

QUIZZING STUDENTS ON THE MYTHS OF SCIENCE

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While an impressive body of content knowledge is associated with science courses, there is more about the scientific enterprise itself that students should learn. In addition to viewing science as a body of knowledge, students should also view science as a way of thinking and investigating and should have an understanding of how science interacts with technology and society (Chiappetta and Koballa 2002). The most complete science education experience must give students opportunities to learn about the very nature of science (NOS).

So what is the nature of this enterprise that we call science? How does science differ from other ways of knowing? And, how can science teachers help students develop a deep and rich understanding of science that depicts its true nature? These questions are addressed in science education documents including the *National Science Education Standards (NSES)*, which states “Science is a way of knowing that is characterized by empirical criteria, logical argument, and skeptical review. Students should develop an understanding of what science is, what science is not, what science can and cannot do, and how science contributes to culture” (NRC 1996, 21).

The American Association for the Advancement of Science places great emphasis on teaching and learning about NOS throughout the grades. *Science for All Americans: Project 2061* promotes the belief that the world is understandable and although scientific ideas are subject to change, scientific



A nature of science quiz helps teachers assess students' notions about authentic science

knowledge is durable (AAAS 1990). While science relies heavily on evidence, it also requires logic and imagination to form valid conclusions. Science is a complex social activity that is organized into many disciplines.

Given the emphasis placed on high-stakes testing of students' science understandings by many states, great pressure exists to teach content and to prepare students to demonstrate their knowledge on paper-and-pencil tests. Nevertheless, we urge high school science teachers to incorporate other facets of science into their courses and recommend that teachers

- ◆ teach and assess many aspects of science—content knowledge, process skill development, attitudes toward science, and how science works; and
- ◆ check for students' understanding of NOS throughout a course—at the beginning of a teaching session, during lectures, discussions, and laboratory work, and at the end of lessons and units of study.

One way to promote better understanding of science is to study myths of science by teaching, testing, and reflecting on these ideas at many points during instruction. We have taken the core ideas of NOS [provided by William F. McComas in this issue of *The Science Teacher* (p. 24–27)], modified some ideas and incorporated others, and developed a “Myths of Science” quiz for students (Figure 1) that may be useful both as an assessment tool and advance instructional organizer. Some of the quiz statements represent myths regarding NOS, while others more accurately reflect NOS. These statements provide an engaging focus on faulty notions of how authentic science really functions.

Explaining the quiz items

Figure 1 presents a true/false quiz on some myths of science held by many individuals. Before continuing on with this article, take the quiz yourself and write a few

FIGURE 1

“Myths of Science” quiz.

Directions:

Each statement below is about science. Some statements are true and some are false. On the line in front of each statement, write a “T” if it is true and an “F” if false. Then support your response to each statement with at least one paragraph on a separate sheet of paper.

- ___ 1. Science is a system of beliefs.
- ___ 2. Most scientists are men because males are better at scientific thinking.
- ___ 3. Scientists rely heavily on imagination to carry out their work.
- ___ 4. Scientists are totally objective in their work.
- ___ 5. The scientific method is the accepted guide for conducting research.
- ___ 6. Experiments are carried out to prove cause-and-effect relationships.
- ___ 7. All scientific ideas are discovered and tested by controlled experiments.
- ___ 8. A hypothesis is an educated guess.
- ___ 9. When a theory has been supported by a great deal of scientific evidence, it becomes a law.
- ___ 10. Scientific ideas are tentative and can be modified or disproved, but never proved.
- ___ 11. Technology preceded science in the history of civilization.
- ___ 12. In time, science can solve most of society's problems.

sentences to support your evaluation of each statement (the answers are available at the end of this article, p. 61). After completing the quiz, read the rest of the article as preparation for helping students distinguish between myths and more correct statements about NOS. (Note: Throughout this article we will refer to the specific statements in Figure 1 by number.)

Many students, science teachers, and the general public often believe that science is a system of beliefs (Statement 1). One of the distinguishing aspects of the scien-

tific enterprise is its continuing search for *evidence* in natural phenomena. Although humans have the inclination to look for evidence to support their ideas in many pursuits, not just in science, scientific ideas are established only after compelling evidence has accumulated from observations of nature. Scientists use reasoning and imagination, study the work of other scientists, and collaborate with other professionals, always looking for evidence to support or disprove their ideas. Rather than a belief system, science is based on empirical evidence provided by observations of the natural world.

The idea that science is a male domain (Statement 2) is more a remnant of historical prejudice than a true understanding of the history and nature of science. Societal attitudes have often made it difficult for girls and women to pursue science, to the point that a female scientist like astronomer Caroline Herschel (1750–1848) needed to rely on her brothers William and John to disseminate her research. But there is no evidence that men are inherently better at science. Although women are still underrepresented in some fields, women like Marie Curie, Rosalind Franklin, Barbara McClintock, Dian Fossey, Dorothy Crowfoot Hodgkin, Lise Meitner, and many others stand among the giants of modern science.

There can be no doubt that scientists rely heavily on their imagination in carrying out their work (Statement 3); the creative imagination has always been an important part of science. August Kekule’s visualization of the molecular shape of benzene—often called the crowning achievement of nineteenth century theoretical organic chemistry—is thought to have been partly the result of his prior training in architecture. Scientists draw upon their imagination and creativity to visualize how nature works, using analogies, metaphors, and mathematics. However, scientists are often stereotyped as bespectacled, serious-looking individuals in lab coats, conducting laboratory experiments that require superior intellect to be understood. Further, many people believe that **scientists are totally objective in their work** (Statement 4). Scientists, like all humans, are attached to their work and look for evidence to support their favored or promising ideas, sometimes overlooking and even rejecting ideas that are contrary to their own beliefs.



