Introduction

> The most important single factor influencing learning is what the learner knows. Ascertain this and teach accordingly.
> —David Ausubel, *Educational Psychology: A Cognitive View*

Classroom Assessment

> *In the broadest sense of the word, assessment is something we do all the time. We encounter a new situation, make a judgment about what is happening, and decide what to do next. The evidence of our encounters continually shapes and reshapes our actions. Our actions may be more effective if we are flexible—that is, if we are prepared to modify our intentions in light of events. They might also be more effective if we probe the situation carefully in order to ensure that we understand what is going on before jumping to conclusions.* (Black et al. 2003, p. 6)

Classroom assessment occurs every day, most often as formative assessment. "The first thing that comes to mind for many people when they think of 'classroom assessment' is a midterm or end of course exam, used by the teacher for summative grading purposes. But such practices represent only a fraction of the kinds of assessments that occur on an ongoing basis in an effective classroom" (Pelligrino, Chudowsky, and Glaser 2001, p. 225). Everyday classroom assessment is unique to your classroom context. It depends more on the skills, knowledge, and priorities you and your students have than on any particular protocol or strategy (Atkin and Coffey 2003, p. xi). Throughout the course of a unit or lesson, you assess students using various formats, including individual, small-group, or whole-class elicitation questions; student interviews; observations; informal conversations; journaling; performance tasks; even traditional assessments such as quizzes or tests during or after a lesson.

Classroom assessment is continuous and

provides you with a rich set of data about student learning. However, for the assessment to be considered "formative," you must use the data to modify your curriculum, alter your teaching, or provide feedback to your students. Classroom assessment serves multiple purposes, including diagnosing, monitoring, providing feedback, and measuring. Each of these assessment purposes links to various stages in your instructional sequence as described in Figure 1.

A key stage in the instructional sequence is *elicitation*. Elicitation gives students the opportunity to make their ideas and reasons explicit as they begin the study of a unit topic. It engages them and also alerts them to what they will be thinking and learning about in the upcoming instruction. "By providing the opportunity to articulate their initial conceptions and to clarify these ideas, the elicitation questions and subsequent discussions help students begin building new, more powerful conceptions" (Minstrell and van Zee 2003, p. 62). In a similar vein, another group of researchers put it this way:

> *Knowledge of children's learning and the development of expertise clearly indicates that assessment practices should focus on making students' thinking visible to themselves and to others by drawing out their current understandings so that instructional strategies can be selected to support an appropriate course for future learning. In particular, assessment practices should focus on identifying the preconceptions children bring to learning settings.* (Pelligrino, Chudowsky, and Glaser 2001, p. 91)

Using the probes provided in this book at the elicitation and exploration and concept development stages of instruction is consistent with the current research on how students learn and with recommendations for

Figure 1 **Purposes and Stages of Classroom Assessment**

Type of Classroom Assessment	Purpose	Link to Stage in an Instructional Sequence
Formative (pre-instruction)	Diagnostic—to find out students' existing ideas	Elicitation Stage—Used prior to developing instruction or during the instructional sequence when new ideas are encountered.
Formative	To monitor student learning and/or to provide feedback to students on their learning	Exploration and Concept Development Stage—Used continuously throughout the instructional sequence.
Summative	To measure the extent to which students have achieved a learning goal	Application Stage—Used primarily at the end of an instructional sequence.
Note: The assessment probes provided in this book are formative in nature and are designed to be used during the elicitation and exploration and concept development stages of an instructional sequence.		

using assessment for learning and informing instruction.

What Is a Formative Assessment Probe?

The assessment examples in this book, which we call *probes*, are formative in nature. They are used primarily for diagnostic and monitoring purposes. They are assessments *for* learning, not assessments *of* learning. While several of these probes could indeed serve to summatively assess your students' learning, their primary purpose is not to measure the extent to which your students achieved proficiency in science subject matter knowledge, but rather to reveal the types of conceptions your students have about common science concepts before and throughout instruction. "Students enter the study of science with a vast array of such preconceptions based on their everyday experiences. Teachers will need to engage those ideas if students are to understand science" (Donovan and Bransford 2005, p. 399). The probes in this book shift the focus from measuring and documenting student learning to examining student thinking for the purpose of informing teaching and learning.

This book focuses on formative assessments that will enable you to probe for and quickly and efficiently examine a multitude of possible ideas your students hold, including misconceptions, naive thoughts, and incomplete ideas. (Many educators and researchers prefer to collectively call these ideas *alternative frameworks* rather than *misconceptions*—meaning that students' ideas are not always wrong, even though they may differ from those of a scientist [Sneider 2003].) The probes also uncover the correct ideas your students hold and the critical-thinking and reasoning strategies they use to support their ideas. These strategies can be based on intuition, logic, everyday experiences, or scientific knowledge.

Why is it important for you to take the time to uncover the preconceptions your students have? Research has shown that preconceived ideas in science develop early in a student's K–12 experience and can be tenacious (Donovan and Bransford 2005; Bransford, Brown, and Cocking 1999). Through their daily, informal experiences with objects and phenomena, students develop ideas and schema for organizing and explaining scientific concepts even before they are formally taught scientific ideas in school. Sometimes these ideas are congruent with scientific knowledge. Other times they conflict with the scientific view. This formation of students' own conceptions, which may be correct, partially correct, or incorrect, continues throughout their K–12 school years regardless of whether or not the ideas are taught in science class. If these ideas are ignored, they may get in the way when new ideas are introduced. They simply do not go away, even as students progress from elementary grades to middle school and even into high school and adulthood. Surprisingly, many of the probes in this book reveal that high school students have partially understood ideas and misconceptions that are not much different from those of their elementary school counterparts.

Thus, a major challenge for science teachers is to build conceptual bridges from students' own ideas to scientifically accepted views. To do this, you must know what your students' starting points are so that you can provide experiences that support the development of correct conceptual understanding.

