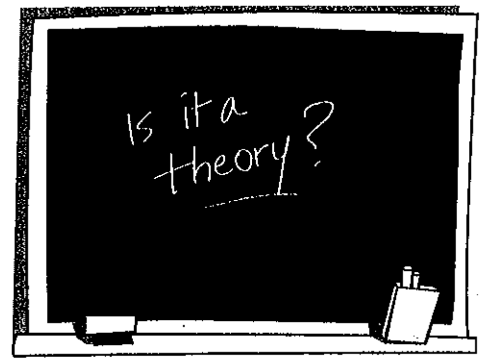
Is It a Theory?

Put an X next to the statements you think best apply to scientific theories.



_____ **A** Theories include observations.

_____ **B** Theories are "hunches" scientists have.

_____ **C** Theories can include personal beliefs or opinions.

_____ **D** Theories have been tested many times.

_____ **E** Theories are incomplete, temporary ideas.

_____ **F** A theory never changes.

_____ **G** Theories are inferred explanations, strongly supported by evidence.

_____ **H** A scientific law has been proven and a theory has not.

_____ **I** Theories are used to make predictions.

_____ **J** Laws are more important to science than theories.

Examine the statements you checked off. Describe what a theory in science means to you.

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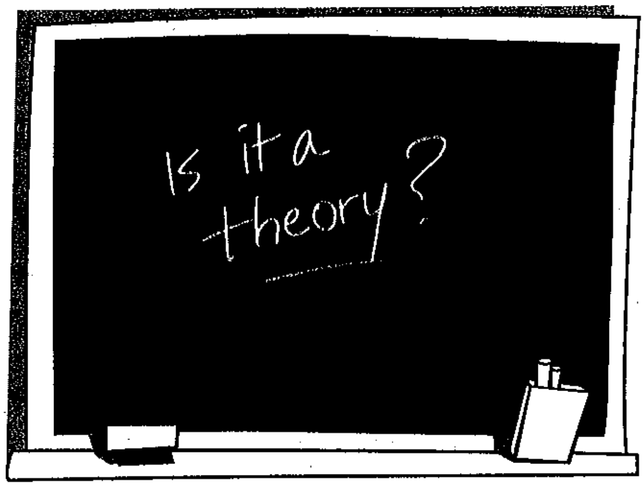
Is It a Theory?

Teacher Notes



Purpose

The purpose of this assessment probe is to elicit students' ideas about the nature of science. The probe is designed to find out if students distinguish scientific theories from the common use of the word *theory* and if they understand how theories differ from laws.

Related Concepts

hypothesis, nature of science, scientific law, theory

Explanation

The statements that best describe scientific theories are A, D, G, and I. Scientific theories are evidence-based explanations based on related observations of phenomena or events. A scientific theory is based on a solid body of supporting evidence that has been tested and supported with multiple lines of evidence. Theories are widely accepted in the scientific community and can be used to make predictions. Theories in science are not kept in doubt, although because of the dynamic nature of science, they can change if new evidence becomes available. Such new evidence may be made possible through new technological tools, techniques of analysis, new theoretical advances, or shifts in research emphasis that lead the scientific community to reconsider an existing explanation and revise it to fit new evidence that is available and accepted. Theories can also change when scientists view the same evidence differently, such as the example of Darwinian evolution and punctuate evolution in which the same evidence was looked at from a different perspective.

Examples of scientific theories include the germ theory of disease, the theory of biological evolution, plate tectonics theory, string theory, big bang theory, and kinetic molecular theory. Each of these theories provide an explanation accepted by the scientific community for observed phenomena. For example, plate tectonics explains the observed evidence for large-scale motions of the Earth's lithosphere.

Students and nonscientist adults often have definitions for the word *theory* that are quite different from the scientific meaning of the word. To nonscientists, the word *theory* often means a hunch, opinion, or a guess. In common usage it is not unusual to hear someone say, "I have a theory about...." A theory in the nonscientific sense of the word does not require firm evidence to support it nor does it require the consensus of others.

Sometimes the words *hypothesis, theory,* and *law* are inaccurately portrayed in science textbooks as an "evolution" of a scientific idea. There isn't a definite sequence or hierarchy for the development of scientific ideas—such as a hypothesis leads to a theory, which eventually becomes a law—because they represent different types of knowledge. For example, it is possible to develop a law (observed behavior of nature) and not have the explanation (theory) for it, such as when Isaac Newton helped develop the law of gravity, but at the time he did not have an explanation for it.

