Formative Assessment Probes

Uncovering Students' Ideas in Science

by Page Keeley, Francis Eberle, and Lynn Farrin

Seventh-grade science teacher Sonia Mangano stared at the results of her district's mid-year science assessment and asked herself, "Why is it my students seem to have trouble with matter-related ideas? Our district's spiral science curriculum builds on previous concepts from year to year. Yet these results show my students have difficulty with basic ideas that were introduced well before seventh grade. What is going on here? Why is it so many of my students are failing to grasp the ideas they have been taught?"

Sonia had put a lot of thought into her Matter: Interactions and Properties unit over the past few years. She had worked hard on restructuring the sequence of lessons presented to her students, added several hands-on activities, and aligned the unit with local and national standards. She had spent almost the entire first trimester teaching matter-related concepts and believed her teaching strategies were engaging and effective. Puzzled, she gazed at the test results wondering what went wrong. Isn't teaching supposed to result in learning?

Later in the spring Sonia attended an assessment conference where she learned about the use of science assessment probes as a strategy for examining students' ideas. She learned that many students of all abilities have alternative ideas in science that often go unnoticed. She was excited to learn how she could use assessment probes to find out what her students' ideas were before she taught her lessons. She could use the information to adjust her instructional strategies and help all of her students build a bridge between their existing ideas and the scientific explanations. She decided to do something different this year. Instead of planning out her entire unit and starting with the first lesson, she would begin by using a probe or two to determine her students' existing ideas and design her unit to explicitly address their current thinking, guiding them through and monitoring the conceptual change.

Formative assessment probes—What are they?

In the current climate of accountability and high stakes testing, most classroom assessments are focused on measuring and documenting student learning. Similarly, professional development has become focused on training teachers how to score student work to determine the extent to which students meet standards. Formative assessment probes shift the focus to include examining student thinking for the purpose of informing teaching and learning. Formative assessment probes are designed to address difficulties identified in the research on student learning. For example, several studies on students' ideas related to plants indicate that many students are likely to believe that plants get their food from the soil. A two-tiered assessment probe is a type of enhanced multiple-choice item that includes two parts—Part 1: Selected response distracters that include research-identified ideas held by students, and Part 2: An open-ended response that asks students to explain their thinking. For example, the distracters A, B, D, E, and F in Figure 1 are based on frequent ideas students have about evaporation mentioned in the research literature. The second part asks students to provide a rationale for their thinking. Students may describe intuitive rules or ideas, evidence from prior learning, or state scientific knowledge they learned in school. The first part of the probe provides a quick class snapshot to the teacher about where students think evaporated water goes. The second part provides more detailed information on individual student thinking as well as common reasons used by students in the class.

Information from an assessment probe can be quickly analyzed by a teacher and used to design instruction using strategies that explicitly target their students' ideas and guide them through a conceptual change. The probe may be used before the teaching unit as well as during the unit when feedback may indicate a need to change course and differentiate instruction to meet the needs of students who may be conceptually resistant to ideas that challenge their current conceptions. This is consistent with the idea of assessment for learning that says, "The roles for assessment must be expanded beyond the traditional concept of testing. The use of frequent formative assessment helps make students' thinking visible to themselves, their peers, and their teacher. This provides feedback that can guide modification and refinement in thinking" (Bransford, Brown, and Cocking 1999).

Science probes have been used extensively in our work with Maine teachers. It is not enough for teachers to know what standards they must address and assess in their curricu-

---

__Page Keeley__ is a senior program director, __Francis Eberle__ is the executive director, and __Lynn Farrin__ is a science associate at the Maine Mathematics and Science Alliance in Augusta, Maine.

lum. Teachers also need to know how assessment connects to the research on student learning related to those standards. Much has been learned about how students think about ideas in science. The diagnostic nature of a science probe helps teachers uncover misconceptions and incomplete ideas identified in cognitive research literature and examine the implications for their curriculum and instruction. Unlike summative assessments, the probes are not grade-level specific and can be used to trace back where a gap may have occurred in students' opportunities to learn. For example, middle school teachers using the water cycle probe realize students have been using the word *evaporation* since elementary grades, but fail to understand that water is in the air around them. They may get an item on an assessment correct in identifying the part on a water cycle diagram that shows water evaporating, yet they believe it may go immediately up to a cloud, since that is often what the representation shows. As a result, middle school teachers may find they need to go back and address the concept of evaporation—which was probably introduced in the third grade—by providing experiences for students that bring them to the realization that water evaporates and forms water vapor in the air surrounding them.

