

VOL. 3

Uncovering Student Ideas in Science

Another 25 Formative
Assessment
Probes

By Page Keeley,
Francis Eberle,
and Chad Dorsey

NSTApress
National Science Teachers Association

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Dedication

This book is dedicated to Dr. Gerry Wheeler, upon his retirement as executive director of the National Science Teachers Association. His leadership, vision, creativity, respect for science teachers, and commitment to all students will live on for many years.



Preface

Overview

This book is the third in the highly successful *Uncovering Student Ideas in Science* series. The addition of 25 more formative assessment probes has now expanded the collection to a total of 75 probes into student thinking in science—thinking that is rarely revealed through standard assessment questions. A new addition to the collection of Earth, space, physical, and life science probes is the inclusion of three probes that target the nature of science and science as inquiry. Together, the probes focus on important fundamental ideas in science that cut across multiple grade spans.

Regardless of whether you teach elementary, middle, or high school science, misconceptions are tenacious and often follow students from one grade to the next. Taking the time to elicit and examine student thinking is one of the most effective ways to support instruction that leads to conceptual change and enduring understanding. It is also the starting point for differentiating instruction to meet the content needs of all students.

Since Volume 1 was released in October 2005, thousands of teachers and hundreds of thousands of K–12 and university students have used the probes. The response has been very encouraging. Teachers have said that students actually ask for and look forward to the opportunity to use an assessment probe. Students eagerly ask teachers for “one of those

probe things”—certainly not the typical student reaction when it comes to assessment!

Not only are teachers using probes to elicit students’ ideas and inform instructional practices, but they have become a tool for transformative teacher learning. In our work at the Maine Mathematics and Science Alliance, we provide professional development to many school districts, math-science partnership projects, and other teacher enhancement initiatives throughout the United States that have embedded the use of these probes in their teacher professional development programs. Working with teachers has shown us that formative assessment is a powerful catalyst for engaging teachers in examining student learning and teacher practice. As a result of the growing interest in using these probes for teacher professional development, we decided to focus Volume 3 on considerations for using probes in a professional learning context.

While you are probably most interested in using the 25 probes in this book, don’t overlook the Introduction (pp. 1–13) or the Introductions in Volumes 1 and 2. Each Introduction will expand your understanding of formative assessment and its inextricable link to instruction and learning. Volume 1 provides an overview of formative assessment, including what it is and how it differs from summative assessment. It also provides background on probes as specific types of formative assessments and

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how they are developed. Volume 2 describes the link between formative assessment and instruction and suggests ways to embed the probes in your teaching. This volume (Volume 3) describes how you can use the probes and student work to deepen your understanding of teaching and learning.

Each probe is accompanied by an extensive Teacher Notes section that clarifies the probe and can be used to improve teachers' content knowledge of fundamental ideas in science as well as increase their knowledge of appropriate curricular emphasis and pedagogical implications. The Teacher Notes are made up of the following elements:

Purpose

This section describes the general concept or topic targeted by the probe and the specific idea being elicited by the probe. It is important to be clear about what the probe is going to reveal. Being clear will help you decide if the probe fits your intended target.

Related Concepts

Each probe is designed to target one or more related concepts that cut across grade spans. These concepts are described in the Teacher Notes and are also included on the matrix charts on pages 16 and 110. A single concept may be addressed by multiple probes. You may find it helpful to use a cluster of probes to target a concept or specific ideas within a concept. For example, there are three probes that target kinetic molecular theory.

Explanation

A brief scientific explanation, reviewed by scientists and content specialists, accompanies each probe and provides clarification of the scientific content that underlies the probe. The explanations are designed to help you identify what the best or most scientifically acceptable answers are (sometimes there is not a "right" answer) as well as 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 based on. If you have a need for further explanation of the content, several of the probe notes list NSTA resources, such as the series *Stop Faking It! Finally Understanding Science So You Can Teach It*, 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 as summative assessments are. Rather, they provide insights into the knowledge and thinking that your students may have related to a topic as they progress from one grade span to the next. Some of the probes can be used for grades K–12, while others may cross over just a few grade levels. Teachers from two grade spans (e.g., middle school and high school) might decide to use the same probe and come together and discuss their findings. To do this, it is helpful to have insight into what students typically experience at a given grade span

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as it relates to the ideas elicited by the probe. Because the probes do not prescribe a specific grade level for use, you are encouraged to read the curricular and instructional considerations and decide if your students have had sufficient experience to make the probe useful.

The Teacher Notes also describe how the information gleaned from the probe is useful at a given grade span. For example, it 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. Sometimes the student learning data gained through use of the probe indicates that you have to back up several grade levels to teach ideas that are not really clear to students.