Law and theory are two different key elements of the nature of scientific knowledge. Laws are generalizations, principles, or patterns in nature derived from scientific facts that often describe how the natural world behaves under certain conditions. Laws describe relationships among observable phenomena. Some laws are expressed mathematically. Examples of scientific laws include Newton's laws of motion, universal law of gravitation, Boyle's law, and Mendel's laws. A law describes a phenomenon or event but it does not explain it, like a theory does. A theory is not a "law in waiting." Theories do not mature into laws (Lederman and Lederman 2004). A theory is a well-established explanation. Laws describe *what,* and theories explain *why.*

Curricular and Instructional Considerations

Elementary Students

From their very first day in school, young students should be actively engaged in learning to view the world scientifically. They should be encouraged to ask questions about nature and to seek answers, collect things, count and measure things, make qualitative observations, organize collections and observations, discuss findings, and so on. These skills and activities are precursors to understanding how science relies on evidence. Getting into the spirit of science and enjoying science are important at this age. Students can learn some things about the nature of scientific inquiry and significant people from history, which will provide a foundation for the development of sophisticated ideas related to the history and nature of science that will be developed in later years (NRC 1996).

Middle School Students

In middle school, students begin to deal with the changing nature of scientific knowledge. Both incremental changes and more radical changes in scientific knowledge should be taken up (AAAS 1993). At this grade level, students should be introduced to the scientific meaning of the word *theory* and become familiar with scientific theories (and their historical development) that are appropriately connected to the content they are learning (e.g., germ theory).

High School Students

Students at this level should be able to distinguish between facts, hypotheses, theories, and laws. Their formal understanding of what a scientific theory is should be developed both through historical episodes in science and by reflecting on developments in current science. This is a time when it is important to precede the teaching of important theories that are central to the different disciplines of science, such as the centrality of the theory of evolution in biology, with explicit teaching of the nature of science. For example, biological evolution is one of the strongest, most important, and useful scientific theories we have in science (NRC 1996). By helping students understand what a theory is in science before teaching about major theories such as biological evolution, teachers are also helping students to better understand why a theory is accepted by the scientific community and how personal beliefs and religious views that are not based on scientific evidence are not part of learning science.

Administering the Probe

This probe is best used at the middle school and high school levels. It can be used as a paper-pencil assessment to gather students' ideas for later analysis as well as a stimulus for provoking discussion about the nature of science. It can also be administered as a card sort with small groups of students sorting each statement into two groups, "applies to scientific theories" or "does not apply to scientific theories," while defending their reasons for placing each card.

Related Ideas in *National Science Education Standards* (NRC 1996)

5–8 Understandings About Scientific Inquiry

- ★ Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories. The scientific community accepts and uses such explanations until displaced by better scientific ones. When such displacement occurs, science advances.

5–8 The History and Nature of Science

- ★ Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models. Although all scientific ideas are tentative and subject to change and improvement in principle, for most major ideas in science, there is much experimental and observational confirmation. Those ideas are not likely to change greatly in

★ Indicates a strong match between the ideas elicited by the probe and a national standard's learning goal.

the future. Scientists do change and have changed their ideas about nature when they encounter new experimental evidence that does not match their existing explanations.

- In areas where active research is being pursued and in which there is not a great deal of experimental or observational evidence and understanding, it is normal for scientists to differ with one another about the interpretation of the evidence or theory being considered.

9–12 The History and Nature of Science

- Science distinguishes itself from other ways of knowing and from other bodies of knowledge through the use of empirical standards, logical arguments, and skepticism as scientists strive for the best possible explanations about the natural world.
- ☆ Scientific explanations must meet certain criteria. First and foremost, they must be consistent with experimental and observational evidence about nature and must make accurate predictions, when appropriate, about systems being studied. Scientific explanations should also be logical, respect the rules of evidence, be open to criticism, report methods and procedures, and make knowledge public. Explanations on how the natural world changes based on myths, personal beliefs, religious values, mystical inspiration, superstition, or authority may be personally useful and socially relevant, but they are not scientific.
- Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available. The core ideas of science, such as the conservation of energy or the laws of motion, have been subjected to a wide variety of confirmations and are therefore unlikely to change in the areas in which they have been tested. In areas where data or understanding are incomplete, such as the details of human evolution or questions surrounding global warming, new data may well lead to changes in current ideas or resolve current conflicts. In situations where information is still fragmentary, it is normal for scientific ideas to be incomplete, but this is also where the opportunity for making advances may be greatest.

Related Ideas in *Benchmarks for Science Literacy* (AAAS 1993)

6–8 The Scientific World View

- ☆ Scientific knowledge is subject to modification as new information challenges prevailing theories and as a new theory leads to looking at old observations in a new way.
- Some matters cannot be examined usefully in a scientific way. Among them are matters that by their nature cannot be tested objectively and those that are essentially matters of morality.

9–12 The Scientific World View

- From time to time, major shifts occur in

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the scientific view of how the world works. More often, however, the changes that take place in the body of scientific knowledge are small modifications of prior knowledge. Change and continuity are persistent features of science.