Teacher use of a probe

The next school year Sonia decided to find out her students' ideas about conservation of matter prior to teaching her matter unit with a new class. Although her students had learned about physical changes in previous years, Sonia was not convinced they could apply conservation reasoning during dissolving, boiling, melting, or freezing. Her seventh-grade curriculum included conservation of matter during chemical change. Before she designed instruction to target this idea, she wanted to find out if her students could first apply conservation reasoning during various physical changes, including change in state. She chose a probe called *Ice Cubes in a Bag* to elicit her students' ideas about conservation of mass when ice melts (Figure 2). Furthermore, she decided she would find out if her students used the idea of a closed system in their reasoning. Would they reason that if nothing could get in and nothing could get out, the mass would not change?

Several days before beginning her matter unit, Sonia gave the probe to all her seventh-grade classes. She told her students to do the best they could and that they were not going to be graded. She explained how she was interested in learning about their ideas, regardless if they were right or wrong, so she could design instruction geared especially for them.

Later that day Sonia sifted through the student papers. She was surprised to see student results varied. She wanted to learn what her students knew about conservation of matter during a change in state, whether they recognized a closed system, and how they would explain their reasoning. She decided to organize the student data to get a clear picture of her students' thinking. She tallied the multiple-choice responses and was surprised to see the sum of the incorrect responses exceeded the correct responses. Next she analyzed the data from the second part of the probe that asked students about their reasoning. The students' comments provided a more detailed picture as to what they were actually thinking (Figure 3).

The reasoning behind the student comments made Sonia realize that she needed to provide an opportunity for students to test their ideas. It appeared that they may not have had an opportunity to investigate whether mass changes during melting. An inquiry investigation would be a natural follow-up to the probe. She also realized that she needed to explicitly teach

FIGURE 1 **Example of a two-tiered assessment probe**

The wet jeans

Sam washed his favorite pair of jeans. He hung the wet jeans on a clothesline outside. An hour later the jeans were dry. Circle the answer that best describes *what happened to the water* that was in the wet jeans.

A. It soaked into the ground.
B. It disappeared and no longer exists.
C. It is in the air in an invisible form.
D. It moved upward and formed clouds.
E. It chemically changed into a new substance.
F. It went up to the Sun.

Explain your thinking. What ideas do you have to support your answer?

FIGURE 2 **Ice cubes in a bag**

You are having an argument with your friend about what happens to the mass when matter changes from one form to another. To prove your idea, you put three ice cubes in a sealed bag and recorded the mass of the ice in the bag. You let the ice cubes melt completely. Ten minutes later you recorded the mass of the water in the bag. Which of the following best describes the result? Circle your prediction.

A. The mass of the water in the bag will be less than the mass of the ice in the bag.
B. The mass of the water in the bag will be more than the mass of the ice in the bag.
C. The mass of the water in the bag would be the same as the mass of the ice cubes in the bag.

Explain to your friend why you chose A, B, or C. Describe at least one good reason to support your argument about what happened to the mass.

