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-
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dain, they are often preferred by the learner because they seem more rea-
sonable 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 com-
munity, 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 encoun-
tered 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 stu-
dents test their conceptual bases for understanding motion.
Essay assignments that ask students to explain their reasoning
are useful for detecting students’ misconceptions. These es-
says 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 of-
ten 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 misconcep-
tions 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 Missis-
sippi 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 unchal-

lenged 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 circum-
stantial 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 in-
tact (Blackburn, 1995).

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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.

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:
- 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.


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: physlrnr

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.