- ★ No matter how well one theory fits a set of observations, a new theory might fit it just as well or better, or it might fit a wider range of observations. In science, the testing, revising, and occasional discarding of theories, new and old, never ends. This ongoing process leads to an increasingly better understanding of how things work in the world but not to absolute truth. Evidence for the value of this approach is given by the improving ability of scientists to offer reliable explanations and make accurate predictions.

9–12 Scientific Inquiry

- ★ In the short run, new ideas that do not mesh well with mainstream ideas in science often encounter vigorous criticism. In the long run, theories are judged by how they fit with other theories, the range of observations they explain, how well they explain observations, and how effective they are in predicting new findings.
- New ideas in science are limited by the context in which they are conceived; are often rejected by the scientific establishment; sometimes spring from unexpected findings; and usually grow slowly, through contributions from many investigators.

Related Research

- Students of all ages find it difficult to distinguish between a theory and the evidence for it, or between description of evidence and interpretation of evidence (AAAS 1993).
- Young students often state that a theory involves knowing something about the situation, but they offer no further elaboration (Driver et al. 1996).
- Students often use *theory* to describe a prediction, as in "I have a theory about how that works," that is based on a guess rather than evidence (Driver et al. 1996).
- Middle school students have difficulty understanding the development of scientific knowledge through the interaction of theory and observation (AAAS 1993).
- Younger students tend to characterize testing as a simple process of observation with the outcomes being obvious, while older students seem to be more aware that testing may involve finding out about mechanisms or testing theories (Driver et al. 1996).
- Studies have indicated that students' understanding of evolution is related to their understanding of the nature of science, including understanding what constitutes a theory and their general reasoning abilities (AAAS 1993).
- Over the past two decades, there has been a considerable awareness and acceptance of the importance of developing an understanding of the nature of science among students and among teachers. Research shows that a deep, conceptual understand-

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ing of the nature of science has not been attained (Lederman et al. 2002), despite attempts to improve both students' and teachers' views of the nature of science.

Suggestions for Instruction and Assessment

- Teaching about the nature of science can get lost if it is embedded within regular science instruction (Crowther, Lederman, and Lederman 2005). Nature of science can be embedded within traditional content but should be explicitly and formally taught and assessed as a subject matter topic in much the same way that curricular topics such as life cycles, chemical reactions, or phases of the Moon are taught (Abd-El-Khalick, Bell, and Lederman 1998).
- Almost any science activity can be modified to explicitly teach some aspect of nature of science. An NSTA article by Lederman and Lederman (2004) provides an example of how a typical science activity, such as observing the stages of mitosis, can embed lessons on the nature of science.
- Use historical events to help middle and high school students develop an understanding of the nature of science and development of theories. *Atlas of Science Literacy,* Volume 2 (AAAS 2007), makes key curricular connections between the nature of science and the development of historical ideas, such as Copernican theory, theory of plate tectonics, Einstein's theory of relativity, and more.
- Make teaching the nature of science, including understanding what a theory is, an integral component of the middle school and high school science curriculum and a conscious, deliberate part of teaching. Do not assume students pick up these formal understandings of science automatically by engaging in inquiry-based activities. They should be explicitly taught and formally included in the science curriculum throughout the year, not just as the typical introductory chapter in a textbook.
- Today's students are tomorrow's teachers, parents, politicians, and world leaders. It is essential that today's students be explicitly guided to develop the skills and knowledge to distinguish scientific knowledge from religious, cultural, philosophical, or other beliefs that are not grounded in scientific evidence and can impact the way people address important questions and make informed decisions that affect their lives, society, and the natural world. Teachers should pay careful attention to developing the knowledge students need to hone their ability to distinguish science-based information from that which is not grounded in scientific thinking so that they can make informed decisions about matters that often end up in the public arena.
- A technique to help students maintain a consistent image of the nature of science throughout the year by paying more careful attention to the words they use is to create a "caution words" poster or bulletin board (Schwartz 2007). Important words that have specific meanings in science but are

often used inappropriately in the science classroom and through everyday language can be posted in the room as a reminder to pay careful attention to how students are using these words. For example, words like *hypothesis, theory,* and *law* can be included on the list.

- Activities with pattern cubes provide students with a common experience to develop an understanding of the nature of science and the appropriate language used to describe how science is conducted. Pattern cubes and a description of the activity are available online at *www.nap.edu/readingroom/books/evolution98/evol6-a.html.*
- Take the time during lessons to have discussions with students about the nature of science and encourage reflection on the way they view scientists, scientific knowledge, and scientific practices.
- There are several excellent, diagnostic questionnaires developed by Lederman et al. (2002) that can be used to find out students' views about the nature of science. An internet search can help you locate a source of these questionnaires.

Related NSTA Science Store Publications and NSTA Journal Articles

American Association for the Advancement of Science (AAAS). 1993. *Benchmarks for science literacy.* New York: Oxford University Press.

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Related Curriculum Topic Study Guide
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"The Nature of Scientific Thought and Development"

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