Doing Science

Four students were having a discussion about how scientists do their work. This is what they said:

Antoine: "I think scientists just try out different things until something works."

Tamara: "I think there is a definite set of steps all scientists follow called the scientific method."

Marcos: "I think scientists use different methods depending on their question."

Avery: "I think scientists use different methods but they all involve doing experiments."

Which student do you most agree with? ________________________

Explain why you agree with that student and include why you disagree with the other students.

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Doing Science

Teacher Notes

Purpose

The purpose of this assessment probe is to elicit students' ideas about scientific investigations. The probe is designed to find out if students recognize that scientists investigate the natural world in a variety of ways depending on the question they pose and that there is no fixed sequence of steps called the "scientific method" that all scientists use and follow rigidly.

Related Concepts

experiment, nature of science, scientific inquiry, scientific method

Explanation

The best answer is Marcos's: I think scientists use different methods depending on their question. Doing science is generally a logical, systematic process, unlike Antoine's response, which implies that the approach to science is random rather than methodical. Sometimes creative, divergent thinking and approaches have led to scientific discovery but they usually involve a systematic approach. Fundamentally, the various scientific disciplines are alike in their reliance on evidence, the use of hypotheses and theories when appropriate, the kinds of logic used, and more; however, scientists differ greatly from one another in what phenomena they investigate and in how they go about their work (AAAS 1988, p. 4). The scientific method correctly implies a methodical approach; however, Tamara's response implies that there is one method that includes a definite sequence of steps that all scientists follow. "There simply is no fixed set of steps that scientists always follow, no one path that leads them unerringly to scientific knowledge" (AAAS 1988, p. 4). Scientists move back and forth among processes and do not follow a recipe.

Experimentation is a process in which scientists control conditions in order to test their hypotheses. Unlike Avery's response, not all scientific investigations involve experiments. An experiment is a type of investigation that involves testing cause-and-effect relationships between variables—manipulated (independent) and responding (dependent). Astronomy, field studies in nature, and paleontology are some of the examples of areas of science in which it would be difficult or unfeasible to manipulate and control experimental conditions. In these types of investigations, scientists rely on a wide range of naturally occurring observations to make inferences about organisms, objects, events, or processes. For example, the link between smoking and lung cancer was actually established through correlational research designs as opposed to classic experiments.

Curricular and Instructional Considerations

Elementary Students

From their very first day in school, young students should be actively engaged in using science to investigate the world around them. They should be encouraged to ask questions about familiar phenomena and objects and to seek answers, collect things, count and measure things, make qualitative observations, organize collections and observations, and discuss findings in a systematic way. These early experiences with inquiry are precursors to understanding how science is done in a variety of ways and how it relies on gathering data to use for evidence. By directly experiencing a variety of ways that questions can be answered in science through simple investigations, students will begin to develop the idea that there is no one fixed way to go about answering scientific questions. However, this will only happen if students are asked to reflect on what they have done and instruction explicitly addresses the understandings of inquiry. At this level, students develop the notion of a "fair test" when designing experiments, but caution should be used at this early stage to not imply that all scientific investigations are experiments.

Middle School Students

By middle school, students should understand that science is guided by the question posed. The question and the particular content of the inquiry determine the method used to investigate. Caution is taken to ensure that students do not develop the idea that there is one "scientific method" that involves a prescribed set of linear steps that all scientists follow. At this level, students progress beyond the notion of a fair test to include a formal understanding of experimentation as a way of testing ideas that involves identifying and controlling variables. Often, the scientific method is taught and used in the context of doing experiments. However, at this grade level students need to experience and understand that science is systematically carried out in a variety of ways, including doing experiments, but not limited to that. Students should also become aware of how different domains of science use different methodologies (e.g., in astronomy, observations are made using remote technologies).

High School Students

In high school, students develop more sophisticated abilities and understandings of scientific inquiry. They are able to design and carry out more complex experiments as a way to systematically test their ideas. At this level, they should also engage in using a variety of other methods to investigate their questions, including field studies, observations of remote or microscopic phenomena using technology, modeling, specimen collections, and so on. This is the time when students should have opportunities to read and analyze peer-reviewed published scientific papers that show the variety of methodologies scientists use to do their work.

Administering the Probe

This probe is best used as is at the middle school and high school levels, particularly if students have been previously exposed to the term *scientific method* somewhere in their K–12 science education. However, the language of the probe can be modified as a simpler version for K–5 students. Be sure to emphasize that students should explain not only why they agree with the choice they selected from the four responses, but also why they did not select the other choices. The last selected response (Avery) can be expanded to include "…they all involve developing hypotheses and doing experiments."

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

K–4 Understandings About Scientific Inquiry

- ★ Scientists use different kinds of investigations depending on the questions they are trying to answer. Types of investigations include describing objects, events, and organisms; classifying them; and doing a fair test (experimenting).

5–8 Understandings About Scientific Inquiry

- ★ Different kinds of questions suggest different kinds of investigations. Some investigations involve observing and describing objects, organisms, or events; some involve collecting specimens; some involve experiments; some involve seeking more information; some involve discovery of new objects and phenomena; and some involve making models.
- Current scientific knowledge and understanding guide scientific investigations. Different scientific domains employ different methods, core theories, and standards to advance scientific knowledge and understanding.

