What's in a Word?

How Word Choice Can Develop (Mis)conceptions About the Nature of Science

by Renee Schwartz

What do typical seventh-grade students think about science and what scientists do? As part of a study into this question, I asked a group of students, "When scientists are ready to report their results, what kind of information do you think they need in order to convince others that they have a good conclusion?" Some typical responses students gave:

> *"They go through the scientific method."*
> *"They need data to prove their investigation."*
> *"Data and no opinions."*

Despite over 10 years of reform efforts, research still shows that students typically have inadequate conceptions of what science is and what scientists do (McComas 2004; Lederman 2007). Many science students, as well as some teachers, use a single "scientific method" that, "proves a hypothesis" by systematic data collection. By following a prescribed set of steps, and writing up a report requiring these steps, many students blindly accept that their data provide "proof" for their conclusion. In your own science class, you have probably heard statements such as "The data is right because it proves that the answer is true." This kind of statement overlooks the value of evidence in supporting conclusions, where evidence is a product of data interpretation and not the raw data itself. Such statements present science as rigid and objective. This view does not acknowledge creativity, inference, or tentativeness as characteristics of science. It not only misrepresents the nature of science, but likely makes science inaccessible to many students. The techniques included here raise awareness of common terminology and the image of the nature of science in general.

Scientific habits of mind

The current emphasis in science education is on developing scientific habits of mind and understanding elements of science as a human endeavor (AAAS 1993; NRC 1996). Learners should understand that scientific knowledge is developed through a variety of approaches, and not one "scientific method." Scientific knowledge is developed through creative and inferential processes of collecting and making meaning from observations of the natural world. How the scientist chooses to investigate depends on the question being addressed. The knowledge that is developed, while being accepted as consistent and reliable with current scientific understanding and observations, is not set in stone. Science is subject to revision. Change may result from new observations and/or reinterpretation of existing information. A notable example is the recent debate about Pluto as a planet or an ice ball. Pluto itself has not changed, but scientists' interpretation of Pluto's characteristics has changed. Like the classification of Pluto, all science is subject to revision. Understanding how and why change can occur is a cornerstone to understanding the nature of science.

Source of misconceptions

Where do misconceptions about the nature of science and scientific inquiry come from? Why do they persist? Unfortunately, one source is indisputably the science classroom and the experiences, expectations, and messages students receive. Too often after the "Chapter One: Nature of Science" introduction, students do not hear anything further about this topic. Moreover, students' experiences can reinforce nature- of-science misconceptions. Consider the following excerpt from an article that aims to provide "helpful hints" to science-fair participants. In the article, the author explains each of the typical steps of the "scientific method" and concludes:

"…Finally, you'll want to draw a conclusion. Write down what was learned from the project. Did you find an answer to the hypothesis? Did you prove a statement to be true or false? Don't worry if the hypothesis turns out to be false; you still have learned something. The conclusion reflects the knowledge gained through the science-fair project" (Pettebone 2006).

What image of science do students get by following instructions that suggest they may have proven something true or false? This "helpful hint" is inconsistent with the nature of science. Consider this excerpt from the introduction of a student science-fair report found online through the National Student Research Center (1999):

"These experiments are a continuation of previous research which I've done over the past four years. In these experiments, I set out to prove that there was a correlation between heat and water movement through soils… Each year I've improved my methods and proved my hypotheses…In order to strengthen my results, I must prove three questions" (the student then lists the questions).

Like the quotes earlier, the image of science portrayed here is one of absolute truths obtained through objectively following "the steps." If the "scientific" language students hear, read, and are encouraged to say and write counters the nature of science, we need to make a change in the language of the science classroom. Word choice can (mis)represent nature of science.

Introducing nature-of-science concepts and terminology

There are many strategies and resources available to teachers to introduce the nature of science (see Lederman and Abd-El-Khalcik 1998; NAS 1998; McComas 2004). I begin my biology class with several introductory activities shown to be effective for K–12 children. Many of these are black box investigations where students make observations of a hidden object and its behavior and then make inferences as to its unseen features. These lessons provide common experiences and vocabulary that we revisit during the other biology lessons.