The science assessment probes in this book are field-tested formative assessments that are based on core concepts and ideas in science, many of which cut across multiple grade spans at increasing levels of sophistication. The probes are designed to help you identify students' ideas at various stages during their K–12 experiences. For example, elementary students may have basic notions about atoms, molecules, or "tiny bits," but it is not until later in middle school that students are expected to use the idea of atoms and molecules to explain phenomena. Knowing the ideas students have at different grade levels can give you a clear picture of conceptual change over time.

These probes are intended to be used before and during instruction. Finding out students' ideas, examining them carefully, and using the information obtained from the probes are integral aspects of formative assessment. It is this latter aspect of using the assessment data that is most overlooked in classroom assessment. It is not sufficient to know the misconceptions your students may have. Information from the assessment probes will have little impact unless you make changes in curriculum and instruction based on where students are in their thinking.

Assessment Probe Design and Features

The formative assessment probes included in this book are designed to address several of the student learning difficulties identified in the research literature. In areas where there is little or no research, they have been designed to address problematic areas identified by teachers. Each probe consists of two parts to be completed by the student: a selected response and a justification for selecting the response.

The first part is introduced by an engaging prompt about a familiar phenomenon or objects. The prompt is followed by a question that asks students to select from a set of likely student-held responses. These responses include research-identified ideas, including misconceptions, or common ideas that emerged through the probe field testing. Students' selected responses provide a quick snapshot for you to see what individual students think about an idea. This data can be quickly tallied to get a picture of where your class stands as far as the variety of ideas students have.

The second part of each probe asks students to describe their thinking or provide an explanation or "rule" they used to select their answer. *Rule* is a general term used with younger students (though not limited to younger students) that usually involves a set of basic criteria students use to categorize or make sense of an object or phenomena. For example, in deciding whether certain materials are considered matter or not matter, a student might explain how she used the rule that "it had to be something she could feel and see" to sort objects and materials.

Asking students to describe a rule often leads to uncovering intuitive rules, such as "more A, more B" (Stavy and Tirosh 2000). This rule simply means if you have more of something (such as mass or volume), then other characteristics increase (such as density and boiling point). This rule may be applied in a variety of physical, Earth, and biological contexts and seems to be a core conception that contributes to several common misconceptions. Older students may provide more sophisticated scientific explanations that link a claim with evidence and reasoning strategies to support their answers. In both types of justification, involving either rules or explanations, students provide a rationale for their ideas, giving teachers a detailed glimpse into their thinking.

To develop the probes we used a process and formats described in *Science Curriculum Topic Study: Bridging the Gap Between Standards and Practice* (Keeley 2005). The process begins with identifying the concepts and related ideas in a topic, based on a study of the national standards and research. The concepts and ideas in the standards are then linked to the concepts and ideas addressed in the cognitive research literature and to their associated learning difficulties and misconceptions.

The national standards used to identify the concepts and specific ideas were from *Benchmarks for Science Literacy* (AAAS 1993) and *National Science Education Standards* (NRC 1996). The sources of research summaries were *Benchmarks for Science Literacy* (Chapter 15, "The Research Base") and *Making Sense of Secondary Science: Research into Children's Ideas* (Driver et al. 1994). (Note: The latter resource does not address only high school science. *Secondary science* is a term used in the United Kingdom to describe grade levels beyond early primary grades. The book addresses ideas from grade 1 through adulthood and includes preK–2 ideas in several examples.) Figure 2 shows an example of how the process was used to "unpack" the topic "conservation of matter" in order to match the concepts and ideas in that topic to the research findings. This information was then used to develop a set of assessment probes that target standards and research-based ideas related to conservation of matter.

In Figure 2, the shaded areas designate the specific Benchmarks idea and the related research finding that were used to develop the probe "Ice Cubes in a Bag" (p. 49). Even though the idea in the national standards is a K–2 idea, the probe can be used with higher grade levels to determine if students use the more sophisticated ideas of closed systems or numbers of atoms. Other matches between the research ideas and the standards led to the development of three additional probes in the conservation of matter set ("Lemonade," "Cookie Crumbles," and "Seedlings in a Jar").

The probes are designed to provide you with quick and targeted feedback on students' ideas and learning. The data from the first part of the probe are easy to collect and organize. Individuals or teams of teachers can quantify the data by making charts or graphs that show student results that can be shared with colleagues across grade levels. As you read the students' explanations, you will notice similar

Figure 2 **Mapping Grades 3–8 Conservation of Matter Related Concepts and Ideas to Research Findings for Probe Development**[a]

Science Concepts and Ideas	Research Findings
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) **Physical and Chemical Change** • Water can be a liquid or solid and can go back and forth from one form to another. If water is turned into ice and then ice is allowed to melt, the amount of water is the same as it was before freezing. (BSL K–2, p. 67) • 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) **Intractions in a 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)	**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) • 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. (Driver et al., p. 78) • 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. (Driver et al., p. 80) **Physical and Chemical Change** • 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. (Driver et al., p. 84) • Some students believe one state of matter of the same substance has more or less weight than a different state. (Driver et al., p. 80) • In changes that involve a gas, students are more apt to understand matter is conserved if the gas is visible (BSL, p. 337) • 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) • Students have more difficulty with the quantitative aspect of chemical change and conservation. (Driver et al., p. 88) • The way a student perceives a chemical or physical change may determine whether he or she understands matter is conserved. For example, if it looks as if something has disappeared or spread out more, then students may think the mass changes. (Driver et al., p. 77) **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 being more spread out and less heavy. (Driver et al., p. 77)

Note: NSES = National Research Council. 1996. *National science education standards.* Washington, DC: National Academy Press. BSL = American Association for the Advancement of Science. 1993. *Benchmarks for science literacy.* New York: Oxford University Press. Driver et al. = 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: RoutledgeFalmer.

