



From Misconceptions to Conceptual Change

*Tips for identifying and
overcoming students'
misconceptions*

————— **Julia Gooding and Bill Metz** —————

We all have misconceptions about the world in which we live—how it works, how we interact with it, how it changes, and the reasons behind those changes. These misunderstandings are personal notions we create to make meaning of our surroundings. Often, these misunderstandings go unchallenged for a lifetime. This article addresses how these inaccuracies can occur, what historic missteps may contribute, and which strategies teachers can use to help students move toward conceptual change.

About misconceptions

Throughout our lives, we are inundated with information. Some of it sticks with us; some does not. When we try to understand that information, misconceptions can occur. This may be because humans are pattern makers and pattern seekers—particularly when we answer questions and resolve issues. Much of this has to do with how our brains work.

Wesson (2001, p. 61) explains, “When information arrives in the cerebral cortex for analysis, the brain attempts to match each component with previously stored memory elements on the existing neural network with similar traits.” Simply put, the brain files new data by making connections to existing information. If this new information does not fit the learner’s established pattern of thinking, it is refashioned to fit the existing pattern.

This is when misconceptions are unknowingly created and reinforced—the learner builds explanations, unravels problems, and files new data based on faulty reasoning. The resulting misconceptions can be compounded by linkages to other misunderstandings or inaccuracies—thus perpetuating the cycle.

The longer a misconception remains unchallenged, the more likely it is to become entrenched. According to Wesson (2001, p. 62), “Repeating an activity among the same combination of neurons strengthens their connections...whether [it does] so accurately, prematurely, or even erroneously.” In general, brain connections are strengthened when revisited or rehearsed, so each false practice fortifies the misconception—making it even more resistant to change.

In the documentary *A Private Universe* (Sadler, Schneps, and Woll 1987), Matthew Schneps and Philip Sadler investigate two common misconceptions. In 1986, they interviewed Harvard University graduates, their professors, and several middle school students about the causes of the seasons and the phases of the moon. They found that both the Harvard graduates and the middle school students held false beliefs about these concepts—misconceptions that, regardless of their time in school, remained deeply embedded in their brains.

After being retaught the concepts, only some demonstrated a better understanding, and many retained some of their misguided beliefs. Some even reverted back to their original misconceptions, demonstrating that once information is learned—whether correctly or incorrectly—it is difficult to edit or delete.

The blame game

The National Research Council (NRC) (1997) presents five types of misconceptions that can interfere with learning:

1. preconceived notions,
2. nonscientific beliefs,
3. conceptual misunderstandings,
4. vernacular misconceptions, and
5. factual misconceptions.

Parents, folklore, teachers, multimedia, and even learners themselves are responsible for cultivating and fostering misconceptions. Despite our best efforts, students continue to craft their own versions of reality.

Science curricula and textbooks are also responsible for perpetuating misconceptions. Some contain blatantly false information. Walton (2002) presents two examples: a discussion of sound that says humans cannot hear below 400 Hz and a description of the “bronze outer structure” of the Statue of Liberty. Both of these are incorrect—47 notes on a piano are below 400 Hz, and the Statue of Liberty is made of copper.

Our personal experiences with commercial publications have repeatedly revealed this phenomenon, as well. For example, textbooks sometimes represent the phases of the moon incorrectly or in a way that is difficult for students to understand. Others suggest that photosynthesis occurs in plants by day and that respiration occurs at night. If plants only respired by night, they would die. A few even describe water as a good conductor of electricity—when this is not the case.

Another concern is the introduction of concepts without regard to student readiness or current research on brain development and function. Lowery (2008) contends that the organization of most curricula and the teaching design of most commercial textbooks do not match learners’ thinking capacity. Topics are often introduced when students are not developmentally or psychologically ready to learn them. For example, elementary-age children cannot fully understand the relative positions and motions of the Earth-Sun system responsible for Earth’s seasonal changes (see the article on p. 52), or the inter-relatedness of the biotic and abiotic factors of an ecosystem. This issue is further complicated by school district science curricula that are based, partly or entirely, on other erroneous documents, instead of on research and best practice.

Beyond textbooks, adults, too, harbor misconceptions, including many well-meaning teachers who unknowingly pass these inaccuracies on to students—misinformation that may never be caught, challenged, or changed. For example, requiring students to follow “the scientific method” often creates more misconceptions than it dispels (Donovan and Bransford 2005; NRC 1996). Another personal favorite is the idea that hypotheses become theories, which become laws (McComas 1996). In fact, there are many different approaches to scientific inquiry, and *theories* (i.e., thoroughly tested, well-accepted explanations of natural phenomena) and *laws* (i.e.,

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FIGURE 1

Common science misconceptions.

Adapted in part from New York Science Teacher 2010.

1. Objects float in water because they are lighter than water.
2. The bubbles in boiling water contain “air,” “oxygen,” or “nothing,” rather than water vapor.
3. The Moon does not rotate on its axis as it revolves around Earth.
4. The phases of the Moon are caused by shadows cast on its surface by other objects in the solar system.
5. Seasons are caused by the Earth’s distance from the Sun.
6. Evolution is only a theory because it has not been proved.
7. Dinosaurs, humans, and cavemen lived at the same time.
8. Humans are responsible for the dinosaurs’ extinction.
9. The terms *energy* and *force* have the same meaning.
10. Batteries have electricity inside them.

summaries of generally observed behavior) represent two different types of scientific knowledge.

