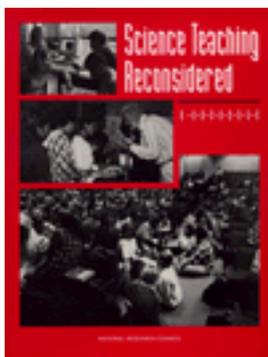


Science Teaching Reconsidered: A Handbook



Committee on Undergraduate Science Education,
National Research Council

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Misconceptions as Barriers to Understanding Science

- The role of misconceptions in the learning process
- Descriptions and examples of some common misconceptions in science
- Methods to identify misconceptions
- Methods to break down misconceptions

Teachers can be astonished to learn that despite their best efforts, students do not grasp fundamental ideas covered in class. Even some of the best students give the right answers but are only using correctly memorized words. When questioned more closely, these students reveal their failure to understand fully the underlying concepts. Students are often able to use algorithms to solve numerical problems without completely understanding the underlying scientific concept. Mazur (1996) reports that students in his physics class had memorized equations and problem-solving skills, but performed poorly on tests of conceptual understanding. Nakhleh and Mitchell (1993) studied sixty students in an introductory course for chemistry majors. In an exam which paired an algorithmic problem with a conceptual question on the same topic, only 49% of those students classified as having high algorithmic ability were able to answer the parallel conceptual question.

Besides offering students information and helpful examples, we must show them the reasoning processes that lead to algorithms and conceptual generalizations. Inclusion of conceptual questions on tests is another way to emphasize the importance of this aspect of problem solving (see Chapter 6). In many cases students have developed partially correct ideas that can be used as the foundation for further learning (Clement et al., 1989). However, many students have not developed an appropriate understanding of fundamental concepts from the beginning of their studies, and this shortcoming can interfere with subsequent learning.

TYPES OF MISCONCEPTIONS

A familiar example from elementary school is students' understanding of the relationship between the earth and the sun. While growing up, children are told by adults that the "sun is rising and setting," giving them an

image of a sun that moves about the earth. In school, students are told by teachers (years after they have already formed their own mental model of how things work) that the earth rotates. Students are then faced with the difficult task of deleting a mental image that makes sense to them, based on their own observations, and replacing it with a model that is not as intuitively acceptable. This task is not trivial, for students must undo a whole mental framework of knowledge that they have used to understand the world.

The example of the earth rotating rather than the sun orbiting the earth is one of many that teachers refer to collectively as misconceptions. Misconceptions can be categorized as follows:

- *Preconceived notions* are popular conceptions rooted in everyday experiences. For example, many people believe that water flowing underground must flow in streams because the water they see at the earth's surface flows in streams. Preconceived notions plague students' views of heat, energy, and gravity (Brown and Clement, 1991), among others.
- *Nonscientific beliefs* include views learned by students from sources other than scientific education, such as religious or mythical teachings. For example, some students have learned through religious instruction about an abbreviated history of the earth and its life forms. The disparity between this widely held belief and the scientific evidence for a far more extended pre-history has led to considerable controversy in the teaching of science.
- *Conceptual misunderstandings* arise when students are taught scientific information in a way that does not provoke them to confront paradoxes and conflicts resulting from their own preconceived notions and nonscientific beliefs. To deal with their confusion, students construct faulty models that usually are so weak that the students themselves are insecure about the concepts.
- *Vernacular misconceptions* arise from the use of words that mean one thing in everyday life and another in a scientific context (e.g., "work"). A geology professor noted that students have difficulty with the idea that glaciers retreat, because they picture the glacier stopping, turning around, and moving in the opposite direction. Substitution of the word "melt" for "retreat" helps reinforce the correct interpretation that the front end of the glacier simply melts faster than the ice advances.
- *Factual misconceptions* are falsities often learned at an early age and retained unchallenged into adulthood. If you think about it, the idea that "lightning never strikes twice in the same place" is clearly nonsense, but that notion may be buried somewhere in your belief system. (See the sidebar for another example.)

HOW TO BREAK DOWN MISCONCEPTIONS

Although vernacular and factual misconceptions can often be easily corrected, even by the students themselves, it is not effective for a teacher simply to insist that the learner dismiss preconceived notions and ingrained nonscientific beliefs. Recent research on students' conceptual misunderstandings of natural phenomena indicates that new concepts cannot be learned if alternative models that explain a phenomenon already exist in the learner's mind. Although scientists commonly view such erroneous models with dis-

tain, they are often preferred by the learner because they seem more reasonable and perhaps are more useful for the learner's purpose (Mayer, 1987). These beliefs can persist as lingering suspicions in a student's mind and can hinder further learning (McDermott, 1991).

Before embracing the concepts held to be correct by the scientific community, students must confront their own beliefs along with their associated paradoxes and limitations and then attempt to reconstruct the knowledge necessary to understand the scientific model being presented. This process requires that the teacher:

- Identify students' misconceptions.
- Provide a forum for students to confront their misconceptions.
- Help students reconstruct and internalize their knowledge, based on scientific models.