We deliberately chose not to suggest a grade level for each probe. If these were intended to be used for summative purposes, a grade level, aligned with a standard, would be suggested. However, these probes have a different purpose. Do you want to know about the ideas your students are expected to learn in your grade-level standards? Are you interested in how ideas develop and change across multiple grade levels in your school even when they are not formally taught? Are you interested in whether students have 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

In this section, we suggest ways to administer the probe, including a variety of modifications that may make the probe more useful at certain grade spans. For example, the Teacher Notes might recommend eliminating certain examples from a justified list for younger students who may not be familiar with particular words or examples, or using the word *weight* instead of *mass* with younger elementary students who might confuse the word *mass* with *massive*. The notes also include suggestions for demonstrating the probe context with artifacts and eliciting the probe responses while students interact within a group.

Related Ideas in the National Standards

This section lists the learning goals stated in the two national documents generally considered the “national standards”: *Benchmarks for Science Literacy* (AAAS 1993) and *National Science Education Standards* (NRC 1996). Since the probes are not designed as summative assessments, the learning goals from those two documents are not intended to be considered alignments but rather as related ideas connected to the probe. Some targeted ideas, such as a student’s conception of a life cycle on page 111, are not explicitly stated as learning goals in the standards but are clearly related to national standards concepts that address specific ideas about life cycles. 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 (★).

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Related Research

Each probe is informed by related research when it is available. Because the probes were not designed primarily for research purposes, an exhaustive literature search was not conducted as part of the development process. We drew primarily from two comprehensive research summaries commonly available to educators: Chapter 15 in *Benchmarks for Science Literacy* (AAAS 1993) and *Making Sense of Secondary Science: Research Into Children's Ideas* (Driver et al. 1994). Although both of these resources describe studies that have been conducted in past decades, and involved children not only in the United States but in other countries as well, many of the results of these studies are considered timeless and universal. Many of the ideas students held that were uncovered in the research during the 1980s and 1990s still apply today. It is important to recognize that cultural and societal contexts can influence students' thinking, but research also indicates that many of these ideas are pervasive regardless of geographic boundaries. Hence the descriptions from the research can help you better understand the intent of the probe and the variety of responses your students are likely to have. 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 appropriate student interventions and instructional planning. We have included suggestions gathered from the wisdom of teachers, the knowledge base on effective science teaching, and our own collective experience as former teachers and specialists involved in science education. These are not exhaustive or prescribed lists but rather suggestions that may help you modify your curriculum or instruction 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 a specific strategy or activity might work with your students. Learning is a very complex process and most likely no single suggestion will help all students learn the science ideas. But that is part of what formative assessment encourages: thinking carefully about the variety of instructional strategies and experiences needed to help students learn scientific ideas.

Related NSTA Bookstore Publications and Journal Articles

NSTA's journals and books are increasingly targeting the ideas that students bring to their learning. We have provided suggestions for additional readings that complement or extend the use of the individual probes and the background information that accompanies them. For example, Bill Robertson's *Stop Faking It!* series may be helpful in clarifying content that teachers struggle with. A journal article from

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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. Other resources listed in this section provide a more comprehensive overview of the topic addressed by the probe.

Related Curriculum Topic Study Guides

NSTA is a copublisher 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. Teachers who wish to delve deeper

into the standards and research-based findings that informed the development of the probe and are linked to its use in curriculum and instruction may wish to use the CTS guides for further information.

References

References are provided for the standards and research findings cited in the Teacher Notes.

As a companion to this book and the other two volumes, NSTA has copublished *Science Formative Assessment: 75 Practical Strategies for Linking Assessment, Instruction, and Learning* (Keeley 2008). In this book you will find a variety of strategies to use with the probes to facilitate elicitation, support metacognition, spark inquiry, encourage discussion, monitor progress toward conceptual change, encourage feedback, and promote self-assessment and reflection.

We hope this volume of probes will be as useful to you as the other two volumes. As the popular saying goes, "Build it and they will come," and indeed, you came. In concluding this third volume, we turn the cliché around to say, "Come and we will build it." In other words, we sincerely hope the demand for quality formative assessment continues—and, if it keeps coming, we will keep "building"!

Acknowledgments

The assessment probes in this book have been extensively field-tested by several teachers and hundreds of students in Maine, New Hampshire, Iowa, Missouri, Florida, and California by the Maine Mathematics and Science Alliance (MMSA). We would like to thank the teachers