On one of the first days of the semester, I use a set of pattern cubes (see Resources for activity) to teach about the differences among observation and inference, creativity, and subjectivity, as well as raw data and evidence. Each group of four students gets a cube made from the template provided on the website. The cube is made of paper that is folded together and taped. It has a three-letter word on each visible side, but the bottom face remains hidden. Students work together to make observations (e.g., there are six sides; there are words on each visible side; the words are *mat* (top face), *cat*, *bat*, *fat*, and *hat*). Through analysis of the words, they identify patterns and make inferences about what they think is on the unseen bottom face. As a class, students share what they think is on the bottom face and explain why *(What is your evidence?)*. They cannot just restate the observed words on the faces. They also have to say if there are other possible answers. For example, the cube used here yields several different patterns and possible answers, such as words are

FIGURE 1 Dead words and alternatives

Dead words	Alternative words	Examples from students
Proof	Support/evidence	Example: "We proved that plants grown in topsoil grow taller than plants grown in clay. Our data proved our hypothesis was right. The topsoil plant grew 30.5 cm (12") and the clay plant grew 12.7 cm (5")." Alternative: "Our conclusion is that the plants grow taller in topsoil than they do in clay. The evidence that supports this conclusion is that the plants grown in the topsoil grew 18 cm (7") taller than those grown in clay." Example: "The purpose of the experiment was to prove the cause of the phases of the Moon. Our answer is correct because the data prove it." Alternative: "The purpose of the investigation was to gather data to answer the question of "What causes the phases of the Moon?"
Prove	Support/provide evidence	
Proving (any other iteration of proof or prove)	Supporting	
Truth/true	Valid/supported/evidence-based	
Right/wrong answer (when making or discussing a conclusion to an investigation)	Valid/supported/evidence-based	
Correct answer (when making or discussing a conclusion to an investigation)	Valid/supported/evidence-based	

three letters; beginning letters follow alphabetical order of real English words; words rhyme, and so on. The class then discusses different patterns and weighs alternatives.

Sometime during this discussion I ask, "Do you know for sure what is on the bottom face?" There is a resounding "no," to which I respond with, "Could you ever prove 100% what the pattern is?" Students think about this and respond, "By looking at the bottom face we could prove what it is." This exchange is typical, and provides an opportunity to talk about the tentative nature of science and to distinguish between data and evidence. I do this by asking, "Even if you can directly see the bottom face and know what is there, you've made another observation, but do you know for sure what the pattern is that explains the observation?" The answer is "no" because there still may be more than one pattern that explains the data. Plus, somewhere in the future we might find another pattern cube and notice something different. The pattern they infer now may have to change with additional observations. Because we can never gather all the data for all time, we can never have 100% proof of any claim in science. In the case of the pattern cubes, the inferred word on the bottom face is supported with the inferred pattern from the available data. The data (words on faces) were analyzed to infer a pattern (evidence), which is used to support a claim (word on bottom face).

To conclude the activity, I do not always show the bottom face of the cubes. By showing students the bottom face, all thinking screeches to a halt. They revert to an "I got the right answer" mode and forget the process.

FIGURE 2 Rephrasing science questions

Questions that misrepresent the nature of science	Misconception	Alternative questions to better represent the nature of science
Did you prove your hypothesis?	Science finds absolute answers	Were you able to support your hypothesis?
How do you know your hypothesis is true?	Science finds absolute answers	What evidence do you have that supports your hypothesis?
What proof do scientists have that prove they are right?	Science finds absolute answers	What evidence do scientists use to support their conclusions?
Where is your proof?	Science finds absolute answers	What is your evidence?
How did you use the scientific method in your investigation?	All science investigations require the use of the scientific method	What was your question and how did you do your investigation to answer that question? Follow-up questions: Did you do an experiment or another kind of scientific investigation? Why? (This asks students to think about how the questions they ask influence the type of investigation they do. Not all questions are to be answered through typical experiments.)