These steps are discussed throughout the remainder of this chapter.

Identifying Misconceptions

Before misconceptions can be corrected, they need to be identified. Many researchers and teachers have compiled lists of commonly encountered misconceptions (see sidebar at the end of the chapter). A number of professional societies have developed conceptual tests which allow you to

identify students' misconceptions; we urge you to consult the organizations in Appendix B for more information. Additionally, small group discussions and office hours provide effective forums for identifying student misconceptions. With practice and effort, a teacher can learn to probe a student's conceptual framework (often by simply listening) without resorting to authority or embarrassing the student. Mazur has found a way to help students check their conceptual frameworks even within the large lecture format (see the sidebar in Chapter 3). Hake (1992) has used introductory laboratory exercises to help students test their conceptual bases for understanding motion. Essay assignments that ask students to explain their reasoning are useful for detecting students' misconceptions. These essays and discussions need not be used for grading, but rather can be used as part of the learning process to find out what and how your students are thinking.

Misconceptions can occur in students' understanding of scientific methods as well as in their organization of scientific knowledge. For example, students in a science class will often express disappointment that an experiment did not work. They do not fully understand that experiments are a means of testing ideas and hypotheses, not of arriving at an expected result. To the scientist, an experiment yields a result which needs to be interpreted. In that sense, each experiment "works," but it may not work as expected.

Helping Students Confront Their Misconceptions

It is useful to review and think about possible misconceptions before teaching a class or laboratory in which new ma-

Example of a Factual Misconception

A grade-school geography teacher once informed my whole class that the Gulf Stream is simply and entirely the Mississippi River, floating across the surface of the salty Atlantic all the way to Norway. I duly learned that, and never thought about it again. It sat unexamined and unchallenged in my head for several decades, until the subject arose in a discussion with colleagues, and up it came like some weird deep-sea fish; I had only to mention it to be roundly hooted (by myself as well after giving it a half-second's thought). I was impressed by the clarity and circumstantial detail with which that fragile "unfact" was preserved for decades in my head; I bet there are others, and I bet we all have them. There may be families of them, lurking like coelacanths in the collective depths. I know there are twenty or thirty of us out there who either have dredged up and exploded the Gulf Stream heresy, or are still carrying it around intact (Blackburn, 1995).

material is introduced. Use questions and discussion to probe for additional misconceptions. Students will often surprise you with the variety of their preconceptions, so be careful to listen closely to their answers and explanations. You can help students by asking them to give evidence to support their explanations and by revisiting difficult or misunderstood concepts after a few days or weeks. Misconceptions are often deeply held, largely unexplained, and sometimes strongly defended. To be effective, a science teacher should not underestimate the importance and the persistence of these barriers to true understanding. Confronting them is difficult for the student and the teacher.

Example of a Conceptual Misunderstanding

Students were asked to sketch the air in a sealed flask initially and after half of the air was removed. In this study, fifteen percent of college chemistry students sketched the second flask with regions containing air and other regions containing empty space (Benson et al., 1993).

Some misconceptions can be uncovered by asking students to sketch or describe some object or phenomenon. For example, one might ask students to sketch an atom before doing so on the board. Even students who have a strong high school background might show a small nucleus surrounded by many electrons circling in discrete orbital paths, much like the solar system. By asking them to draw their own model first and then asking some students to share their answers with the class, a teacher can identify preexisting models and use them to show the need for new models.

Helping Students Overcome Their Misconceptions

Strategies for helping students to overcome their misconceptions are based on research about how we learn (Arons, 1990; Minstrell, 1989). The key to success is ensuring that students are constructing or reconstructing a correct framework for their new knowledge. One way of establishing this framework is to have students create "concept maps," an approach pioneered by Novak and Gowin (1984). With this technique, students learn to visualize a group of concepts and their interrelationships. Boxes containing nouns (and sometimes adjectives) are connected to related terms with a series of lines; prepositions or verbs are superimposed on the connecting lines to help clarify the relationship. A sample concept map is shown in

Figure 4.1 While some studies indicate that concept maps do not enhance meaningful learning in biology (Lehman et al., 1985), others have obtained the opposite result (Okebukola and Jegede, 1988). Esiobu and Soyibo (1995) reported that students constructing concept maps in cooperative groups show a greater increase in conceptual learning than students working individually, thus the utility of concept mapping may depend on the instructional setting. Similar results were obtained by Basili and Sanford (1991), who found that cooperative group work on concept-focused tasks had a significant effect in helping college students overcome certain misconceptions in chemistry, even though it did not involve concept maps.

Helping students to reconstruct their conceptual framework is a difficult task, and it necessarily takes time away from other activities in a science course. However, if you decide to make the effort to help students overcome their misconceptions you might try the following methods:

Using Demonstrations to Help Students Overcome Misconceptions

Carefully selected demonstrations are one way of helping students overcome misconceptions, and there are a variety of resources available (Katz, 1991). In the example of a conceptual misunderstanding about gas volume cited in an earlier sidebar, the authors suggest that a demonstration using a colored gas could be very effective in showing students that the gas fills its container.

