## VOL 1. SECONDEDITION UNCOVERING STUDENTIDEAS IN SCIENCE 25 FORMATIVE ASSESSMENT PROBES





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By Page Keeley





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Cataloging-in-Publication Data for this book and the e-book are available from the Library of Congress. ISBN: 978-1-68140-563-6 e-ISBN: 978-1-68140-564-3

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## Preface



Uncovering Student Ideas in Science, Volume 1, Second Edition: 25 Formative Assessment Probes updates the 2005 version by including a Spanish language version for each student probe page, adding current research summaries, linking to related ideas in A Framework for K–12 Science Education (the Framework; NRC 2012) and the Next Generation Science Standards (NGSS; NGSS Lead States 2013), adding new instructional suggestions and National Science Teachers Association (NSTA) resources, and making minor changes to the text in a few of the probes.

Similar to the other books in the Uncovering Student Ideas in Science series, this book provides a collection of unique questions, called formative assessment probes, purposefully designed to reveal preconceptions students bring to their learning and to identify misunderstandings students develop during instruction that may go unnoticed by the teacher. Each probe is carefully researched to develop distracters that mirror commonly held ideas students have about concepts or phenomena. Although a suggested grade level is provided, the probes are not grade-specific. They are designed to be used across multiple grade spans as well as with adults for professional learning or preservice education; especially since alternative ideas that go unchallenged will often follow students from one grade to the next, right into adulthood. The 25 probes in this book are organized into two sections: Physical Science Probes (Section 1) and Life, Earth, and Space Science Probes (Section 2). A concept matrix precedes each section.

## Teacher Notes That Accompany the Probes

Each of the 25 formative assessment probes includes detailed background information for teachers. These "Teacher Notes" are a vital component of this book, and should always be read before using a probe. This section

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describes the components included in each set of Teacher Notes.

## 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" (Pellegrino, Chudowsky, and Glaser 2001, p. 178). This section describes the purpose of the probe-that is, what you will learn about your students' ideas as you use the probe. It begins by describing the overarching concept the probe targets, followed by the specific idea the probe elicits. Before choosing a probe, it is important to understand what the probe is intended to reveal about students' thinking. Taking time to read the purpose will help you decide if the probe will provide the information you need to plan responsive instruction and attend to students' thinking.

### **Type of Probe**

This section describes the format used to develop the probe. Common formats used in this book include justified lists, friendly talk, opposing views, and P-E-O (predict-explainobserve). Similar to the crosscutting concept of structure and function, in which structure often determines function, the format of a probe is related to how a probe is used. For example, justified list probes, such as "Making Sound" on page 37, are often used to determine whether students can use a concept beyond the context in which they learned it. Friendly talk probes, such as "Human Body Basics" on page 151, are designed to model and encourage sharing of ideas. Opposing views probes, such as "Talking About Gravity" on page 99, provide an opportunity for students to engage in argumentation over two different points of view. P-E-O probes, such as "Ice Cubes in a Bag" on page 45, are followed by an investigation

in which students can compare their initial prediction to their observation and revise their explanation when their observations do not support their prediction.

## **Related Concepts**

Each probe is designed to target one or more concepts that develop across multiple grades at increasing levels of sophistication. A concept is a one-, two-, or three-word mental construct used to organize the ideas the probe addresses (Konicek-Moran and Keeley 2015). Examples of concepts used in this book include light reflection, conservation of matter, transfer of energy, Moon phases, cells, evaporation, and living. Concepts make up the disciplinary core ideas in the Framework (NRC 2012) and the NGSS (NGSS Lead States 2013). Multiple probes may be used to address a concept. For example, four probes in this book address the concept of conservation of matter. A concept matrix is included at the beginning of the book's two sections (see pp. 16 and 124).

## Explanation

The *best answer* choice is provided in this section. *Best answer* is used rather than *correct* or *right answer* because the probes are not intended to pass judgment on whether students are "right or wrong." Instead, they are used to encourage students to reveal their *best thinking so far* without the worry of being "wrong." Sometimes there is no single "right" answer because the probe may uncover different ways of thinking that sometimes support an alternative answer choice. In many ways, the "best answer" mirrors the nature of science as scientists initially share their best thinking and modify their explanations as they gather more evidence.

A brief scientific explanation is provided for teachers to help them understand the scientific content that underlies the probe and clarify misunderstandings students (and teachers) may have related to the content. The explanations do not give detailed scientific background knowledge. They are provided to support teachers' basic content knowledge. Teachers with limited coursework or professional development in science, new to teaching science, or teaching outside their disciplinary major in science actively seek to build and expand their content knowledge. Therefore, the explanations are carefully written to avoid highly technical language and complex descriptions so that a teacher does not have to specialize in an area of science to understand the explanation. At the same time, the challenge is to not to oversimplify the science. The probe explanations are carefully constructed to provide the concise information a novice would need to understand and respond to students' thinking.

## Curricular and Instructional Considerations

The curricular and instructional considerations give insight into how concepts and specific ideas are addressed and how they progress at different grade spans. 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. Since the probes are not gradelevel specific, this section helps determine where and how a probe fits into teaching and learning. For example, the information might be useful for planning instruction when a core idea 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. This section is also helpful in determining whether modifications should be made to the probe to appropriately assess the level of complexity expected at different grade levels.

