p> <p>Theories provide frameworks for data interpretation.</p>

Figure 2. The relationship between sample process skills and the nature of scientific knowledge.

conducting experiments (Bell et al., 2003). In short, research demonstrates that students will learn what we want them to learn about the nature of science only when they are taught about it in a purposive manner.

Connect to Context

Keep in mind that purposive instruction is not synonymous with direct instruction. Students are not likely to develop meaningful understandings of the nature of science simply by reading a list of nature of science concepts. Instead, students need to experience specific activities designed to highlight particular aspects of the nature of science. Inquiry activities, socio-scientific issues, and episodes from the history of science can all be used effectively as contexts in which to introduce and reinforce nature of science concepts.

Link to Process Skills

While there is no single “right” approach, researchers have begun to show that linking the nature of science to process skills instruction can be effective (Bell, Toti, McNall, & Tai, 2004). Science process skills are a familiar topic for most elementary teachers. At an early age, students are taught to observe, measure, infer, classify, and predict as part of normal science

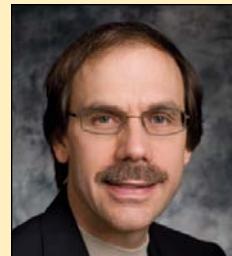
instruction. By linking instruction about the nature of science into lessons involving process skills, students can learn about science as they learn the skills necessary to do science (Figure 2). Thus, any science process skills lesson is a potential lesson about the nature of science, provided teachers highlight the connection between the two.

Conclusion

Current science education reform efforts focus on scientific literacy as a principal goal and framework for instruction. *National Geographic Science* integrates science content, science process skills, and the nature of science in ways that promote accurate understandings of science. The program uses engaging text, pictures, and activities to encourage students to “think like scientists” as they learn standards-based science content.

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