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and science coordinators we have worked with for their willingness to field-test probes, share student data, and contribute ideas for additional assessment probe development. In particular we would like to acknowledge the following people for their contributions to this volume: Dick Beer, Kennebunk, ME; Margaret Collins, Hooksett, NH; Bev Cox, Orlando, FL; Linda D'apolito, Falmouth, ME; Michelle DeBlois, Livermore Falls, ME; Kevin Fleury, Hooksett, NH; David Gerlach, Cedar Rapids, IA; Susan German, Hallsville, MO; Rita Harvey, Cathedral City, CA; Mark Koenig, Gardiner, ME; Kelle Kolkmeier, Cedar Rapids, IA; Elizabeth Lynch, Dover, NH; Anne MacDonald, Falmouth, ME; Molly Malloy, Orlando, FL; Kellie Martino, Hooksett, NH; Rainey Miller, Cedar Rapids, IA; Bonnie Mizzell, Orlando, FL; Margo Murphy, Thomaston, ME; Lisa Nash, Dover, NH; Betsy O'Day, Hallsville, MO; Michael Praschak, Lewiston, ME; Nicole Rodway, Hooksett, NH; Terri Schott, Cedar Rapids, IA; Amy Troiano, Poland, ME; Jane Voth-Palisi, Concord, NH; Joan Walker, Orlando, FL; Andy Weatherhead, Kittery, ME; Katherine Wheeler, Hillsboro, NH. We sincerely apologize if we overlooked anyone.

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Weller at the University of Maine whose graduate seminar, attended by one of the authors, sparked an interest in the nature of science that subsequently went into developing the nature of science probes for this volume. And certainly, we are deeply appreciative of the efforts of the National Science Teachers Association (NSTA) in supporting formative assessment and the outstanding staff that make up the NSTA Press.

About the Authors

Page Keeley, senior science program director; Dr. Francis Eberle, executive director; and Chad Dorsey, science and technology specialist, all work at the Maine Mathematics and Science Alliance (MMSA) in Augusta, Maine, where they develop, support, and coordinate various science education initiatives throughout Maine and New England and provide professional development in formative assessment nationally. Combined, they have a total of over 30 years of teaching experience in middle and high school science and have served as adjunct instructors in the University of Maine system. They have worked with teachers, schools, and organizations in the areas of professional development, leadership, mentoring, standards, curriculum development, technology, assessment, and school reform. The authors have served as co-PIs and senior personnel on six National Science Foundation grants and three state Math-Science Partnership Projects. They currently serve on state and national advisory boards and committees and frequently present their work each year at the NSTA conferences.

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In addition, Page Keeley is the 2008–2009 president of NSTA.

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Introduction

When data are used by teachers to make decisions about next steps for a student or group of students, to plan instruction, and to improve their own practice, they help *inform* as well as *form* practice; this is *formative assessment*.

—Maura O’Brien Carlson, Gregg E. Humphrey, and Karen S. Reinhardt, *Weaving Science Learning and Continuous Assessment* (2003, p. 4.)

Imagine a team of fourth-grade teachers meeting after school with their district science coordinator to plan for implementation of a new curriculum unit, called “Silkworm.” The unit, developed at a summer institute with the support of an entomologist university partner, addresses culminating learning goals related to the characteristics and needs of organisms, life cycles, and behaviors. The teachers are excited about using silkworms as a new context for learning about life cycles.

The unit is designed to help students understand that the life cycles of different organisms differ in their details, but all include a cycle of birth, growth and development, reproduction, and death.

The district science coordinator relates that in previous grades students investigated the life cycles of painted lady butterflies using one of the kit-based science programs: The students hatched frog eggs from the local pond, observed the development from

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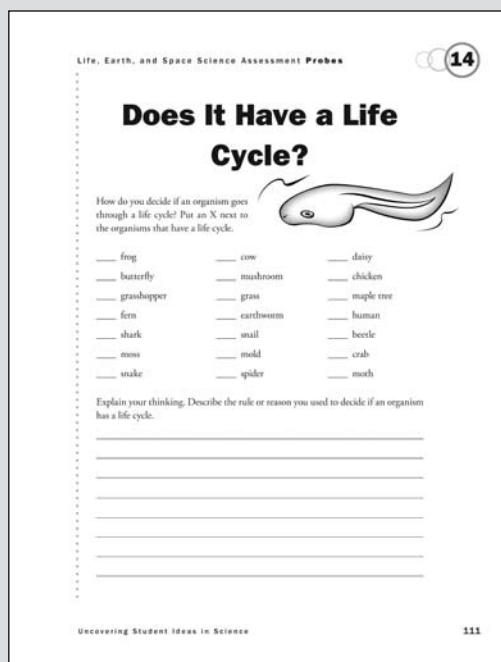
tadpole to frog, and planted bean seeds to observe their development from seed to flowering plants. The teachers conclude that their fourth-grade students have sufficient prior knowledge of life cycles to begin the silkworm investigation without the need to review basic life-cycle concepts.

During the meeting, the district science coordinator alerts the teachers to a new book in their district resource library, *Uncovering Student Ideas in Science, Volume 3: Another 25 Formative Assessment Probes* (this book). One of the probes, shown in Figure 1, is titled, “Does It Have a Life Cycle?” The science coordinator shows the teachers the probe, along with the accompanying Teacher Notes. The notes indicate that some students tend to associate life cycles only with the examples they have encountered in school, such as certain types of plant, butterfly, frog, or mealworm life cycles or organisms that are similar to those they studied.