## Administering the Probe

This section provides intended grade levels for using the probe and suggestions for administering the probe to students. The section may also include response methods, ways to use props or demonstrate the probe scenario, modifications for differentiation, or use of a formative assessment classroom technique (FACT).

## Related Disciplinary Core Ideas From the *Framework* (NRC 2012)

The Framework is the primary source document that has informed the development of many recent state standards and will continue to inform most states' standards development as their standards come up for revision. This replaces previous standards-related documents referred to in the first edition, such as the Benchmarks for Science Literacy (AAAS 1993) and the National Science Education Standards (NRC 1996). This section lists the disciplinary core ideas from the Framework that are related to the probe. Because the probes are not designed as summative assessments, this section is not considered an alignment, but rather identifies ideas that are related in some way to the probe. Sometimes these ideas are an exact match to the probe at a specific grade level. Other times students may use ideas to develop an understanding of a disciplinary core idea. Seeing a related core idea that precedes a grade level is useful when using the probe, as is seeing the core idea that builds on the probe at the next grade level. In other words, teachers can see how the foundational ideas they teach relate to a spiraling progression of understanding as students move from one grade level to the next.

While this section describes the disciplinary core ideas related to the probe, keep in mind that the probes also provide opportunities for students to use scientific and engineering practices as well as crosscutting concepts. For

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example, all of the probes address the practice of constructing explanations since the second part of every probe asks students to provide an explanation. Additional ways to support the use of the scientific practices and crosscutting concepts may be included for each probe in the Suggestions for Instruction and Assessment section.

## Related NGSS Performance Expectations (NGSS Lead States 2013)

The performance expectations in the NGSS describe how students will be assessed and show how all three dimensions (science and engineering practices, disciplinary core ideas, and crosscutting concepts) converge to provide evidence of student understanding. The probes are not intended to be a performance assessment. Instead they provide valuable information to the teacher that will help determine students' instructional path and readiness for assessment and give feedback to the students that may help them revise or solidify their initial ideas as they move toward a performance expectation.

## **Related Research**

Each probe is informed by research when available. Much of the research on students' alternative conceptions was conducted in the 1980s and 1990s. Two comprehensive sources of these research summaries available to educators that are still relevant today are Chapter 15 in the Benchmarks for Science Literacy (AAAS 1993) and Making Sense of Secondary Science: Research Into Students' Ideas (Driver et al. 1994). In addition to drawing upon these sources, recent research from science education journals is cited where available. Although many of the research citations describe studies that have been conducted in past decades as well as studies that include children outside the United States, most of these studies' results are considered timeless and universal. Whether students develop their ideas in the United States or other countries, research indicates that many of these commonly held ideas are pervasive regardless of geographic boundaries and societal and cultural influences.

For some concepts, few or no formal research studies have been conducted to identify and describe commonly held ideas or difficulties students may have related to the probe. For probes that lack formal research studies on commonly held ideas, this section may describe common ideas that surfaced during the fieldtesting of the probe or similar findings from teachers who have used the probe.

Although your students may have different backgrounds, experiences, and contexts for learning, the descriptions from the research can help you better understand the intent of the probe and the kinds of thinking your students are likely to reveal when they respond to the probe. The research also helps you understand why the distracters are written a certain way, as they are often intended to mirror research findings. As you use the probes, you are encouraged to seek new and additional published research, engage in your own action research to learn more about students' thinking, and share your results with other teachers to extend and build on the research summaries in the Teacher Notes. To learn more about conducting action research using the probes, read the Science and Children article "Formative Assessment Probes: Teachers as Classroom Researchers" (Keeley 2011), or read Chapter 12 in the book What Are They Thinking? Promoting Elementary Learning Through Formative Assessment (Keeley 2014).

## **Related NSTA Resources**

This section includes updated resources related to a probe available through NSTA, including journal articles, NSTA Press books, online NSTA Science Objects, and archived NSTA webinars. If you are an NSTA member, you have online access to all the NSTA journals, regardless of which journal you subscribe to.

## Suggestions for Instruction and Assessment

Uncovering and examining the ideas children bring to their learning is considered diagnostic assessment. Diagnostic assessment becomes formative assessment when the teacher uses the assessment data in a feedback loop to make decisions about instruction that will move students toward the intended learning target. Thus, for the probe to be used formatively, a teacher needs to think about how to choose or modify a lesson or activity to best address the ideas students bring to their learning or the misunderstandings that might surface or develop during the learning process.

As you carefully analyze your students' responses, the most important next step is to make an instructional decision that would work best in your particular context. This includes considering the learning goal, your students' ideas, the materials you have available, and the diverse learners you have in your classroom.

The suggestions provided in this section have been gathered from the wisdom of teachers, the knowledge base on effective science teaching, and research on specific strategies used to address commonly held ideas and conceptual difficulties. These suggestions are not lesson plans, but rather brief recommendations that may help you plan or modify your curriculum or instruction to help students move toward learning scientific ideas. It may be as simple as realizing that you need to provide a relevant, familiar context, or there may be a specific strategy, resource, or activity that you could use with your students. Learning is a complex process and most likely no single suggestion will help all students learn. Formative assessment encourages thinking carefully about the instructional strategies, resources, and experiences needed to help students learn scientific ideas.