- Anticipate the most common misconceptions about the material and be alert for others.
- Encourage students to test their conceptual frameworks in discussion with other students and by thinking about the evidence and possible tests.
- Think about how to address common misconceptions with demonstrations and lab work.
- Revisit common misconceptions as often as you can.
- Assess and reassess the validity of student concepts.

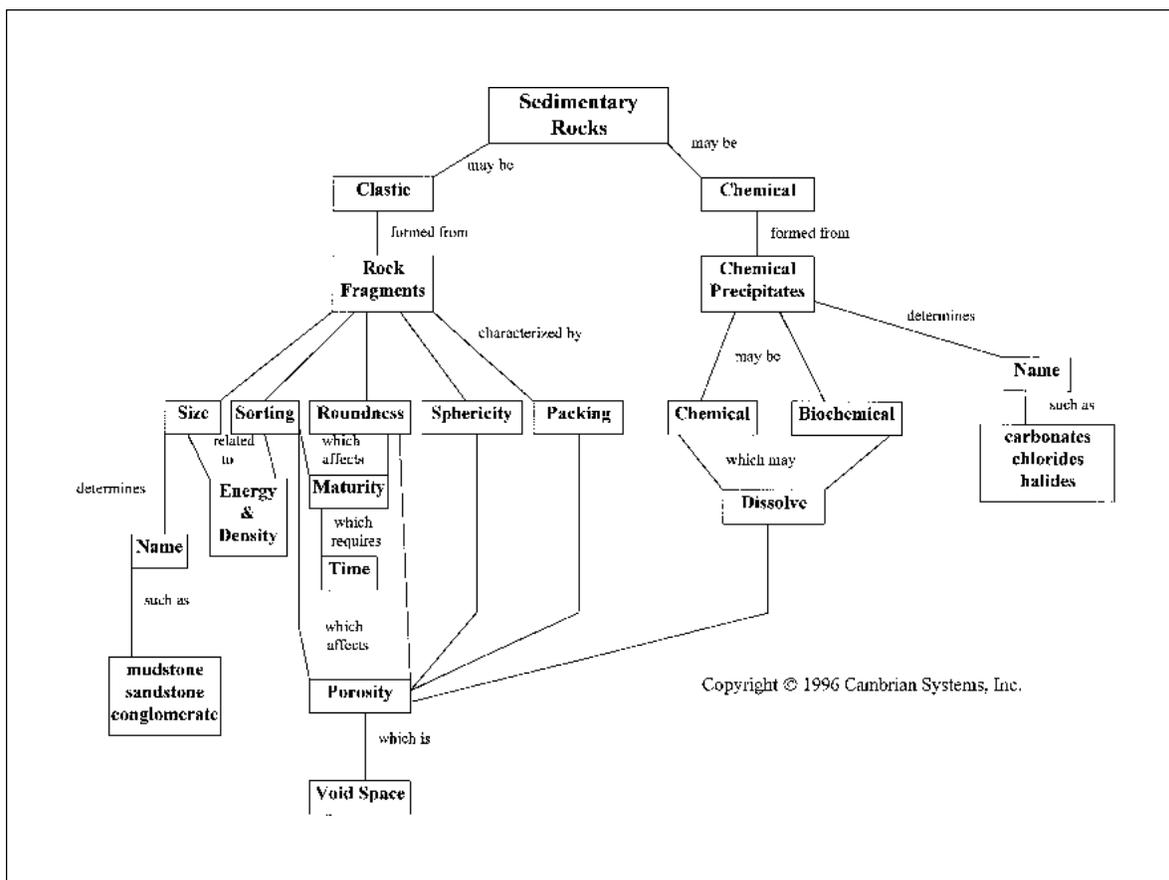


Figure 4.1. Sample concept map

Selected Resources on Misconceptions

This list is not intended to be comprehensive, but instead aims to provide a starting point for those seeking additional reading on this topic.

Cho, H., J. B. Kahle, and F. H. Nordland. 1985. An investigation of high school biology textbooks as sources of misconceptions and difficulties in genetics and some suggestions for teaching genetics. *Sci. Educ.* 69(5):707-719.

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Zoller, U. 1990. Students' misunderstandings and misconceptions in college freshman chemistry. *J. Res. Sci. Teaching*. 27(10):1053-1065.

A bibliography of some 3,500 published items called *Students' Alternative Frameworks in Science* is available on-line in two parts (introduction and database) and can be downloaded anonymously from an FTP server.

host: topgun.idbsu.edu

user id: anonymous

password: your e-mail address

directory: physlrr

Download files "plr11" (the intro, about 25 KB) and "plr12" (the database, about 700 KB). There are two versions of each, one in Word 5.1 for Mac suffixed "mac.bin" and another for pc in Word for Windows 2.0 suffixed "pc.doc."

Dykstra, D. I., Jr. 1995. From email discussion list posted to cur-l@listserv.ncsu.edu on Feb. 15, 1995, subject Scientific misunderstandings, by David Houseman. The archive for this list is located at listserv@ncsu.edu.