[a] The shaded items are the specific Benchmark idea and the related research finding that were used to develop the probe "Ice Cubes in a Bag."

ideas held by a number of students as well as idiosyncratic ones held by individual students. Overall, the quick and easy snapshot you can glean from the probe results can inform adjustments to curriculum and instruction in order to improve student learning. Sometimes these adjustments can be made in your classroom. Other times the results can provide valuable information to teachers who have had some of the same students before you or will have them after you.

Formative Assessment Probes in This Book

The probes in this book are "enhanced selected-response" items. In other words, students must choose from a predetermined list of responses that may match their thinking and then justify their reasons for choosing that response. The probes begin with the selected-choice option. The distracters are particularly useful in determining if your own students' "misconceptions" match those found in the research. The two types of selected-response items are (1) multiple-choice questions with one *best* answer (Note: We don't use the term *correct answer* as it often depends on students' interpretation and reasoning), such as in the probe "Ice Cubes in a Bag" (p. 49), and (2) justified lists, such as used in "Is It Matter?" (p. 79). The multiple-choice questions include a stem that provides students with a familiar phenomenon or object to explain an idea, contrasts opposing views, or provides a situation where students commit to a prediction. Justified lists begin with a statement about objects, materials, or phenomena, followed by multiple examples students select from that match their ideas related to the statement. Justified lists are particularly helpful in determining if students can transfer their learning from one context to another and what rules or explanations they use to base their selected choices on. For example, in "Making Sound" (p. 43), if students learned about sound and vibration in the context of making musical instruments, they may select mostly items on the list that are similar to musical instruments rather than generalizing their knowledge across contexts.

The probes are also designed not to cue students too much, so that you can gain the most information from their original thinking. For example, in "Making Sound," the task refers to objects that make sound but does not mention the air or other material contacting or surrounding the objects that also vibrates. Evidence of recognizing and using this knowledge in their explanation or rule may not be evident if the students were cued to this idea. A major challenge in developing these probes was to provide just enough detail and appropriate language without putting ideas into students' heads or perpetuating their misconceptions.

The probes in this book are paper-and-pencil tasks. However, they also lend themselves to oral questioning prompts for small- or large-group discussion, card sorts, and individual interviews. Alternative ways to administer the probes to students are explained in the teacher notes accompanying each probe. Probes can easily be adapted to include language and examples that may be more appropriate at a given grade level. You are encouraged to modify the probes to best fit your students.

Using the Probes

"Students bring conceptions of everyday phenomena to the classroom that are quite sensible, but scientifically limited or incorrect" (Donovan and Bransford 2005, p. 399). Many of these preconceptions are based on students' everyday experiences outside the classroom, things they hear or see in the media, and ideas that go unchallenged in school settings. Teachers need to engage students in sharing these ideas if students are to understand science. One way to begin this engagement is to provide a probe and ask students to write down their ideas in response to the prompt. Writing a response to the prompt is one method of making students' thinking visible and engaging them in the ideas they will be learning about. At the same time it encourages your students to pay careful attention to the reasoning they use to support their ideas.

The probes can also be used orally to engage small or large groups of students in discussion. Using a probe to elicit individual ideas and then asking students to share and discuss their ideas with others provides you with valuable assessment information and at the same time enhances student learning. The process of making students' thinking explicit through discourse serves a dual purpose. First, it allows teachers to see what types of ideas students have so they can provide interventions that address misconceptions or provide for further learning opportunities. Second, encouraging students to make their ideas explicit to others actually promotes learning for both the thinker and those with whom he or she shares the ideas (Black et al. 2003).

Questioning is a key component of science teaching and formative assessment. "In many science classrooms, questioning typically involves a three-turn exchange in which the teacher asks a question, a student answers, and the teacher evaluates the answer" (Minstrell and van Zee 2003, p. 61). In too many other science classrooms, teachers try to get students to accept "the right answer" rather than engaging them in a conversation that elicits their ideas and uses those ideas as the starting point for activities, investigations, demonstrations, and readings. You can avoid the "right answer" approach by using the probes to uncover your students' conceptions at any time during an instructional sequence and holding back on giving students an answer so they can discover it for themselves.

Probes also "turn the spotlight from examining students' work to examining teachers' work" (Sneider 2003, p. 39). In other words, they help you understand student thinking so that you can develop more effective ways of teaching. While it is clearly important for you to understand the concepts and skills you teach, "without a way of stepping inside our students' shoes it is impossible for us to communicate those concepts and skills in a deep and meaningful way" (Sneider 2003, p. 39).

The use of assessment probes and their results as a means for determining how to alter curriculum and instruction can be stimulating both personally and professionally. Jim Minstrell, a teacher and researcher well known for his development and use of diagnostic assessment, sums up these rewards in the following quote:

> *When in the classroom I now wear two hats, one as a teacher and another as a researcher studying my students' thinking and how to effect better learning. I can no longer teach without learning about my students' thinking. The more I learn about my students' thinking, the more I can tune my instruction to help students bridge from their initial ideas to more formal, scientific thinking. Rather than merely serving students the activities from the book, we are first using questions to diagnose their thinking. Then, we choose activities to address their thinking. Thinking in this way about our work in the interest of improving our practice is part of what it means to be professional. Teaching never becomes boring—quite the contrary. As teachers, we can expect to be lifelong learners about our profession.* (Minstrell and van Zee 2003, p. 72)

The best way to learn how to use a probe is to test one out by giving it to your students and then deciding what to do with the information you have gathered. Try one with your colleagues, too, and together discuss the implications for teaching and learning. Modify the ways you use the probes. In other words, do not always administer the probe as an individual written task. Use the probes during small-group and whole-class discussions and listen carefully to students as they share their ideas. You can use a probe to interview an individual student or have informal conversations with students during nonstructured times. Feel free to adapt the probes as needed. Some language is problematic for certain students or grade levels. Modify the probe so that it best fits your individual circumstances but, at the same time, do not change it so much that it no longer probes what it was intended for.