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 and understanding. This section points out other related probes in the *Uncovering Student Ideas in Science* series that can be modified or used as is to further assess students' conceptual understanding. It may also provide suggestions for ways to use scientific practices or crosscutting concepts to support three-dimensional learning when using a probe.

When applicable, this section includes safety notes for the proposed suggestions. These guidelines should be adopted and enforced to provide for a safer learning and teaching experience. Teachers should also review and follow local polices and protocols used within their school and school district. For additional safety information, read NSTA's "Safety in the Science Classroom" article (*www.nsta.org/ pdfs/SafetyInTheScienceClassroom.pdf*) or visit the NSTA Safety Portal (*www.nsta.org/safety*).

## References

References are provided for the information cited in the Teacher Notes.

## **Connection to Other Formative Assessment Resources**

Now that you have the background on the probes and the Teacher Notes in this updated version of *Uncovering Student Ideas in Science, Volume 1: 25 Formative Assessment Probes,* remember that a probe is not formative unless you use the information from the probe to modify, adapt, or change your instruction so that students have the opportunity to learn the important scientific ideas. As a companion to this book and all the other volumes in this series, NSTA has co-published the books *Science Formative Assessment, Volume 1,* 

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Second Edition: 75 Practical Strategies for Linking Assessment, Instruction, and Learning (Keeley 2016) and Science Formative Assessment, Volume 2: 50 More Strategies for Linking Assessment, Instruction, and Learning (Keeley 2015). In these books, you will find a variety of techniques to use along with the probes, to facilitate elicitation, support metacognition, spark investigation, encourage discussion, monitor progress toward conceptual change and understanding, encourage feedback, and promote self-assessment and reflection. In addition, these formative assessment classroom techniques (FACTs) provide opportunities for students to use scientific practices such as modeling, designing investigations, argumentation, and explanation construction.

Finally, a primary purpose of formative assessment is to break away from teaching and assessing disconnected facts and an overemphasis on selecting activities to support conceptual learning of science by understanding what students are thinking before, during, and after instruction. Because conceptual change is the underpinning of the Uncovering Student Ideas in Science series, the NSTA book Teaching for Conceptual Understanding in Science (Konicek-Moran and Keeley 2015) is highly recommended as a resource to extend your learning. The book includes chapters on understanding the nature of students' thinking; instructional models and strategies that support conceptual change; and ways to link assessment, instruction, and learning.

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## Acknowledgments

I would like to thank Francis Eberle and Lynn Farrin for their initial feedback and contributions to developing the Teacher Notes for the first edition of this book. Also, gracias to my trilingual niece, Barbara Donaldson, for your superb work in translating the probes into Spanish. In addition, I would like to thank Karen Norris and her colleagues at the Momentous Institute for reviewing the translations as well as making elementary science a priority for the children at their outstanding school in Dallas, Texas. I thank Jose Rivas, an outstanding physics teacher from the Lennox Academy in Lennox, California, for his assistance in reviewing the Spanish translations. I would also like to give a huge thank you to the thousands of teachers across the United States and internationally who have used these probes and shared their experiences with me. I will never tire of hearing how this series has transformed teaching and learning in your K-12 and university classrooms! A huge thanks to Linda Olliver, an extraordinarily talented artist who has an amazing knack for transforming the ideas in a probe into visual representations. And of course my heartfelt, deepest appreciation goes to Claire Reinburg, Donna Yudkin, Rachel Ledbetter, and the outstanding staff at NSTA Press who so artfully bring my work to fruition and publish the best books in science education!

## **About the Author**



**Page Keeley** is the primary author of 11 books in the *Uncovering Student Ideas in Science* series. Her assessment probes and FACTs (formative assessment classroom techniques) are widely used by K–12 teachers, university profes-

sors, and professional development and science specialists throughout the United States and internationally. Page "retired" from the Maine Mathematics and Science Alliance (MMSA) where she had been the senior science program director since 1996, directing projects in the areas of leadership, coaching and mentoring, linking standards and research, and science and literacy. She has been a principal investigator and project director of three major National Science Foundation (NSF)-funded projects: the Northern New England Co-Mentoring Network (NNECN), Curriculum Topic Study (CTS), and Phenomena and Representations for Instruction of Science in Middle School (PRISMS). Today she works as an independent consultant, speaker, and author providing professional development to school districts and organizations in the areas of science and STEM formative assessment, understanding student thinking, teaching science for conceptual understanding, and designing effective instruction.

Page is a prolific author of 18 national bestselling and award-winning books in science and mathematics education. Several of her books have received national distinguished awards in educational publishing. She has authored numerous journal articles and contributed to several book chapters. She also develops formative assessment probes for McGraw-Hill's middle and elementary school science programs.