Laws and theories are distinct types of knowledge and therefore, laws do not become theories nor do theories become laws.

During the past 50 years, philosophers of science and science educational researchers have attempted to dispel the notion of a **scientific method** (Statement 5). The idea of “a method of science” has established a hold in science teaching but not in science itself. Posters are still hanging up in science classrooms that list the steps of the scientific method and these steps are still used to judge students’ procedures in science fair competitions. We need to be reminded that although scientific papers seem to follow the scientific method, they are reconstructed to account for key elements of the study. The actual

sequence of events for any investigation varies considerably and may take many wrong turns, encountering many dead ends.

The scientific method is carried out to **prove cause-and-effect relationships** (Statement 6). At first, this statement seems correct. Upon reflection, however, the statement is flawed. In mathematics, theorems are *proven* and in television courtroom scenes the term *proof* is used freely. In science, though, nothing stands as proven or completely true. Controlled experimentation only provides evidence that either supports or fails to add support to a hypothesis, not absolute proof. The reasoning, collaboration, and argumentation, as well as empirical evidence, all contribute to cause-and-effect understandings that are durable but tentative, always awaiting further evidence.

While controlled experiments can offer compelling evidence to support a hypothesis or theory, it is a myth to believe that **the most credible scientific theories are supported by controlled experiments** (Statement 7). Not all of the support for theories comes from experimentation. For example, the theoretical basis of the evolution of species, the expansion of the universe, and the movement of plates in Earth’s crust were developed by studying phenomena through observation rather than through the manipulation of variables. Science advances from many types of investigative evidence, which are subject to scrutiny and argumentation by the scientific community. Historical and observational methods of study are very much a part of authentic science.

It is often said that a **hypothesis is an educated guess** (Statement 8). A hypothesis holds a more rigorous position in science than a mere guess. A guess is usually thought of as a judgment put forth with little

information. However, scientists usually possess a considerable amount of knowledge about a phenomenon before they form a hypothesis to be tested. “In the scientific world, the hypothesis typically is formulated only after hours of observation, days of calculating and studying, and sometimes years of research into the phenomena of interest” (Galus 2003).

Some people believe that **when a theory has been supported by a great deal of scientific evidence, it becomes a law** (Statement 9). Laws and theories are distinct types of knowledge and therefore, laws do not become theories nor do theories become laws. A law is used to *describe* a phenomenon or pattern in nature. Laws hold true under most conditions, but can be modified or discredited. A theory is used to *explain* a phenomenon. Theories pertain to complex events that were initiated many years in the past, occur over long periods of time, relate to very small entities, or exist at great distances from us. In addition, theories combine many facts, concepts, and laws to form scientific understandings. A good example of this is the *law* of conservation of mass in chemistry and the atomic *theory* used to explain it.

Theories are tentative and can be modified or disproved, but never proved (Statement 10). This is the flipside of Statement 6 and is a true statement because while scientific theories are shored up by considerable evidence, they all are considered provisional and subject to change or rejection. Theories are inferred explanations and science is a way of knowing that does not represent absolute truth. This way of thinking removes science from being an all-knowing human enterprise. One philosopher of science, in discussing how knowledge progresses by *conjecture*, went so far as to assert that: “They may survive these tests; but they can never be positively justified: They can neither be established as certainly true nor even as ‘probable’ (in the sense of the probability calculus)” (Popper 1963, vii). However, we should not think of scientific theories as ideas built on shaky facts and flimsy evidence because many of the major theories of science have held up to considerable scrutiny and have shown to be durable.

While many individuals believe that technology is the application of science, this is not always the case. Actually, **technology preceded science in the history of civilization** (Statement 11). Civilizations were making tools for survival long before the understandings of these devices were reasoned out. Technology invents devices and systems to aid in human survival and to improve life. Science provides a better fundamental understanding of nature. However, today science and technology are closely associated, whereby technology supports the advancement of science and science supports the progress of technology. In some cases science precedes technology, while in other instances technology precedes science.

The statement “**In time, science can solve most of society’s problems,**” reflects a poor understanding of the nature and role of science in society (Statement 12). Science has improved life considerably for many people on the planet. Agriculture, medicine, and electronic communication have benefited enormously from scientific knowledge, but not everyone in the world has benefited from these examples of scientific advancement. Many problems in the world are political in nature, whereby individuals and governments promote or suppress economic and scientific development in their country. For example, science has provided us with the knowledge of how to produce enough food to feed most of the world’s hungry, but getting the food to their mouths is a problem that transcends science.

Sharpening student understanding

This quiz can be used at the beginning of the school year or at any point throughout the year as a tool to sharpen students’ understanding of NOS. Students can be asked to discuss why some NOS statements are correct as well as why some are false and to justify their reasoning. Students need more than content lectures and inquiry-based laboratory exercises to understand authentic science. Teachers must be explicit when teaching NOS and these ideas must be addressed directly in the planning, teaching, and assessment of science courses. ■

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Answer key to Figure 1:

1-F, 2-F, 3-T, 4-F, 5-F, 6-F, 7-F, 8-F, 9-F, 10-T, 11-T, 12-F