Use the teacher notes provided with each probe to consider implications for curriculum and instruction. The format and suggested ideas in the teacher notes provide a framework for summarizing, evaluating, and using the student learning data you collect. Above all, remember that for the probes to be formative you must do something with the data you collect.

Teacher Notes That Accompany the Probes

Each of the probes in this book contains detailed teacher notes to help you to (a) decide how, when, and with whom to use the assessment probe; (b) link the ideas addressed by the probe to related standards; (c) examine research that informed the development of the probe and that provides additional insight into students' thinking; (d) consider new instructional strategies; and (e) access additional information to learn more about the topic addressed by the probe. We describe the components of the teacher notes below.

Purpose

"Deciding what to assess is not as simple as it might appear. Existing guidelines for assessment design emphasize that the process should begin with a statement of the purpose for the assessment and a definition of the content domain to be measured" (Pelligrino, Chudowsky, and Glaser 2001, p. 178). This section describes the concept or general topic for the specific idea the probe is intended to elicit and it describes that idea. It is important that you be clear about what the probe is going to reveal so that you can decide if the probe fits your intended target.

Related Concepts

A concept is a one-, two-, or three-word mental construct used to organize ideas in a topic (Keeley 2005). Each probe is designed to target one or more related concepts that cut across grade spans. Conversely, multiple probes may address a single concept. You may find it useful to use a cluster of probes to target a concept or specific ideas within a concept. For example, there are four probes that target the concept of conservation of matter. The concept matrices on pages 24 and 116 can help you identify related probes.

Explanation

A brief scientific explanation accompanies each probe to provide clarification of the scientific content that underlies the probe. The explanations are designed to help you identify what the most scientifically acceptable answers are (sometimes there is not a "right" answer) as well as to clarify any misunderstandings you might have about the content. The explanations are not intended to provide detailed background knowledge on the concept, but enough to connect the idea in the probe with the scientific knowledge it is primarily based on. If you have a need for further explanation of the content, the teacher notes list National Science Teachers Association (NSTA) resources, such as the *Stop Faking It! Finally Understanding Science So You Can Teach It* series, that will enhance and extend your understanding of the content.

Curricular and Instructional Considerations

The probes in this book are not limited to one grade level in the way that summative assessments are. Instead, they provide insights into the knowledge and thinking that students in your school may have as they progress from one grade level to the next. Ideas are included that students may not encounter until later in their education (e.g., high school), but teachers in the later grades will come to understand where and how ideas originate. Some of the probes can be used in grades K–12; others may cross over just a few grade levels. Teachers in two different grade spans (e.g., middle and high school) might decide to use the same probe and come together and discuss their findings.

The curricular and instructional considerations also describe how the information gleaned from the probe is useful at a given grade span. For example, the information might be useful for planning instruction when an idea in the probe is a grade-level expectation or it might be useful at a later grade to find out whether students have sufficient prior knowledge to move on to the next level of sophistication. Sometimes the knowledge gained through use of the probe indicates that you might have to back up several grade levels to teach ideas that have not been fully understood in previous grades.

We deliberately chose not to suggest a grade level for each probe. If the probes had been intended to be used for summative purposes, a grade level, aligned with a standard, would have been suggested. However, the probes have a different purpose. Do you want to know about the ideas your students are expected to learn according to your grade-level standards? Are you interested in how preconceived ideas develop and change across multiple grade levels in your school even when they are not yet formally taught? Are you interested in whether students achieved a scientific understanding of previous grade-level ideas before you introduce higher-level concepts? The descriptions of grade-level considerations in this section can be coupled with the section that lists related ideas in the national standards in order to make the best judgment about grade-level use.

Administering the Probe

Suggestions are provided for administering the probe to students, including a variety of modifications that may make the probe more useful at certain grade spans. For example, the notes might recommend eliminating certain examples from a list for younger students who may not be familiar with particular words or examples, or using the word *weight* instead of *mass* with elementary students. This section may also include suggestions for demonstrating the probe context with artifacts or ways to elicit the probe responses while students interact within a group.

Related Ideas in *National Science Education Standards* (NRC 1996) and *Benchmarks for Science Literacy* (AAAS 1993)

This section lists the learning goals stated in the two national documents generally considered the "national standards": *National Science Education Standards* (NRC 1996) and *Benchmarks for Science Literacy* (AAAS 1993). Since the probes are not designed as summative assessments, the learning goals listed are not intended to be considered as alignments to the probe, but rather as related ideas. Some targeted ideas, such as a student's conception of matter in "Is It Matter?" (p. 79), are not explicitly stated as learning goals in the standards but are clearly related to national standards concepts such as properties of matter, states of matter, and conservation of matter. When the ideas elicited by a probe appear to be a strong match with a national standard's learning goal, these matches are indicated by a star ★ symbol. You may find this information useful in using probes with lessons and instructional materials that are aligned to national standards and used at a specific grade level.

Related Research

Each probe is informed by related research where available. Since the probes were not designed primarily for research purposes, an exhaustive literature search was not conducted as part of the development process. The authors drew on two comprehensive research summaries commonly available to educators: Chapter 15, "The Research Base," in *Benchmarks for Science Literacy* (AAAS 1993) and Rosalind Driver et al.'s *Making Sense of Secondary Science: Research Into Children's Ideas* (1994). Although both of these resources describe studies that have been conducted in past decades, and studied children not only in the United States but in other countries as well, many of the studies' results are considered timeless and universal. (At the same time, however, it is important to recognize that cultural and societal contexts can also influence students' thinking.)

As you use the probes, you are encouraged to seek new and additional research findings. One source of updated research can be found on the Curriculum Topic Study (CTS) website at *www.curriculumtopicstudy.org.* A searchable database on this site links each of the CTS topics to additional research articles and resources.