Prior to joining the Maine Mathematics and Science Alliance in 1996, Page taught middle and high school science for 15 years. At that time she was an active teacher leader at the state and national levels, serving as president of the Maine Science Teachers Association and NSTA District II Director and NSTA Executive Board member from 1994 to 1997. She received the Presidential Award for Excellence in Secondary Science Teaching in 1992, the Milken National Distinguished Educator Award in 1993, and the AT&T Maine Governor's Fellowship in 1994. Since leaving the classroom in 1996, her work in leadership and professional development has been nationally recognized. In 2008, she was elected the 63rd president of the National Science Teachers Association (NSTA). In 2009, she received the National Staff Development Council's (now Learning Forward) Susan Loucks-Horsley Award for Leadership in Science and Mathematics Professional Development. In 2013, she received the Outstanding Leadership in Science Education Award from the National Science Education Leadership Association (NSELA). She has served as an adjunct instructor at the University of Maine, was a Cohort 1 Fellow in the National Academy for Science and Mathematics Education Leadership, was a science literacy leader for the AAAS/Project 2061 Professional Development Program, and

## **About the Author**

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Before entering the teaching profession, Page was the research assistant for immunogeneticist Dr. Leonard Shultz at the Jackson Laboratory of Mammalian Genetics in Bar Harbor, Maine. She received her BS in life sciences from the University of New Hampshire and her MS in science education from the University of Maine. In her spare time she enjoys travel, reading, fiber art, and photography, and also dabbles in modernist cooking and culinary art. A Maine resident for almost 40 years, Page and her husband recently moved to Fort Myers, Florida.

You can contact Page through her website at *www.uncoveringstudentideas.org.* You can follow her on Twitter at @CTSKeeley or on Facebook at Uncovering Student Ideas in Science and Mathematics.



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 and Formative Assessment Probes

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)

"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" (Pellegrino, Chudowsky, and Glaser 2001, p. 225). Teachers assess students every day, both formally and informally. Throughout an instructional unit or lesson, teachers assess students in various ways, including individual, small-group, or whole-class elicitation questions; student interviews; observations of students while they are engaged in an activity; informal conversations; journaling; performance tasks; presentations; and even traditional assessments such as quizzes or tests after a lesson or unit.

Classroom assessment is continuous and provides teachers with a rich set of data about student learning. Teachers have control over classroom assessment, unlike standardized testing. Classroom assessment serves multiple purposes, including diagnosing, monitoring, providing feedback, evaluating, and measuring. Each classroom assessment type also links to

Type of Classroom Assessment	Purpose	Stage in an Instructional Sequence
Diagnostic	To identify preconceptions and	Pre-instruction
	learning difficulties	During instruction
Formative	To provide information that is	Pre-instruction
	used to inform instruction and provide feedback to the learner	During instruction
		Post-instruction
Summative	To evaluate and measure the extent to which students have met a learning target	Post-instruction
<i>Note:</i> The probes in this book are c information is used by the teacher	liagnostic in nature. They become forr and the student.	mative when the

### Table 1. Purposes and Stages of Classroom Assessment

stages in an instructional cycle, ranging from a single lesson or set of lessons that are part of a unit to a full unit of instruction. The three types of classroom assessment, their purpose, and stage in instruction are described in Table 1. However, for classroom assessment to be considered "formative," teachers must use the data to modify the curriculum, alter their teaching, or provide feedback to their students. That is the type of assessment this book is about. These are assessments *for* learning, rather than assessments *of* learning. The preposition makes a difference!

Dylan Wiliam describes five strategies for formative assessment (Wiliam 2011, p. 46):

- 1. Clarifying, sharing, and understanding learning intentions and criteria for success
- 2. Engineering effective classroom discussions, activities, and learning tasks that elicit evidence of learning
- 3. Providing feedback that moves learning forward
- 4. Activating learners as instructional resources for one another

## 5. Activating learners as owners of their own learning

Formative assessment encompasses all five of these strategies. Each strategy involves different techniques and tools used to implement the strategy. You might be wondering how formative assessment probes fit with these five strategies. Each formative assessment probe in this book is considered a technique or tool rather than a strategy. Probes are particularly useful in enacting the second strategy on Wiliam's list—elicitation.

A key stage in an instructional sequence, whether you are using the 5E model, the Conceptual Change Model (CCM), or another instructional model, is elicitation. Elicitation gives students the opportunity to surface and explain their initial ideas as they begin a sequence of learning. "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). Another group of researchers puts 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" (Pellegrino, Chudowsky, and Glaser 2001, p. 91).

The probes in this book are powerful techniques or tools to use for elicitation and are consistent with current research on effective instruction and how students learn. However, they are used not only at the beginning of instruction to surface prior ideas and ways of thinking students bring to their learning, but also throughout a sequence of instruction to gather evidence of how students' ideas are evolving. Whether students change their ideas when confronted with new or more powerful evidence or build on and solidify their initial basic understanding, the probes become a central part of instruction in determining where students are at any point in time in moving toward a learning target. Probes are also used at the end of a sequence of instruction, not as summative assessments but as opportunities for students to reflect back on their learning and recognize how their ideas have changed. Whether used before, during, or at the end of instruction, the formative assessment probes in this book will occupy a central position in classroom assessment as long as they are used to inform instruction and engage students in learning science.

## What Are Formative Assessment Probes and Why Should Teachers Use Them?

Now that you know how this book fits into classroom assessment, particularly formative assessment, you might be wondering how a formative assessment probe is different from other types of questions and assessments. First, consider the name, formative assessment probe. Why are these questions called probes? Think about how the word *probe* is used in other contexts. For example, NASA sends probes into space to gather information that cannot be obtained with ordinary land instruments. A doctor inserts a probe into a patient's body to see things that cannot be observed from outside the body. You may have used a probe during Thanksgiving-the white plastic temperature probe that pops up when your turkey is fully cooked, since you cannot tell by merely looking at it. Formative assessment probes are similar. They tell you what students really think and have inside their heads, rather than what students think the teacher wants to hear. They provide information about students' ideas that typical questions and assessments do not reveal. However, to be formative, the information must be used to make instructional decisions and promote learning, otherwise a probe is merely a diagnostic assessment.