Students initially get frustrated with not knowing for sure what is on the bottom, but by not showing them, they have to rely on the available information to justify their inference. Through careful questioning, students begin to understand the value of evidence and the role of inference in science. Some useful questions:

- What would happen to your thinking if I showed you the bottom of the cube? (Students are quick to state, "We'd know if we were right or not.")
- Do scientists have an answer book?
- How do scientists know if they have come up with good explanations from their observations?
- What are some situations where scientists cannot directly see what has happened, or is happening? (After some thought and probing, students begin to realize that there are many familiar examples, such as space exploration and Earth systems. For example, scientists cannot go to the center of the Earth, yet they develop a model of what is there based on other observations.)

Through this type of facilitated discussion, we examine the important role of inference based on observations. This is an important discussion because students have a tendency to swing their ideas toward anything goes if scientists cannot observe something directly. However, it is important to guide students to understand that not all answers are equally acceptable. For example, with the cubes, not just any prediction of what is on the bottom face can be justified. You might suggest some strange made-up word and ask students if they think such an idea is as good as the others. This discussion should challenge students to think about why science involves observations and inferences, how it can potentially change, and why data are different from evidence.

Dead words

A helpful technique for expecting and maintaining a consistent image of the nature of science is through the use of dead words. During the introductory activities students invariably use phrases such as "we proved our theory" or "our pattern proves that." After we go through some examples and have the discussion about there not being any 100% proof in science, I introduce dead words to the class. We create a list of words we are not allowed to use in our science classroom because they misrepresent the nature of science (Figure 1). A poster displayed in the room is an effective reminder of these words. They are dead in that they are gone from our vocabulary and no longer available for our use in science class. I had heard of a middle school language-arts teacher who used this technique to expand students' vocabulary beyond slang and poor descriptors. The approach has the same effect in science class, only we eliminate words that misrepresent the nature of science.

The list applies to teachers as well as students. To help students connect evidence to their conclusions, teachers should ask questions that require students to be explicit about why and how they came to their conclusions. The way in which questions are phrased can produce an image of science. Careful word choice can turn a poor question into a powerful one. Figure 2 presents typical questions that misrepresent the tentative nature of science by reinforcing the idea that science finds absolute answers and students should find the right answer or they have failed.

Caution words

Some important words have specific meanings in science, but are often used inappropriately and can reinforce misconceptions. Because of their prominence within science they cannot be dead words, but teachers and students should be aware of how they are using the words. Are they using them in a way that is consistent with their meaning and with the nature of science? Several examples of caution words follow.

Experiment vs. investigation

Experiment in science is an investigation that involves variables (independent and dependent) and establishes cause-and-effect relationships. The investigation with testing plant growth in different soil types is an example of an *experiment.* The experimental approach is the classic scientific method. Despite this specific meaning, experiment is often used in a general way to mean any activity in science, regardless of the procedure or purpose. The consequence is that the scientific method is reinforced as the only way of doing science. Consider the following example: A seventh-grade class is studying food webs. They walk around the school grounds and identify as many types of living organisms as they can. They record their observations. Upon return to the classroom, the teacher states, "Now take a look at the data from our experiment and draw a food web."

Did the class do an experiment? Did they identify independent and dependent variables? Was a hypothesis necessary? Obviously the answer is no. The use of *experiment* in this context misrepresents what students did. Their activity is similar to what many scientists do; that is, study the natural world, without interference or manipulation. This is valid science, but not an experiment. In this case, the teacher would better represent the student activity by using the more general term *investigation* and referring to clear questions that drive the investigation, such as "What living things are in our schoolyard? How can we show connections among them with a food web?"