FIGURE 3 **Students' most common reasons for their prediction selection**

Reasons for Prediction A	Total
Melted ice (water) weighs more than ice or liquids weigh more than solids	17
Solids (frozen things, ice) weigh more than liquids	13
Water expands when it freezes (or ice takes up more room), so it has more mass	10
There is more matter (or mass) in ice than water	2
Ice is more compact (molecules tightly packed). The more compact, the more mass	6
Reasons for Prediction B	
Water takes up more space in the bag, is more spread out	13
Ice is less dense than water (water is more dense than ice) or floats in water so it is lighter	7
Ice has more air in it	6
In solid objects the weight is evenly distributed instead of spread out like liquids	3
When ice melts there is more water in the bag	2
Reasons for Prediction C	
The substance or amount didn't change, just the form	34
Everything stayed in the bag, nothing could escape or get in (like air)	13
It's just a physical change and nothing was destroyed, lost, or added	12
Mentions Law of Conservation of Matter (or Mass)	8
Mass can't be created or destroyed (without mentioning the law)	5
There was no chemical reaction or chemical change	4

the idea of closed systems. Few students failed to use that idea in their reasoning, even when it was stated in the stem of the task. She noticed several students confused the idea of density with mass and seemed to have difficulty distinguishing weight and mass. She noticed that some students who selected the correct response, C, used faulty reasoning. She was particularly interested in the idea that some students thought mass changed only when there was a chemical change. She would keep this in mind after students moved from conservation in a physical context to a chemical one. Examining her students' responses also raised several additional questions, such as when and where did they get these ideas? Did they ever have an opportunity in other grades to test conservation ideas during physical change? Sonia decided she would share this data with teachers in other grades. Perhaps teachers from multiple grades would be interested in using similar probes and sharing the data as a way to developmentally target curriculum and instruction.

Developing an assessment probe

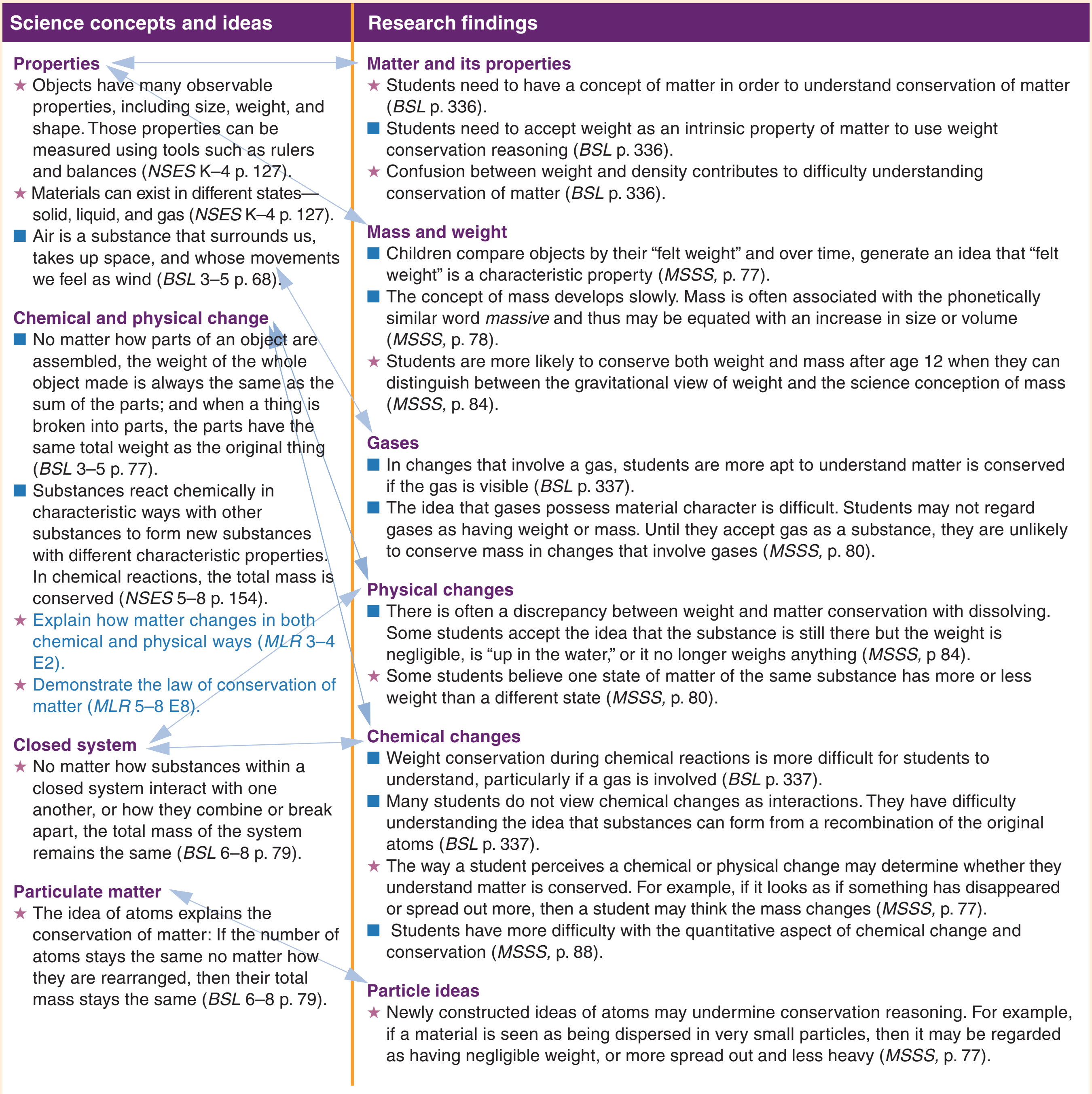
The vignette described above illustrates how teachers make use of formative assessment data to uncover student ideas and inform their instruction. There are numerous resources on assessment that help teachers design and use assessment to measure student learning, but few are readily available that help educators design assessments based on cognitive research that can identify students' misconceptions before and during instruction. In our work with teachers, we use a process described in *Curriculum Topic Study: Bridging the Gap Between Standards and Practice* (Keeley, Forthcoming) that links national and state standards concepts and ideas to research findings. By targeting specific misconceptions related to learning goals, teachers can design their own probes that target similar findings in the research. Figure 4 shows an example of how a careful analysis of the concepts and learning goals related to conservation of matter in the *National Science Education Standards*, *Benchmarks*, and state standards (e.g., *Maine's Learning Results*, noted as *MLR* in Figure 4) were matched to the cognitive research findings from Chapter 15 in *Benchmarks* and Rosalind Driver's book, *Making Sense of Secondary Science* (noted as *MSSS* in Figure 4).