5–8 The History and Nature of Science

- Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.

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

9–12 Understandings About Scientific Inquiry

- Scientists usually inquire about how physical, living, or designed systems function. Conceptual principles and knowledge guide scientific inquiries. Historical and current scientific knowledge influence the design and interpretation of investigations and the evaluation of proposed explanations made by other scientists.

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

K–2 Scientific Inquiry

- People can often learn about things around them by just observing those things carefully. Sometimes they can learn more by doing something to the things around them and noting what happens.

3–5 Scientific Inquiry

★ Scientific investigations may take many different forms, including observing what things are like or what is happening somewhere, collecting specimens for analysis, and doing experiments.

6–8 Scientific Inquiry

★ Scientists differ greatly in what phenomena they study and how they go about their work. Although there is no fixed set of steps that all scientists follow, scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence.

9–12 Scientific Inquiry

- Investigations are conducted for different reasons, including to explore new phenomena, to check on previous results, to test how well a theory predicts, and to compare different theories.

★ Sometimes scientists can control conditions in order to obtain evidence. When that is not possible for practical or ethical reasons, they try to observe as wide a range of natural occurrences as possible to be able to discern patterns.

Related Research

- The idea that there is a common series of steps that is followed by all scientists is likely to be the most common myth of science (McComas 1998).
- Students generally have difficulty with explaining how science is conducted because they have had little contact with real scientists. Their familiarity with doing science, even at older ages, is "school science," which is often not how science is generally conducted in the scientific community (Driver et al. 1996).
- Despite over 10 years of reform efforts in science education, research still shows that students typically have inadequate conceptions of what science is and what scientists do (Schwartz 2007).

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

Suggestions for Instruction and Assessment

- The scientific method is often the first topic students encounter when using textbooks, and this can erroneously imply that there is a rigid set of steps all scientists follow. Often the scientific method described in textbooks applies to experimentation, which is only one of many ways scientists conduct their work. Embedding explicit instruction of the various ways to do science in the actual investigations students do throughout the year as well as in their studies of investigations done by scientists is a better approach to understanding how science is done than starting off the year with the so-called scientific method in a way that is devoid of a context through which students can learn the content and process of science.
- Use caution when referring to the scientific method. It may be better to refer to *a* scientific method rather than *the* scientific method in order not to imply that there is one, fixed method.
- Be aware that even though scientists may refer to the term *scientific method,* they use this term to generalize the systematic process of doing science, not a rigid, fixed set of steps all scientists follow.
- Use caution when asking students to write lab reports that use the same format regardless of the type of investigation conducted. The format used in writing about an investigation may imply a rigid, fixed process or may erroneously misrepresent aspects of science, such as the idea that hypotheses are developed for every scientific investigation.
- Be careful how the word *experiment* is used. Students and some teachers use *experiment* as a general term for investigation rather than a specific type of investigation that involves variables or fair testing. Consistently remind students to consider, and explicitly point out, that all experiments are investigations but not all investigations are experiments.
- A technique to help students maintain a consistent image of science as inquiry 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 *experiment, hypothesis,* and *scientific method* can be posted as a caution to be careful in their use.
- Opportunities to experience a variety of ways science is conducted is not enough for students to develop deep understandings about inquiry. For students to understand that science can be carried out in a variety of ways, students need to be given time to reflect on what they have done. Like the nature of science, these understandings need to be explicitly addressed.

- Provide students with a variety of ways to investigate scientific questions, including experiments, field observations, modeling, collecting specimens, making remote observations, and so on. Point out how each has its own methodologies depending on the question being asked and the domain of study. For example, an astronomer cannot control conditions in space but can make observations using technology to help understand astronomical phenomena. Point out the similarities of the different ways to do science, including use of existing knowledge, an organized or systematic approach, and reliance on evidence.
- Use historical accounts and nonfiction readings from articles and books about scientists doing their work, such as *The Beak of the Finch* (Weiner 1994).
- Ensuring that students develop the abilities to carry out scientific inquiries is an important part of the standards. However, it is just as important for students to develop understandings of inquiry. Students can perform investigations yet not understand why they are done in a particular way.

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.

Keeley, P. 2005. *Science curriculum topic study: Bridging the gap between standards and practice.* Thousand Oaks, CA: Corwin Press.

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NSTA Position Statement on Scientific Inquiry. *www.nsta.org/about/positions/inquiry.aspx*

Schwartz, R. 2007. What's in a word? How word choice can develop (mis)conceptions about the nature of science. *Science Scope* 31 (2): 42–47.

Sullivan, M. 2006. *All in a day's work: Careers using science.* Arlington, VA: NSTA Press.

Watson, S., and L. James. 2004. Science sampler: The scientific method—is it still useful? *Science Scope* (Nov./Dec.): 37–39.

Related Curriculum Topic Study Guide

(Keeley 2005)

"Understandings About Scientific Inquiry"

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