Conceptual change

With so many misconceptions out there, how do we begin to re-educate students and work toward conceptual change? Fraser (1995) likens this to an impossible quest:

I find teaching of science fairly easy. I have no difficulties with science education; my difficulties are with science re-education. If I can teach something about which the students have never heard, I find that they generally both welcome and understand it. It is when I have to teach them about something that they have already learned incorrectly that I start to identify with Sisyphus.

The NRC (1997) suggests that to break down students’ misconceptions, teachers must first identify those misconceptions, provide a forum for students to confront them, and then help students reconstruct and internalize their knowledge, based on scientific models. Figure 1 provides a list of students’ common misconceptions, and Figure 2 lists suggestions for teachers who want to help students overcome them. There are many resources available to help teachers identify common misconceptions among students, including books, journals, and websites, such as Bad Science and Children’s Misconceptions About Science (see “On the web”).

Though many common science misconceptions have been identified (Figure 1), this is only the first step. We must also identify each student’s misconceptions. Each student is an individual learner, with individual misunderstandings. By listening carefully to our students’ responses, analyzing them, seeking clarification, and demanding explanations and discussions, we can determine whether their understanding of the content is superficial or deep.

We must also understand how students put pieces of information together to facilitate their learning and encourage student discourse, individual reflection, metacognition, and acceptance of alternatives. It is essential to find out how students are processing information. To help students identify their own misconceptions, we (Gooding and Metz 2008) suggest the following strategies:

- ◆ Call for clarification (ask students to further explain, rephrase, illustrate, or demonstrate)
- ◆ Call for evidence (seek substantiation for student claims)
- ◆ Call for evaluation (ask students to speculate beyond the collected data)
- ◆ Wait time I and wait time II (nonverbal tactics that allow students to extend their responses and encourage student-to-student discussion)
- ◆ Play devil’s advocate (provide opportunities for students to present and defend their data-based decisions)
- ◆ Do not seek the “right answer” (maintain an open mind about alternative solutions and procedures)

Though these strategies sound easy, there is more to them than meets the eye. Too often, clarification strategies are overshadowed by the zeal to get to the “right answer.” We dismiss incorrect student input as simply that, instead of seeing it as an opportunity for conceptual change. To compound matters, correcting an incorrect student response does not always make things right. Learners construct their own explanations, and do not always take in new information if

FIGURE 2

Tips for overcoming student misconceptions (NRC 1997, p. 31).

1. Anticipate the most common misconceptions about the materials and be alert for others.
2. Encourage students to test their conceptual frameworks by discussing with other students and thinking about the evidence and possible tests.
3. Think about how to address common misconceptions with demonstrations and lab work.
4. Revisit common misconceptions as often as you can.
5. Assess and reassess the validity of student concepts.

it does not fit their established pattern of thinking. Students may only process selected bits and pieces, refashioning the information to fit this pattern.

Not a simple fix

Teachers should focus not just on repairing that which is already broken, but also on preventative measures to help students avoid misconceptions in the first place. According to Abiko (2002): Brain science research, common experiences of teachers, and other psychological data substantiate the existence of developmental stages. Therefore, one way to help students avoid misconceptions is to make sure district curricula are developmentally appropriate (Figure 3). Abiko (2002, p. 169) suggests that “the high school level...place less emphasis on a common curriculum and offer electives that are deep in focus, narrow in scope, long term, fewer in number, and ‘heavy’ in content.”

Misconceptions can be corrected, but since they are individualized paradigms, they must be corrected by their owners. A once-misunderstood concept must be revisited and finally recognized as a discrepancy—and the observer must be developmentally and conceptually able to make proper meaning of the event. These epiphanies, or “ah-ha” moments, occur in each of us when the conditions are right.

We must provide our students with such opportunities for conceptual change. These may take the form of discrepant events, inquiry-based activities, or other minds-on experiences, and should help students reconstruct and internalize their knowledge. Again, metacognition plays a significant role. If students are thinking about *why* they have a particular understanding and reflecting on those thoughts, they may recognize a discrepancy, and reach a new and better scientific understanding based on the evidence presented.

A Private Universe concludes with the following poignant statement:

Every time we communicate, new concepts compete with preconceived ideas...All students hold these ideas, but are unaware of their private theories. We must make them aware. Only then can we enable them to learn, and free them from their private universe. (Sadler, Schneps, and Woll 1987) ■

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On the web

Bad Science: www.ems.psu.edu/~fraser/BadScience.html

Children’s Misconceptions About Science: www.amasci.com/miscon/opphys.html

FIGURE 3

Curricula evaluation.

Lowery (2008) suggests using the following questions to evaluate curricula:

- ◆ Is this document written to reflect current brain research when possible, or is it simply a rehash of traditional content and conventional teaching approaches?
- ◆ Are the concepts presented at grade-appropriate levels?
- ◆ Does the curriculum go into depth with fewer topics?
- ◆ Does the program move from direct experience to the abstract?
- ◆ Does the program emphasize hands-on experiences supported by good reading materials?
- ◆ Does the curriculum build on prior learning as it progresses through the grades?
- ◆ Are students provided multiple opportunities to rehearse and reflect?

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