The arrows show matches between the concepts and ideas in the state (blue represents Maine's standards) and national standards and the research findings. The red stars mark assessment information to guide the development of a probe that would target conservation of matter in a change of state context. This information was used to develop the *Ice Cubes in a Bag* assessment probe, as well as reflect on the students' reasons for their selected response on the task. The next step in the development process involved selecting a familiar phenomenon (in this case the melting ice cube); developing the stem and distracters; piloting with a class and revising, administering the probe, and analyzing the results; and adjusting instruction accordingly. It is this last step that makes a case for why formative assessment is one of the most powerful ways to inform teaching and learning. This is the essence of assessment for learning.

Sources of probes

Teachers can design probes from scratch using the process we have designed or modify their existing assessments to be more in line with research findings, providing information that is useful to the teacher. In addition, NSTA will be publishing a book containing sets of probes, including the examples described in this article, in the fall of 2005 (Keeley, Eberle, and Farrin, Forthcoming). If you have a suggestion

FIGURE 4 **Mapping grades 3–8 conservation of matter concepts and learning goals to research findings**



Science concepts and ideas

Properties

- ★ Objects have many observable properties, including size, weight, and shape. Those properties can be measured using tools such as rulers and balances (*NSES* K–4 p. 127).
- ★ Materials can exist in different states—solid, liquid, and gas (*NSES* K–4 p. 127).
- ■ Air is a substance that surrounds us, takes up space, and whose movements we feel as wind (*BSL* 3–5 p. 68).