Suggestions for Instruction and Assessment

After analyzing your students' responses, it is up to you to decide on the student interventions and instructional planning that would work best in your particular curricular and instructional context. We have included suggestions gathered from the wisdom of teachers, from the knowledge base on effective science teaching, and from our own collective experience as former teachers and specialists involved in science education. These are not exhaustive or prescribed lists but rather a listing of possible suggestions that may help you modify your curriculum or instruction, based on the results of your probe, in order to help students learn ideas that they may be struggling with. It may be as simple as realizing that you need to provide a variety of contexts or that there may be a specific strategy or activity you could use with your students. Learning is a very complex process, and it is unlikely that any single suggestion will help all students learn the science ideas. But that is part of what formative assessment encourages—thinking carefully about a variety of instructional strategies and experiences. As you become more familiar with the ideas your students have and the multifaceted factors that may have contributed to their misunderstandings, you will identify additional strategies that you can use to teach for conceptual change.

Related NSTA Science Store Publications and NSTA Journal Articles

The National Science Teachers Association's (NSTA) journals and books are increasingly targeting the ideas that students bring to their learning. For example, Bill Robertson's *Stop Faking It!* series of books may be helpful in clarifying content for students (as well as for teachers!). A journal article from one of NSTA's elementary, middle school, or high school journals may provide additional insight into students' misconceptions or provide an example of an effective instructional strategy or activity that can be used to develop understanding of the ideas targeted by a probe. To access the Science Store and journal articles, go to *www.nsta.org* and click on the appropriate site.

Related Curriculum Topic Study Guides

NSTA is a co-publisher of the book *Science Curriculum Topic Study: Bridging the Gap Between Standards and Practice* (Keeley 2005). This book was developed as a professional development resource for teachers with funding from the National Science Foundation's Teacher Professional Continuum Program. It provides a set of 147 Curriculum Topic Study (CTS) guides that can be used to learn more about a science topic's content, examine instructional implications, identify specific learning goals and scientific ideas, examine the research on student learning, consider connections to other topics, examine the coherency of ideas that build over time, and link understandings to state and district standards. The CTS guides use national standards and research in a systematic process that deepens teachers' understanding of the topics they teach.

The probes in this book were developed using the CTS guides and the assessment tools and processes described in Chapter 4 of the CTS book. The CTS guides that were used to inform the development of each of the probes are listed in the teacher notes that follow each probe and can be used by teachers to extend those notes.

References

References are provided for the standards and research findings cited in the teacher notes.

Vignettes

The following three vignettes illustrate how a probe can be used in a variety of ways by teachers in elementary, middle, and high school. They show how teachers used the probes to elicit students' ideas before, during, and even after instruction for the purpose of informing their immediate teaching plans, adjusting instruction the next time they teach a unit, making curricular changes, or sharing their learning about students' ideas with their colleagues. The teachers in the vignettes are composites of teachers with whom the authors have worked.

Elementary Vignette: Using the Probe "Is It an Animal?"

Before we began teaching our forest unit this year, the other third-grade teacher in my building and I decided to work on updating and revising the unit together. Both of us had taught this unit for several years and had gathered an enormous number of resources and teaching activities on the topic of "forests." Our elementary curriculum has a theme each year that draws on ideas from the state science standards about the diversity of life, ecology, structure and function, and how living things change over time. In first grade, students use butterflies as the context in which to learn ideas. In second grade, dinosaurs are the theme. Fourth graders use the theme of oceans to develop life science ideas.

We started by identifying goals for our students. We focused our first meeting on the goal of developing an understanding of what distinguished animals from other organisms. This goal includes three performance indicators from our state (Maine Department of Education 1997):

- Design and describe a classification system for organisms.
- Describe the different living things within a given habitat.
- Compare and contrast the life cycles, behavior, and structure of different organisms.

Because we wanted to determine our students' level of knowledge and the kinds of prior experiences they would bring to the unit, we introduced the unit using the K-W-L strategy. This formative assessment strategy included asking what students knew about the topic, what they wanted to learn, and then, at the end of the unit, describing what they learned. Through this exercise we learned that students could name and describe a number of forest animals, but would certainly benefit from the activities we had designed in the upcoming weeks. We kept notes on our lessons as we worked through the unit and got together regularly to discuss the progress students were making. We found students sorted organisms in a variety of ways, including grouping organisms into plant and animal categories and forest and nonforest categories and by body coverings and motility strategies.

As a culminating activity, each student selected a forest animal to write a report on using information text and created a three-dimensional papier-mâché model of his or her chosen animal to put in the classroom "forest." Through these engaging experiences, our students learned a great deal about the forest and about the characteristics of the animals that live there. We had student "experts" on a variety of animals, including bears, deer, squirrels, owls, chipmunks, skunks, bobcats, wolves, raccoons, and even a lynx!

Later that year, my colleague and I attended a formative assessment conference where we learned about science assessment probes. We were encouraged to select a probe that we could try in our own classrooms. We were excited to discover the "Is It an Animal?" probe (Figure 3) because it fit so nicely with our forest unit. We took the probe back to school and immediately administered it to our third-grade students. Even though we had already taught the unit, we wanted to see if our instruction had made an impact on students' ability to retain the ideas they learned. Because some students in our class are English as a second language learners, we asked students to complete the first part of the probe independently after giving the directions and examples verbally and using pictures along with the examples. We then used an interview protocol for the second part, designed to capture students' thinking about why the pictures they circled were animals. We engaged the entire class in a discussion of the choices they made about animals and the reasons for their choices.

As we looked through the student papers and recalled the students' list of "rules" that emerged from the class discussion, we noted similarities in student thinking. The majority of students identified the cow, tiger, frog, snake, and monkey as animals. A little less than a quarter of the students identified the beetle, shark, snail, chicken, worm, and spider as animals, and an even fewer number of students recognized the boy or starfish as an animal. As a matter of fact, out of the 84 students we gave the probe to, only 9 identified the boy as an animal and 12 identified the worm! Even more revealing were the rules students gave in deciding whether or not something was an animal. These included the following:

- Animals have tails.
- Animals have fur and bones.
- Animals cannot walk on two feet.
- Animals have four or more legs.
- Animals can move by themselves.