Hypothesis, theory, and law

A commonly misunderstood concept in science is the relationship among *hypothesis*, *scientific theory*, and *scientific law* (NAS 1998). People generally see a hierarchical relationship, where hypotheses become theories that become laws, after much testing. This relationship is a misrepresentation, and one perpetuated by misuse of terminology. *Hypothesis* is a statement that answers a posed question. For example, if the question is, "Why does a basketball go flat when used outdoors in the winter?" a student may pose the hypothesis, "The ball goes flat outside in the winter because it is cold outside." The hypothesis is not a prediction, but it may lead to a prediction, such as, "If I take the ball back inside where it is warmer, the ball will bounce higher." This student can then test this prediction. The investigation can lead to study of difference in air pressure with change in temperature. These types of statements involving hypotheses guide some types of investigations. Be mindful that not all types of investigations lend themselves to hypothesis testing. For example, a study of flower anatomy ("What types of structures does a flower have?") would not be guided by a specific hypothesis, nor would this be an experiment. Asking students to state a hypothesis when one is not appropriate misrepresents the nature of scientific inquiry.

A scientific theory is a well-established explanation for how or why a phenomenon happens. For the basketball example, kinetic molecular theory helps explain why increasing air temperature increases the bounce of a basketball. With the gain in temperature, the increased movement of air particles results in more hits against the inside of the basketball, resulting in increased pressure. Kinetic molecular theory provides an explanation for what is observed. A scientific law in this case is the ideal gas law, Pv = nRT. This law describes the relationship among the observable variables of temperature, volume, and pressure. The law describes *what*. The theory explains *why*.

Take caution when using the words *theory* and *hypothesis*. They are often inappropriately used interchangeably. This minimizes the power of scientific theory as a well-supported explanatory concept, tested and accepted by the scientific community. Stating, for example, that natural selection is just a theory misrepresents the theory by misrepresenting the nature of science.

Data vs. evidence

"Science requires evidence. We need to collect evidence." Although this statement reinforces the need for evidence in science, it also misrepresents the nature of evidence. Typical misconceptions students hold about data and evidence include the following:

- Data are numbers only.
- Evidence is tangible, not numbers.
- Data and evidence are the same thing.
- Data are the answer.
- Scientists collect evidence (as opposed to data or observations).
- Evidence and data are proof.

Evidence is a product of data interpretation, not the data itself. For example, during the experiment comparing plant growth in different soils, students would take measurements of plant height over several weeks. This is their *data*. They examine the data to answer their question "Does this type of plant grow taller in topsoil or clay?" Students typically calculate the differences between the average plant heights over time, and conclude that the ones grown in topsoil grow taller than the ones in clay. The raw data are not the evidence, but the difference between the heights is. So, data are the observations; evidence is the support that justifies a conclusion.

Asking why

Like the seventh-grade students in the language-arts class, science students quickly catch on to dead words and caution words. They not only challenge each other to use the appropriate words, they do not hesitate to point out teacher mistakes also. I sometimes ask "What's your proof?" on purpose, just to see how many students gasp. I then ask what the problem is. The dead-word technique is more effective when students are required to explain why the words misrepresent the nature of science and give examples from their own experiences that demonstrate a more authentic image of the nature of science. ■

References

American Association for the Advancement of Science (AAAS). 1993. *Benchmarks for science literacy: A Project 2061 report*. New York: Oxford University Press.

Lederman, N. 2007. Nature of science: Past, present, and future. In *Handbook of research on science education*, eds. S. Abell and N. Lederman. Mahwah, NJ: Lawrence Erlbaum Associates.

Lederman, N., and F. Abd-El-Khalick. 1998. Avoiding denatured science: Activities that promote understanding of the nature of science. In *The nature of science in science education: Rationales and strategies*, ed. W. McComas, 83–12. Dordrecht, The Netherlands: Kluwer Academic Publishers.

McComas, W. 2004. Keys to teaching the nature of science. *The Science Teacher* 71 (9): 24–27.

National Academy of Science (NAS). 1998. *Teaching evolution and the nature of science*. Washington, DC: National Academy Press.

National Research Council (NRC). 1996. *National science education standards*. Washington, DC: National Academy Press.

National Student Research Center. 1999. *Student research reports* 7 (6). Available online at *www.youth.net/nsrc/sci/sci049.html.*

Pettebone, D. 2006. *Catalogs.com, careers & education*. Available online at *www.catalogs.com/info/education/ideas-for-middle-school-science-fair-projects.html*.

Resource

Pattern cube activity—*www.nap.edu/readingroom/books/evolution98/evol6-a.html*

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