Every probe is a two-tiered question-a type of enhanced multiple-choice question. The first tier consists of an engaging prompt and selected answer choices that include distracters and a best answer choice. The reason for providing selected answer choices rather than open-ended questions is that that students are less apt to leave a question blank or say "I don't know" if there is an answer choice that is similar to what students already have in their heads. Since the answer choices are designed to mirror the research on commonly held ideas, it is highly likely that students will select one that is similar to their thinking. The second tier is the explanation, where students have to explain their thinking in support of their answer choice. This is where, as a diagnostician, teachers can really get into their students' heads and understand their thinking. Because students already have an idea to support (their

answer choice), constructing an explanation comes easier to them than if they did not have anything to start with.

Asking students to describe a rule often leads to uncovering intuitive rules, such as "more A equals more B" (Stavy and Tirosh 2000). This rule simply means if you have more of one characteristic (such as mass or volume), then other characteristics increase (such as density and boiling point). This strongly held rule is often applied in a variety of physical, Earth, and life science contexts and seems to contribute 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 give teachers a detailed glimpse into their thinking.

Other features of the probes include an engaging title; a visual to spark thinking, especially for visual learners; and an avoidance of unfamiliar terminology so that the focus is on conceptual understanding, not vocabulary.

Formative assessment probes enable teachers to probe for and quickly and efficiently examine a multitude of ideas their students hold, including misconceptions and partially correct ideas. Many educators and researchers prefer to collectively call these ideas *alternative* conceptions-meaning that students' ideas are not always completely wrong, even though they may differ from those of a scientist (Sneider 2003). For this book, these ideas will be referred to as misconceptions, generally meaning ideas that are not completely scientifically correct. The probes also uncover critical-thinking and reasoning strategies students use to support their ideas. These strategies can be based on intuition, logic, everyday experiences, or application of scientific knowledge.

Why is it important for teachers to take the time to uncover the ideas their 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 and phenomena even before they are formally taught scientific ideas in school. Sometimes these ideas are congruent with scientific explanations. Other times they conflict with the scientific view. This formation of students' own ideas, which may be correct, partially correct, or incorrect, continues throughout their K-12 school years regardless of whether the scientific ideas are taught in the science class. If these initial ideas are ignored, they may get in the way when new ideas are introduced. They do not simply go away, even as students progress from elementary grades to middle school and even into high school and adulthood. Surprisingly, many probes in this book reveal that high school students have 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 their students' own ideas to scientifically accepted views. To do this, teachers must know what their students' starting points are so that they can provide instructional opportunities that support the development of conceptual understanding. Sometimes this involves uncovering ideas that teachers assume students learned in previous grades.

## **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 probe. Writing an individual response to the probe is one way of making students' own thinking visible and interesting them in the ideas they will be learning about. At the same time, writing a response encourages students to pay careful attention to the reasoning they use to support their ideas.

The probes can also be used in a talk format to engage small or large groups of students in discussion. Using a probe to elicit individual ideas first and then asking students to share and discuss their ideas with others provides you with valuable assessment information and at the same time supports student learning as they talk through their ideas and serve as resources for each other. The process of making students' thinking explicit through discourse serves a dual purpose. First, it allows teachers to see the range of ideas students have so they can provide adaptive instruction. 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 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" and then moves on to ask another question (Minstrell and van Zee 2003, p. 61). This typical pattern has been labeled I-R-E: initiate, respond, evaluate. In some science classrooms, teachers try to get students to accept "the right answer" rather than engaging them in discussion and argumentation 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 students' conceptions at any time during an instructional sequence and holding back on giving students the answer so they can come to discover it for themselves after they have had the opportunity to develop and use scientific ideas. Revisiting a probe after students have developed scientific ideas and giving students the opportunity to revise or strengthen their initial explanation is a powerful way to support *metacognition* thinking about one's thinking.

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, an extraordinary 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)

Several formative assessment classroom techniques (FACTs) can be used with the probes, such as card sorts, claim cards, and lines of agreement. Several of these techniques are suggested in the probes' Teacher Notes section. If you are not familiar with the FACTs, you are encouraged to refer to Science Formative Assessment, Volume 1, Second Edition: 75 Practical Strategies for Linking Assessment, Instruction, and Learning (Keeley 2016) and Science Formative Assessment, Volume 2: 50 More Strategies for Linking Assessment, Instruction, and Learning (Keeley 2015). Combined, these two resources contain 125 techniques that can help you build a repertoire of effective strategies when using the formative assessment probes.

The best way to learn how to use a probe is to try 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 may be problematic for certain students or grade levels. Modify the probe so that it best fits your individual circumstances and cultural context, but do not change it so much that it no longer probes what it was intended to uncover. Use the Teacher Notes (explained in the Preface) provided with each probe to consider implications for curriculum and instruction. The Teacher Notes provide support for summarizing, evaluating, and using the student learning data you collect. Above all, remember that for the probes to be formative you must use the information you gather to make better-informed instructional decisions.