Clearly our students had a limited view of animals. We reflected on what we could do differently in the future to better address and more fully develop the concept of "animal" with our third-grade students. We realized how helpful it would have been to have known the concepts our students held of animals before we developed the forest unit. We now know it is important to make certain that as students group organisms as animals they carefully examine the characteristics to see if they are truly exclusive. Which features do all animals have in common? Which features are different? Which characteristics of organisms are important to consider? Animals are more than warm, furry, four-legged creatures! Because so many students seemed

Figure 3 **Is It an Animal?**

Life, Earth, and Space Science Assessment **Probes** 16

Is It an Animal?

Which of the organisms listed are animals? Put an X next to each organism that is considered to be an animal.

___ cow	___ spider	
___ tree	___ snail	
___ mushroom	___ flower	
___ human	___ monkey	
___ worm	___ beetle	
___ tiger	___ whale	
___ shark	___ frog	___ mold
___ starfish	___ chicken	___ snake

Explain your thinking. Describe the "rule" or reasoning you used to decide if something is an animal.

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to have a very narrow definition of *animal*, we need to diversify the organisms students come in contact with in our unit. We also realize we should give students real inquiry opportunities to observe and investigate real animals—not the papier-mâché variety.

Perhaps the most powerful learning from the experience of using a probe was the incredible depth of insight it provided to us as teachers. Using a probe that had been carefully designed to pull out some of the finer points and trouble spots based on cognitive research allowed us to "see" what was in the heads of our third graders, enabling us, in the future, to meet students where they were. The teacher notes that accompanied the assessment probe clearly indicated that we had overemphasized vertebrates, particularly mammals. We learned that the research shows that people have a limited understanding of the term *animal*.

Our intention in using the K-W-L strategy was to get information about the present thinking and understanding of third graders with respect to forests and animals. While this method did inform us of how students initially viewed the forest, it did not tell us all we needed to know about what students considered to be an animal. The forest was just a context for learning. A conception of "animal" was one of the ideas. We decided to have our students revisit their forest unit projects in the spring when we could go outside and visit a local woodland. We would design the experience to build on their prior learning, challenge their current ideas about what an animal is, and expand their classification of animals to include a variety of other animals found in the forest, such as salamanders, millipedes, worms, birds, beetles, moths, toads, spiders, snakes, and even people.

The notion of using formative assessment probes to regularly "check in" on students' ideas has spurred us to use additional probes to gather information that will help us provide a more flexible and suitable pathway for students' learning. From now on our unit planning will always be informed by results from probes. In addition, we have shared our student data with the grade 4 teachers. As a result of seeing what our students struggled with, next year they are going to use a modified version of the same probe using ocean animals as part of their ocean unit, to see if the same students revert back to their preconceived ideas. As a result of what we found out, we will all be sure to develop the idea of what an animal is, using a variety of contexts and examples.

Middle School Vignette: Using the Probe "Wet Jeans"

In sixth grade we study the water cycle. Our unit builds on experiences students had in elementary grades learning about change in state and developing an academic vocabulary to describe water when it changes state. When students come to sixth grade, they still remember the water cycle song they learned in third grade and don't hesitate to use words like *evaporation* and *condensation*.

This year I decided to use the "Wet Jeans" probe (Figure 4) before planning instruction that would include a review of concepts like evaporation and condensation. These seemed like fairly simple concepts that most of my students would probably remember and understand. Nevertheless, it would be helpful to find out if there were any students who still didn't understand evaporation so that I could design special instruction for them before moving on to the next set of ideas.

Wow! I wasn't prepared for the results! Instead of just a few students not understanding where water goes after it evaporates, most of the students in my class had major misconceptions! Even though they could comfortably use the word *evaporation,* over 75% of my students thought the water went immediately up to the Sun or the clouds. A few thought it no longer existed.

As I read through the teacher notes that came with the probe and examined my students' responses, it was clear to me that they used the word *evaporation* without understanding. Furthermore, it seems that they missed the grades 3–5 idea described in the related standards from *Benchmarks* that states, "When liquid water disappears, it turns into a gas (vapor) in the air and can reappear as a liquid when cooled, or as a solid if cooled below the freezing point of water. Clouds and fog are made of tiny droplets of water" (AAAS 1993, p. 68). The research notes said students could understand this by fifth grade if they had received targeted instruction.

When I checked with the grades 3–5 teachers, they agreed that the idea of water existing in the air as water vapor was never explicitly

Figure 4 **Wet Jeans**

Life, Earth, and Space Science Assessment **Probes** 21

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 *an hour later*.

A It soaked into the ground.

B It disappeared and no longer exists.

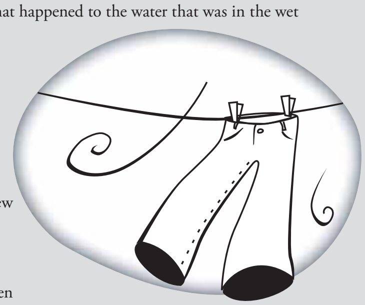
C It is in the air in an invisible form.

D It moved up to the clouds.

E It chemically changed into a new substance.

F It went up to the Sun.

G It broke down into atoms of hydrogen and oxygen.



Describe your thinking. Provide an explanation for your answer.

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addressed. Students did know the water disappeared, but they didn't know where it actually went or what form it was in. This indicated to me that I needed to provide an opportunity for students to understand that the water is in the air around us. Then I could move on to the more complex idea of the global water cycle.

