What Do Kids Know—and Misunderstand—About Science?

In-class discussion and careful assessment can unmask misconceptions and build student understanding.

Cynthia Crockett

Recently, my 5-year-old niece showed me the new pair of socks that she was wearing and told me that the socks were warm. Seizing on the opportunity to explore her understanding of the physical world, I asked her whether she thought the socks had been warm as they hung on the rack in the store, before she put them on.

"Of course not," she said with conviction.

"What about mittens?" I asked. "Are they warm in the store before you buy them and put them on?"

"Yes," she replied, looking astonished that I did not know this.

I followed up: "Why are mittens warm on the rack in the store, when socks are not?"

"Because mittens are thicker and warmer, and they’re for your hands, not your feet."

I found this discussion fascinating. My niece "knew" that socks are not inherently warm. With equal certainty, she "knew" that mittens are inherently warm. And she had specific reasons to back up her thinking.

My niece has never actually measured the inside temperature of mittens or socks when they were not being worn. Where do her ideas come from? What experience, evidence, and knowledge has she drawn on to construct these beliefs? And at what point will she abandon them or will they fail her?

Building Understanding

When do children start building knowledge based on primitive or incorrect information, and how can educators help them correct their misconceptions? Children usually form their own ideas, which become their beliefs, on the basis of their experiences or something they imagined. Common misconceptions include the following:

- Large or heavy objects always sink.
- The moon’s phases are caused by the shadow of the earth falling on the moon.
- Magnets attract all metals.
- The earth is the center of the solar system.

- Batteries have electricity inside them.
- You can see and hear a distant event simultaneously. (Weiler, 1998)

Educators and other adults play an important role in helping students identify their ideas, reflect on evidence that supports or refutes their ideas, and understand what their ideas actually mean.

For instance, in the conversation with my niece, it would have been interesting to pursue her line of
reasoning. Did she actually think that the mittens were somehow heated all by themselves? Had she ever had the opportunity to feel mittens while they were still on the rack in the store? Was she thinking of other soft, fuzzy things, such as kittens, that do give off their own heat?

The ideas that students construct on the basis of their experience or imagination provide them with what I call usable knowledge or usable ideas. The important feature of usable ideas is not whether the ideas are correct or incorrect, but whether they help the student explain an event or phenomenon.

These usable ideas, however, will only carry the students as far in their knowledge building as the robustness of the knowledge that the students have previously built. If a student attempts to build more complex knowledge on a weak scaffold of misconceptions, the structure will collapse at some point. The earlier the student confronts and understands these misconceptions, the better.

A key component of fostering learning is getting students to identify their ideas and then clarifying and challenging the validity of those ideas. This process enables students to redesign their thinking and create a stronger, more accurate structure of knowledge. New ideas and old ideas modify one another in a process of accommodation and assimilation (DeBoer, 1991).

Helping Students Examine Their Ideas

Teachers present material to students in a manner that the teacher has organized and understands. The teacher may not realize that students may understand this material differently, depending on the personal misconceptions that each student brings to the lesson.

A prime example of this disconnect is our experience with teaching students the concept of density. For many years, science teachers—myself included—thought that we were helping our students learn this concept by dropping items into water and putting numbers into an equation. But as my colleagues and I investigated students' ideas on density (Libarkin, Crockett, & Sadler, 2003), we found that many of the students with whom we talked had no idea what density was or how it applied to objects. They all used the correct terminology and even did the math correctly to calculate density. But they had many misconceptions, often equating density with size, shape, or material. And thanks to all of the floating and sinking experiments, they informed us that they could not explore the density of objects unless the investigation used water.

Active classroom conversations enable students and teachers to examine ideas, explore them aloud, and reason and re-reason through them. Such conversations can help teachers recognize and challenge students' misconceptions about science. Teachers should not only have conversations with students but also encourage students to have conversations and respectful debates with one another. When we make time for discussion, we get a more thorough understanding of each student's interpretation of concepts or facts. These discussions enable us to pinpoint students' misconceptions and false ideas early on—before the state test—and to help students begin to reformulate their ideas into something more accurate and useful. For instance, talking with students might help us recognize that many of them—adults as well—believe that the seasons are caused by the earth's distance from the sun rather than by the tilt of the earth's axis.

Specific classroom strategies can help students become more aware of their own ideas and compare them with others' ideas. The carousel activity, a type of brainstorming, works at any age level for all kinds of participants. The purpose of the carousel is to dump all ideas out onto the table (or board or paper) for consideration and review.