Chemical and physical change

- ■ No matter how parts of an object are assembled, the weight of the whole object made is always the same as the sum of the parts; and when a thing is broken into parts, the parts have the same total weight as the original thing (*BSL* 3–5 p. 77).
- ■ Substances react chemically in characteristic ways with other substances to form new substances with different characteristic properties. In chemical reactions, the total mass is conserved (*NSES* 5–8 p. 154).
- ★ Explain how matter changes in both chemical and physical ways (*MLR* 3–4 E2).
- ★ Demonstrate the law of conservation of matter (*MLR* 5–8 E8).

Closed system

- ★ No matter how substances within a closed system interact with one another, or how they combine or break apart, the total mass of the system remains the same (*BSL* 6–8 p. 79).

Particulate matter

- ★ The idea of atoms explains the conservation of matter: If the number of atoms stays the same no matter how they are rearranged, then their total mass stays the same (*BSL* 6–8 p. 79).

Research findings

Matter and its properties

- ★ Students need to have a concept of matter in order to understand conservation of matter (*BSL* p. 336).
- ■ Students need to accept weight as an intrinsic property of matter to use weight conservation reasoning (*BSL* p. 336).
- ★ Confusion between weight and density contributes to difficulty understanding conservation of matter (*BSL* p. 336).

Mass and weight

- ■ Children compare objects by their "felt weight" and over time, generate an idea that "felt weight" is a characteristic property (*MSSS,* p. 77).
- ■ The concept of mass develops slowly. Mass is often associated with the phonetically similar word *massive* and thus may be equated with an increase in size or volume (*MSSS,* p. 78).
- ★ Students are more likely to conserve both weight and mass after age 12 when they can distinguish between the gravitational view of weight and the science conception of mass (*MSSS,* p. 84).

Gases

- ■ In changes that involve a gas, students are more apt to understand matter is conserved if the gas is visible (*BSL* p. 337).
- ■ The idea that gases possess material character is difficult. Students may not regard gases as having weight or mass. Until they accept gas as a substance, they are unlikely to conserve mass in changes that involve gases (*MSSS,* p. 80).

Physical changes

- ■ There is often a discrepancy between weight and matter conservation with dissolving. Some students accept the idea that the substance is still there but the weight is negligible, is "up in the water," or it no longer weighs anything (*MSSS,* p 84).
- ★ Some students believe one state of matter of the same substance has more or less weight than a different state (*MSSS,* p. 80).

Chemical changes

- ■ Weight conservation during chemical reactions is more difficult for students to understand, particularly if a gas is involved (*BSL* p. 337).
- ■ Many students do not view chemical changes as interactions. They have difficulty understanding the idea that substances can form from a recombination of the original atoms (*BSL* p. 337).
- ★ The way a student perceives a chemical or physical change may determine whether they understand matter is conserved. For example, if it looks as if something has disappeared or spread out more, then a student may think the mass changes (*MSSS,* p. 77).
- ■ Students have more difficulty with the quantitative aspect of chemical change and conservation (*MSSS,* p. 88).

Particle ideas

- ★ Newly constructed ideas of atoms may undermine conservation reasoning. For example, if a material is seen as being dispersed in very small particles, then it may be regarded as having negligible weight, or more spread out and less heavy (*MSSS,* p. 77).

for a probe topic we could develop for a future publication, please e-mail us at *pkeeley@mmsa.org*.

References

American Association for the Advancement of Science. 2001. *Atlas of science literacy*. New York, NY: Oxford University Press.

American Association for the Advancement of Science. 1993. *Benchmarks for science literacy*. New York, NY: Oxford University Press.

Bransford, J., A. Brown, and R. Cocking. 1999. *How people learn: Brain, mind, experience, and school*. Washington, DC: National Research Council and National Academy Press.

Driver, R., A. Squires, P. Rushworth, and V. Wood-Robinson. 1994. *Making sense of secondary science—Research into children's ideas*. London and New York: Routledge Falmer.

Keeley, P. Forthcoming. *Curriculum topic study—Bridging the gap between standards and practice*. Thousand Oaks, CA: Corwin Press (copublished by NSTA).

Keeley, P., F. Eberle, and L. Farrin. Forthcoming. *Probing students' ideas in science—Volume 1*. Arlington, VA: NSTA Press.

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