I decided to present my students with several everyday phenomena such as water droplets on the outside of a cold beverage glass, moisture on the bathroom window, and dew on the morning grass. I asked them to explain how the water got there, and they all answered "condensation and evaporation." However, when I pressed them to explain to me how the water actually got there, they had all sorts of interesting explanations. Only a few mentioned the water was in the air that came in contact with the object in question. I challenged students to think of a way they could prove where the water came from, and this led to a variety of interesting investigations. Eventually most students began to accept the idea that the water was in the air in a form they could not see. I also found this was an opportune time to tie the idea to conservation of matter so that students would understand that the water did not disappear in the sense that it no longer existed but rather it was just in a different form and different place.

Once my students could understand the meaning behind the terms *evaporation* and *condensation*, I would use these terms to discuss the processes that contribute to the water cycle. The teacher notes that came with the probe pointed out the flaws in water cycle diagrams. To see if my students continued to accept the idea that water goes into the air initially before some of it travels upward to form clouds, I showed them a picture of the water cycle with an upward arrow pointing from a lake to a cloud. I asked them if that was a correct representation of evaporation. Most of my students pointed out that the diagram makes it look like water goes immediately up to a cloud, rather than existing in the surrounding air. I thought it was a good idea to have students discover this potential misrepresentation for themselves, as this is often the way the water cycle is illustrated in their textbooks.

I don't think I would have realized my students had this idea if I hadn't used the probe and combined my students' results with the readings that were in the probe teacher notes. It is quite possible that we would have covered the water cycle and my students would still believe that the water goes immediately up to the Sun or clouds. They would have passed a standardized assessment item asking them to label the process indicated by the upward arrow on a water cycle illustration and they would know the term, answer the test item correctly, yet still have misconceptions. Knowing the ideas they had about evaporation beforehand gave me an opportunity to design instruction to challenge their ideas and help my students develop a correct conception of where water goes after it evaporates and the form it takes.

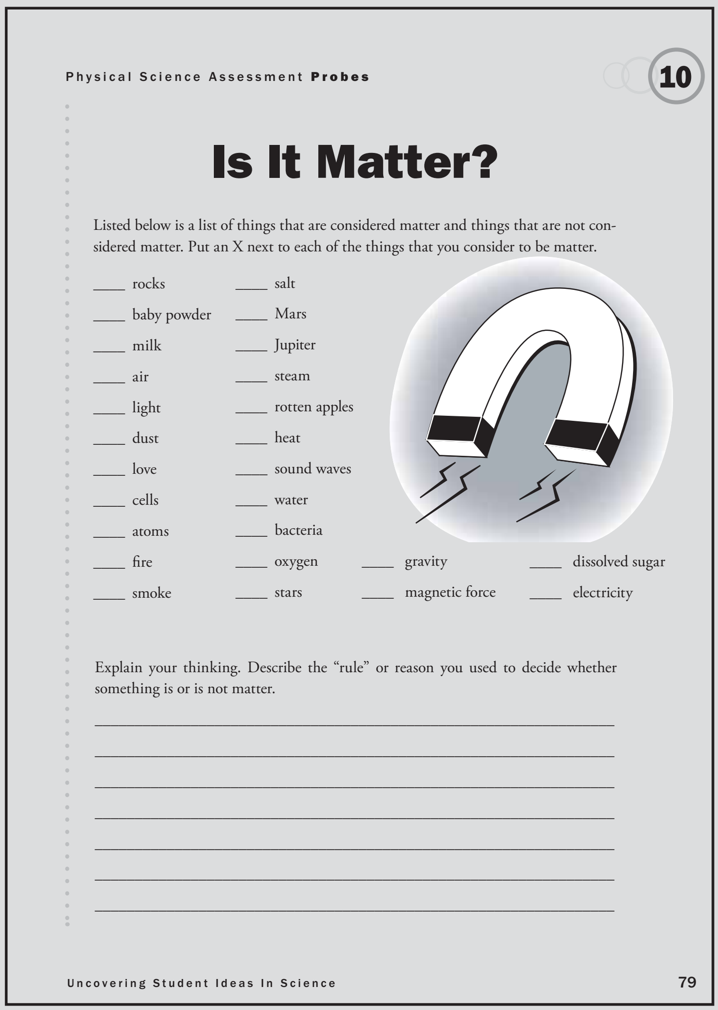
High School Vignette: Using the Probe "Is It Matter?"

This year, I have worked very hard to shift the focus of my chemistry strand in my ninthgrade, heterogeneously grouped integrated science class. One of my goals was to teach the concept of conservation of matter during chemical and physical changes. Understanding this concept will help students when they encounter stoichiometry as juniors in chemistry.

To start off my unit, I asked students to think about what might happen to the mass of solid or liquid matter as it underwent some sort of interaction (a physical or chemical change). After my students suggested a number of scenarios using solids and liquids, they developed and carried out a variety of investigations to test their ideas. Teams of students investigated materials that changed state, changed shape, dissolved, broke into separate pieces, or changed chemically. In general, students could accurately explain what happened to the mass in the experiments they carried out. Students developed a "rule" to explain their observations: "No matter what you do to the material, if nothing new is added or taken away, the mass will stay the same." This rule led to a formal definition of the conservation of matter.

After students had explored conservation of matter ideas in various contexts using solids and liquids, I decided to assess whether they would apply their present understandings to gases as well. I presented students with another scenario. I put an Alka-Seltzer tablet, flask of water, and an empty balloon on a scale. I asked students to predict what would happen to the total mass when the Alka-Seltzer tablet was placed in the flask of water and covered with a balloon. In the scenario it was explicitly stated that nothing could get in or out of the system. Surprisingly, when asked if matter would be con-

Figure 5 **Is It Matter?**



Physical Science Assessment **Probes** 10

Is It Matter?

Listed below is a list of things that are considered matter and things that are not considered matter. Put an X next to each of the things that you consider to be matter.