Students in one class used a carousel process to examine their ideas about the questions, What is magnetism? Where do magnets come from? What are some everyday uses of magnets? Do magnets work underwater? Is it possible to make a magnet? If so, how would you do this? Can we start and stop magnetism? Students sat at tables in small groups of three or four, and each group received a poster-size sheet of paper with a question on it. Each group had four minutes to "dump" all of its ideas—regardless of whether they were right or wrong—onto the paper. At the end of four minutes, each group moved to the next table and to a new question. The groups again had four minutes to consider the ideas that the previous groups had written on the paper and to add their own ideas. When the groups returned to their original tables, they considered all of the ideas on their papers. The groups then summed up the ideas for consideration and discussion with the class.
For example, Group A's question, What is magnetism?, elicited such ideas as "the ability to attract things," "when positive and negative charges attract each other," "when a magnet attracts metal," "when all electrons are aligned in certain metals," and "the flow of electromagnetic fields." As a result of these brainstormed ideas and the ensuing discussion, students were able to discern some of the following facts:

- Magnets have a north "pole" and a south "pole."
- Not all objects are magnetic.
- Not all metals are magnetic.
- The opposite "poles" of magnets are attracted to each other.

Through the carousel process, students become aware of their own ideas, begin to entertain other ways of looking at the world, incorporate new knowledge, and possibly begin to change their own ideas and ways of thinking.

Assessing Student Understanding
School systems and educators often purport to measure what students know and don't know by testing them—early and often. But do we know what students understand by the one answer they choose on a test? Tests, if not thoughtfully constructed, are usually imperfect tools to assess students' understanding of topics and concepts. Many assessments measure students' knowledge without actually probing the depths of their understanding (Dillon, 2003).

The Science Education Department at the Harvard-Smithsonian Center for Astrophysics at Harvard University is studying how the structure of test items affects students' ability to demonstrate their knowledge of science. As part of our ongoing research, we administered assessments based on the National Research Council's (1996) Physical Science Standards for grades 5-8 to nearly 8,000 7th and 8th graders. In preliminary results of the nationwide study, most students scored approximately 40 percent correct on the assessment, demonstrating that these standards require an understanding of concepts that the typical middle school student finds complex and difficult.

On the initial administrations of the assessment, we included answer options for each test item that represented common student misconceptions documented in the research literature. Analyzing the student responses, we found that significant numbers of students chose one or more incorrect responses per test question. These responses seemed to represent the most popular misconceptions about the tested science concepts. When we omitted the misconception distracters from subsequent versions of the assessment, more students selected the correct answer.

For example, one test item asked what would happen if you were on a tour of a closed, artificially lit cave and the lights went out. Rather than choosing the correct response, that everything would look black, many students said that shiny objects and light-colored objects would still be visible. On another item, many students said that stacking books on an electric lamp cord would cause the lamp to gradually dim as more weight was added.

The Science Education Department study demonstrates why it is so crucial to provide well-written, representative responses from which students can choose representations of their own ideas. On a multiple-choice test, students can only convey what they know by the choices provided. If students are presented with a question about a scientific concept and the available responses include the correct answer along with several nonsense
answers, the students who do not understand the concept may still be able to guess the right answer.

When a test item includes the correct answer along with several common misconceptions about that concept, students who do not truly understand the concept are likely to choose the answers reflecting their misconceptions. This kind of test item conveys more thoroughly to the teacher or evaluator just what ideas each student has constructed and where the problems lie in that student's thinking.

It is often a humbling and confusing experience to go beyond superficial test responses and discover what our students really understand. We may believe that we "taught" the material to our students and that they "got it." But when we look further, we often discover that they didn’t get it at all. The students told us all the right words, used the right math, and gave us the desired answer, but they did not have the opportunity to give us their entire answer.

Sadler and colleagues (1989) present a classic example of how a student may produce a correct answer that masks incomplete understanding. In an interview, they asked one student about the seasons and the path that the earth follows around the sun. The student knew that the earth orbits the sun once a year and that, as a result, we have seasons. But when asked to show the earth’s orbit, she created a figure-eight path rather than an ellipse. This student would probably have given the correct answer on a multiple-choice test that asked why we have seasons. Only a thoughtfully constructed test item—perhaps one that gave her the option of selecting different orbit shapes—would have conveyed her actual understanding of the concept.

As educators, we can expose students' misconceptions and help them unravel their false ideas. We must then provide students with the opportunity and support to develop a more accurate set of beliefs on which to build true scientific understanding.

References

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