## 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 real classroom teachers who have used the probes and shared their experiences.

## 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 our unit together to focus on interdependency in ecosystems and how some forest animals live in groups. The third-grade disciplinary core idea LS2.D (*Being part of a group helps animals obtain food, defend themselves, and cope with changes. Groups may serve different functions and vary dramatically in size.*)

was our main focus. Both of us had taught the forest unit for several years and had gathered an enormous number of resources and teaching activities about forest animals, especially wolves, bears, lynx, raccoons, deer, moose, squirrels, and even skunks. Because the examples we used in our previous unit were mostly mammals, and we narrowed the unit this year to focus on the difference between forest animals that live in social groups and forest animals that live alone, we wondered if we might be developing or even reinforcing a misconception that animals are mainly furry, four-legged creatures.

We both decided to use the probe "Is It an Animal?" to identify preconceptions students might have about animals before identifying animals that live in the forest in groups (Figure 1).

We decided to combine our two classes for this assessment activity. After making sure the students were familiar with each of the organisms listed, we had them work in pairs, preferably with a partner from the other class, to sort the examples listed into "animals" and "not animals" and come up with a rule that could be used to decide if something is an animal. After students worked in pairs, they formed small groups of six to discuss their ideas and come up with a list and rule to share with the whole class.

As we listened to the groups share their thinking and agree or disagree with one another, we noticed some commonalities. All





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of the groups easily identified the cow, tiger, and monkey as animals. Most identified the frog, chicken, and snake as animals. Fewer identified the shark, snail, starfish, human, and whale as animals. And none identified the worm, spider, or beetle as animals. Even more revealing were the rules the groups gave in deciding whether 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.

We were careful not to correct our students. We wanted them to freely share their thinking without worrying whether they were right or wrong. When they wanted to know what the right answer was, we told them that they would discover what scientists consider to be an animal in the next lesson and they would be able to go back and change their answers and rules if new information changed their thinking.

Clearly, our students had a limited concept of "animal." We decided to begin the next lesson by having them brainstorm a list of animals of the forest. Again, we noticed that they listed mainly mammals such as deer, bears, raccoons, chipmunks, and squirrels. We took this opportunity to explain that scientists consider an organism to be an animal if it has to obtain its food; has body parts for eating, moving, and sensing its environment; and is a size we can usually see with our eyes. We knew this was a simplistic definition but since our students were not familiar with cells or embryology, it was sufficient for third grade. We revisited the probe and decided which organisms fit a scientist's definition of an animal and why. One student even remarked, "We were thinking animals and mammals

were the same thing but now we know even insects and people are animals!" Next, students were challenged to expand their list of forest animals to include animals of the forest that were not mammals. We observed that that they were now including invertebrates and different classes of vertebrates. After eliminating the animals that do not live in the forest, we introduced the concept of animals that live in groups and have social behaviors, and how this benefits animals, by showing a video of a wolf pack. Next, we asked students to explain why the wolves live in packs. After additional research they conducted using available resources, the students worked together to construct an explanation of how living in groups benefits wolves. Students were then challenged to select forest animals from their previous list that they think live in groups (or add to the previous list), describe the size of their groups, and explain how living in a group benefits the animal.

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 trouble spots based on cognitive research allowed us to "see" what was in the heads of our third graders, enabling us to meet our students where they were. The Teacher Notes that accompanied the assessment probe clearly indicated that in the students' previous learning about animals there was an overemphasis on vertebrates, particularly mammals, that would have carried over into our forest unit. We learned that the research shows that it is common for younger students to have a limited concept of "animal." If we had focused only on the disciplinary core idea (DCI) and not checked to see how students interpreted each of the concepts that made up the DCI, we would not have realized that our students would limit themselves to thinking only about mammals that live in groups. Now during our

forest unit students were interested in learning more about the social and group behaviors of ants, termites, crows, bees, and even garter snakes that hibernate together in large groups.

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 lesson planning will always be informed by results from probes. In addition, we have shared our student data "Wet Jeans" probe (Figure 2) 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 didn't understand evaporation so that I could differentiate 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

with the K–2 teachers. As a result of what we learned about our students' concept of an "animal," the other teachers will be more intentional about making sure students recognize the diversity of animals that live in the environments they study.

## 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 from a solid, liquid, or gas. When students come to sixth grade, they still remember the water cycle song they learned in second grade and don't hesitate to use words like evaporation and condensation. This year I decided to use the

e	, Earth, and Space Science Probes	)
	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 <i>an hour later</i> .	
	A. It soaked into the ground.	
	B. It disappeared and no longer exists.	
	<b>C.</b> It is in the air in an invisible form.	
	<b>D.</b> It moved up to the clouds.	
	E. It chemically changed into a new substance.	
	F. It went up to the Sun.	
	<b>G.</b> It broke down into atoms of hydrogen and oxygen.	
	Describe your thinking. Provide an explanation for your answer.	

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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*, more than 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 any conceptual understanding. Furthermore, it seems that they don't recognize that water exists as a gas in the air around them. Students did know the water disappeared from the jeans, but they didn't know where it actually went before some of it made its way up into the atmosphere to eventually condense and form clouds. This indicated to me that I needed to provide an opportunity for students to understand that there is water in the air around us. Then I could move on to the more complex idea of the global water cycle that is in my grade-level standards.