____ rocks	____ salt		
____ baby powder	____ Mars		
____ milk	____ Jupiter		
____ air	____ steam		
____ light	____ rotten apples		
____ dust	____ heat		
____ love	____ sound waves		
____ cells	____ water		
____ atoms	____ bacteria		
____ fire	____ oxygen	____ gravity	____ dissolved sugar
____ smoke	____ stars	____ magnetic force	____ electricity

Explain your thinking. Describe the "rule" or reason you used to decide whether something is or is not matter.

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served, a number of students said no because there was a gas in the balloon and gases don't weigh anything. Other students stated that the mass was not conserved because the tablet had dissolved into a powder that was weightless. I wondered where these ideas came from. Could my students be lacking a scientific conception of matter?

I decided to use a formative assessment probe to find out what my students' conception of matter was. I specifically wanted to find out what things they thought were matter and what things were not and what their "rule" was for defining matter. I gave them the probe in Figure 5.

I was quite surprised when I looked through the student work. Several students identified gravity, light, magnetic force, fire, and heat as matter while not marking air, cells, stars, dust, and dissolved sugar as matter. A number of students did not mark atoms as matter! What was going on here? Students listed several interesting reasons as their basis for classifying materials as matter or not matter, including that it has to be felt, it needs to be visible, it has to have weight, and the definition "matter is anything that has mass and occupies space." Yet they failed to recognize several forms of matter, such as air having mass, or they mistakenly identified forms of energy as having mass and volume. What was getting in the way of my students' understanding? Several students recalled a definition of *matter* but had difficulty applying it. If they didn't have a correct conception of matter, how could they apply conservation of matter ideas?

After reviewing the student work from the probe "Is It Matter?," I decided to investigate student thinking even further by observing students as they talked about their ideas with each other. The teacher notes that came with the probe described a method of card sorting that could give me additional information. I presented small groups of students with the items from the task on cards and asked them to sort them into two piles—a "matter" pile and "not matter" pile. This method allowed me to watch the faces of students as they worked through the exercise and discussed their ideas with their peers. Students hesitated when they were unclear or struggling with an example such as air, dissolved sugar, or sunlight. Occasionally, students would move cards as they reconsidered earlier choices, indicating uncertainty on their part.

Periodically, I asked students to explain why they had placed an item in a particular category and asked for elaboration when I wanted to explore a particular student's idea further. These observations and additional probing provided further evidence that my students were lacking a correct conception of matter. Furthermore, the research summaries described in the teacher notes confirmed what I was hearing from my students—in particular, the idea that gases do not have material character and thus are not considered matter.

I examined the suggestions for instruction and assessment provided in the teacher notes. I began to consider the contexts in which students had explored matter thus far and how these experiences might have influenced the patterns that were emerging in this set of student work. Had most of their experiences been with matter that they could see? How much experience had they had with gases? What kinds of experiences had they had in earlier grades with weighing and finding volumes? Were some of the items on the list more difficult for them to think about? Did they know what *mass* and *volume* mean? In which grade had they developed an operational definition of *matter*? It seemed as if the definition they were using was memorized without any understanding.

Despite the fact that I had revised my unit to more deliberately target conservation of matter ideas in a variety of contexts, I had missed a critical piece in my planning. Even though my students could express conservation of matter ideas and conserve matter in a number of situations, they would not be able to fully comprehend the idea of conservation of matter without a clear understanding of what matter is. I had been using the term *matter* throughout the unit assuming that students had this prerequisite knowledge. The word *matter* is everywhere! In prior grades we refer to "properties of matter," "changes in matter," and "states of matter," but we fail to first help students develop a conception of what constitutes matter. Even though we were investigating forms of matter and conserving matter, I found it was worth taking the time to make sure that my students have a conception of what matter is. I will change my activities to explicitly address and challenge my students' conception of matter, particularly regarding gases and dissolved substances.

Concept Matrices and Probe Set

The remainder of this book contains a set of 25 probes that you can use with your students along with accompanying teacher notes for each probe. The concept matrices (p. 24 and 116) indicate the concepts most related to each probe and can be used to select probes that match your instructional context. In this volume we focus on the following topics: forms of matter; changes in matter; light, heat, and sound energy; living things and life processes; cells; weathering and erosion; phases of the moon; and gravity. Later volumes will include additional topics in life, Earth, space, and physical science.

References

American Association for the Advancement of Science (AAAS). 1993. *Benchmarks for science literacy*. New York: Oxford University Press.

Atkin, J. M., and J. E. Coffey, eds. 2003. *Everyday assessment in the science classroom.* Arlington, VA: NSTA Press.

Black, P., C. Harrison, C. Lee, B. Marshall, and D. Wiliam. 2003. *Assessment for learning: Putting it into practice*. Berkshire, England: Open University Press.

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

Donovan, M. S., and J. Bransford. 2005.

How students learn science in the classroom. Washington, DC: 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: RoutledgeFalmer.

Keeley, P. 2005. *Science curriculum topic study: Bridging the gap between standards and practice.* Thousand Oaks, CA: Corwin Press.

Maine Department of Education. 1997. *Maine's learning results*. Augusta, ME: Maine State Government Printing Office.

Minstrell, J., and E. van Zee. 2003. Using questioning to assess and foster student thinking. In *Everyday assessment in the science classroom*, eds. J. M. Atkin and J. E. Coffey, 61–73. Arlington, VA: NSTA Press.

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

Pelligrino, J., N. Chudowksy, and R. Glaser. 2001. *Knowing what students know: The science and design of educational assessment.* Washington, DC: National Academy Press.

Sneider, C. 2003. Examining students' work. In *Everyday assessment in the science classroom,* eds. J. M. Atkin and J. E. Coffey, 27–40. Arlington, VA: NSTA Press.

Stavy, R., and D. Tirosh. 2000. *How students (mis-) understand science and mathematics: Intuitive rules.* New York: Teachers College Press.