I decided to confront my students with several everyday phenomena such as water droplets on the outside of a cold beverage glass on a hot day, moisture on the bathroom window after a hot shower, and dew on the morning grass when it hadn't rained and the sprinklers were not turned on. I asked them to explain how the water got there, and they all answered "condensation." 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 in the air in the form of a gas that came in contact with the colder object. I challenged students to think of a way they could show where the water came from, and this led to a variety of interesting demonstrations. 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 that always show large arrows pointing to a cloud, labeled "evaporation." 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 good representation of evaporation from the lake. Most of my students pointed out that the diagram makes it look like the evaporated 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 how this representation leads to a misinterpretation about the short-term process, even though it is commonly used in textbooks to show the long-term cyclic aspect of the water cycle.

I don't think I would have realized my students had this misconception if I hadn't used the probe and seen how my students' ideas were reflected in the research described in the Teacher Notes. It is quite possible that I would have covered the water cycle and my students would still believe that the water goes immediately up to the Sun or clouds. Knowing the ideas they had about evaporation and the water cycle 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 so they could explain several everyday phenomena.

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

This year, I have worked hard to shift the focus of the chemistry strand in my heterogeneously grouped ninth-grade integrated science class to conceptually understanding foundational concepts they will need when they take chemistry. One of my goals was to ensure that students understood and could apply the principle of conservation of matter during chemical reactions as well as physical changes. Understanding this principle will help students when they encounter stoichiometry as juniors in chemistry.

To start off my lesson, I asked students to think about what would happen to the mass of solid or liquid matter as it underwent some sort of physical or chemical change. After describing a variety of scenarios, they developed and carried out investigations to test their ideas. Interestingly, I noticed they focused on solids and liquids. 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 investigations 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 or mass. After students had explored conservation of matter phenomena 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 the balloon was sealed over the flask so nothing could leak in or out. The students watched as the balloon expanded. Surprisingly, when asked if matter would be conserved, a number

Figure 3. Is It Matter?



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 concept of matter? I went to NSTA's online NGSS hub, did a keyword search of the word *matter*, and found it appeared in 17 performance expectations, 52 disciplinary core ideas, and 15 crosscutting concepts. Surely students must have a concept of matter by the time they get to high school!

I decided to use a formative assessment probe to find out what my students' concept 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 "Is It Matter" probe in Figure 3 (see p. 11) as an exit ticket before they get to high school.

I was quite surprised when I looked through the student work that evening. Several students identified gravity, light, magnetic force, and heat as matter while not selecting air, cells, stars, dust, and dissolved sugar as matter. A number of students did not even select atoms as matter! What was going on here? Students listed several reasons as their basis for classifying materials as matter or not matter, including that it has to be tangible, 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, as having mass, or they mistakenly identified energy as having mass and volume. What was getting in the way of my students' understanding of this concept they had learned about since elementary school?

Several students recalled a definition of *matter* but had difficulty applying it. If they didn't have a correct concept of matter, how

could they apply conservation of matter ideas? After reviewing the student work from the "Is It Matter?" probe, I decided to investigate student thinking even further by carefully listening to students as they talked about their ideas with one another. The Teacher Notes that came with the probe mentioned card sorting as a strategy I could use. I put students in small groups of 3-4, gave them a set of cards with examples of matter and non-matter printed on each one. I asked them to sort the cards into three columns-a "matter" column, a "not matter" column, and a third column for the ones they were unsure about or did not all agree on. This method allowed me to observe students as they sorted the cards 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.

Periodically, I asked students to explain why they had placed a card in a particular column 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 scientific concept 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 in previous grades and how these experiences may 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 or finding mass and volumes? Were some of the items on the list more difficult for them to think about? Did they know what *mass* and *volume* are? 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 were not 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 my lessons assuming that high school 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 concept 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 had a concept of what matter is. I changed my lesson to explicitly address and challenge my students' concept of matter, particularly regarding things they cannot see or touch.

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## **Cookie Crumbles**

Imagine you have a whole cookie. You break the cookie into tiny pieces and crumbs.

You weigh all of the pieces and crumbs. How do you

think the weight of the whole cookie compares to

- the total weight of all the cookie crumbs? Circle
- the best answer.
- **A.** The whole cookie weighs more than all of the cookie crumbs.
- **B.** All of the cookie crumbs weigh more than the whole cookie.

**C.** The whole cookie and all of the cookie crumbs weigh the same.

Describe your thinking. Provide an explanation for your answer.





## Las Migas de la Galleta

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## **Cookie Crumbles**

## **Teacher Notes**



## Purpose

The purpose of this assessment probe is to elicit students' ideas about conservation of matter. The probe is designed to reveal whether students think weight is conserved when a whole object is broken up into small pieces.

## **Type of Probe**

P-E-O

## **Related Concepts**

Conservation of matter, weight, physical change

## **Explanation**

The best response is C: The whole cookie and all of the cookie crumbs weigh the same. The total weight of the parts, in this case the cookie crumbs, is equal to the weight of the unbroken cookie. The only thing that changed was the shape and arrangement of the cookie; no new matter was added or taken away. Conservation of matter is a physical principle that applies to ordinary changes in objects as well as to physical and chemical changes in substances. In both cases, matter cannot be created or destroyed in an ordinary physical or chemical change.

## Curricular and Instructional Considerations

## Elementary Students

Conservation reasoning begins in the elementary grades with explaining changes in objects or materials. Students should know that the sum of the weight of the parts of an object is the same as the weight of the whole object. The property of weight, instead of mass, is used here as students below grade 5 may not be familiar with the term *mass*, which is introduced in middle school. Using the word *mass* before students are ready to comprehend its meaning may cause students to confuse the word with *massive*, thus equating mass with size. This probe is useful in determining students' preconceptions about conservation of parts and wholes before formal instruction.



## Middle School Students

In middle school, students progress from conservation of matter ideas about objects and materials to conservation of matter ideas involving physical and chemical changes in substances. Although this probe targets an elementary level of sophistication, it can be used with middle school students to determine if they are ready to use conservation reasoning to explain changes in substances.

## **High School Students**

This probe is designed for lower grades. However, if high school students have difficulty with the other conservation of matter probes in this book, you may consider going all the way back to eliciting students' ideas about conservation of matter with simple changes in objects.

## **Administering the Probe**

This probe is best used with K–5 students. If cookies are available, consider demonstrating the probe scenario. Make sure students know that all of the crumbs and pieces are weighed together. This probe can be used with the P-E-O strategy (Keeley 2016).

## Related Disciplinary Core Idea From the *Framework* (NRC 2012)

3–5 PS1.A: Structure and Properties of Matter

• The amount (weight) of matter is conserved when it changes form, even in transitions in which it seems to vanish.

## Related NGSS Performance Expectations (NGSS Lead States 2013)

Grade 5: Structure and Properties of Matter
5-PS1-2. Measure and graph quantities to provide evidence that regardless of the

type of change that occurs when heating, cooling, or mixing substances, the total weight of matter is conserved.

## **Related Research**

- Several studies have shown that the way a physical change is perceived may influence whether students regard material as being conserved during the change (Driver et al. 1994).
- Although the cookie is broken into crumbs, not powdered, students' ideas about powdered forms of objects may be related to students' ideas in this task. It has been found that children view the change of a bulk solid to a powdered solid as likely to result in a decrease in mass or weight (Driver et al. 1994). They may think that the tiny crumbs are too small to have weight.
- Stavy and Tirosh (2000) investigated intuitive rules used by students of all ages to explain conservation problems. One of these rules is called "less A equals less B." Because it looks like there is less material present in the broken cookie than in the intact cookie, they may reason that the weight would be less.
- Studies have found that even after studying chemistry, many students have a difficult time connecting ideas about atoms to observable phenomena (Treagust, Chittleborough, and Mamiala 2003). Even if students know that matter is conserved, they may fail to use the idea of atoms in their explanation.

## **Related NSTA Resources** NSTA Journal Articles

- Keeley, P. 2015. Formative assessment probes: Snap blocks. *Science and Children* 52 (9): 26–27.
- Lott, K., and A. Jensen. 2012. Changes matter! Science and Children 50 (2): 54-61.

## **NSTA Press Books**

- Mayer, K., and J. Krajcik. 2017. Core idea PS1: Matter and its interactions. In *Disciplinary core ideas: Reshaping teaching and learning*, ed.
  R. Duncan, J. Krajcik, and A. Rivet, 13–32. Arlington, VA: NSTA Press.
- Robertson, B. 2007. *Chemistry basics: Stop faking it! Finally understanding science so you can teach it.* Arlington, VA: NSTA Press.

## **NSTA Learning Center Resource** NSTA Webinar

NGSS Core Ideas: Matter and Its Interactions http://learningcenter.nsta.org/products/symposia\_ seminars/NGSS/webseminar27.aspx

## Suggestions for Instruction and Assessment

- This probe can be followed up with an opportunity to use the scientific practice of planning and carrying out an investigation. Ask the question, encourage students to commit to a prediction and explain their thinking, and then test their prediction with a cookie. Make sure the cookie is placed on something that will contain all of the crumbs. Weighing the cookie before and after using a coffee filter to hold the cookie and the cookie crumbs works well. The dissonance involved in discovering that the weight remains the same should be followed with opportunities for students to discuss their ideas and resolve the dissonance.
- Another version for K-2 children, similar to this probe, is "Snap Blocks" in *Uncovering Primary Students Ideas in Science* (Keeley 2013).
- Provide elementary students with a variety of opportunities to weigh whole objects and then take them apart, weigh the collection of pieces, and compare the weight of the whole object with the weight of all its parts.

- Provide multiple opportunities to weigh objects and materials after they have experienced a physical change. Such changes include changing the shape of clay, tearing or crumpling paper, freezing water, melting butter, squishing bread, stretching dough, mixing salt and sugar, and dissolving sugar.
- In addition to having students compare weights, have them compare numbers of parts that make up an object. For example, have students put together Legos, blocks, or Unifix Cubes in one shape, count the number of pieces, take it apart, and rebuild it differently. Ask them if any pieces (a precursor to parts that make up matter) were lost or gained. Have them support their ideas by counting the number of pieces before and after. This helps students develop an early conception that the same amount of "matter" is there, a precursor idea to developing a concept of mass in later grades.

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