The teachers’ curiosity is piqued by this finding. They wonder if their own students’ understanding of life cycles might be limited by the examples and activities they have experienced in school. Are students able to make generalizations about life cycles beyond the individual organism they have studied? The teachers agree to give the probe to their students the next day and meet after school to look at the results.

The next day the teachers meet again and bring samples of their students’ work.

Figure 1. “Does It Have a Life Cycle?” Probe



Their assumption that the students are ready to begin the unit with a firm foundation of basic life cycle ideas has been shattered: They noticed that the majority of students had little difficulty choosing “butterfly,” “frog,” and “chicken,” and several chose “bean plant,” yet they failed to check off other plants and animals. Few students checked off “human.” The teachers think that the problem may be that their students have never explicitly encountered the bigger idea that every living plant and animal has a life cycle, even though that cycle may vary depending on the type of organism. Analyzing the students’ reasoning, the teachers notice that several students hold similar

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context-bound ideas such as “it has to look very different at one time in its life,” “it has to go through metamorphosis,” and “it has to lay eggs.” They even notice that a few students from each class correctly explained what a life cycle is yet failed to check off all the living things on the list.

As the teachers examine and discuss the data, pointing out similar misconceptions held by groups of students as well as a few idiosyncratic ideas, they realize how much they are learning about their students that they would not have known without using the probe. The district science coordinator asks the teachers to think about how they

can use the data to modify the silkworm life cycle lessons so that their students can move past their context-bound ideas. The teachers discuss ways to challenge students’ preconceptions, to explicitly connect the silkworm’s life cycle to other organisms’ life cycles, and to help students develop the broader generalization that all plants and animals go through a life cycle. The teachers develop a set of probing discussion questions for small groups that will challenge students’ pre-formed ideas and lead to a whole-class discussion. They also decide to share their fourth-grade data with the first-, second-, and third-grade teachers.

The above example illustrates how formative assessment probes can uncover valuable information for teachers that often goes unnoticed in the science classroom and passes on from one grade to the next. The “Silkworm” unit is content rich and inquiry based, designed to develop students’ understanding of life science concepts. It was designed to build on students’ previous experiences with plant and animal life cycles, but it lacked a component that would uncover students’ prior ideas about the basic concept of a life cycle. Students were asked to recall the details of the life cycles of the organisms they studied in previous years, yet they were not called upon to develop the fundamental idea that every plant and animal goes through a life cycle. It is likely that these

students would have simply added the silkworm to their collection of “conceptions of life cycles by individual organisms”—rather than use a generalization that applies to all multicellular organisms they encounter in school and in everyday life—if their teachers had not taken the time to uncover their organism-specific concept of a life cycle. It is also likely that these teachers would not have uncovered this conception if they had not had formative assessment probes whose purpose was to reveal commonly held ideas.

Formative Assessment Probes

This book, as well as the two volumes that precede it, is designed to probe for commonly held ideas about fundamental concepts that

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can develop early in a student's education and persist all the way through high school if not identified and targeted for conceptual change instruction. This third collection of K–12 formative assessment probes continues to provide assessment examples that teachers can use to ask interesting questions, provoke lively discussions, encourage argumentation in small groups about differing ideas, orchestrate classroom discourse that promotes the public sharing of ideas, and examine students' ideas and reasoning through their written science explanations. These probes support students in being more metacognitive—that is, in becoming more aware of how and why they think about ideas in science—and also help teachers to aid individual students and the class progress toward developing scientific understanding (Keeley 2008).

Each assessment probe in this book, as well as those in Volumes 1 and 2, is a carefully designed question based on a formative assessment development process used in *Science Curriculum Topic Study* (Keeley 2005) that gives information to teachers about students' factual and conceptual understandings in science and the connections students make between and across ideas. Students respond to probes in writing as well as through small-group or class discussion, generating a range of ideas that help the teacher diagnose and address potential learning difficulties. Typically, teachers use the probes to identify potential misconceptions that can be barriers as well as springboards for learning, gather information on student thinking and learning in order to

make informed decisions to plan for or adjust instructional activities, monitor the pace of instruction, and spend more time on ideas that students struggle with. In addition to informing instruction and promoting student learning—purposes that are described extensively in Volumes 1 and 2 and in the complementary publication, *Science Formative Assessment: 75 Practical Strategies for Linking Assessment, Instruction, and Learning* (Keeley 2008)—assessment probes are powerful tools to enhance teacher learning.

Using Probes to Examine Teaching and Learning

Probes provide an entry point for teachers at all levels, from preservice to experienced teacher leaders, to examine and discuss the teaching and learning process, including the effective use of formative assessment. Some teachers think they are using formative assessment when they use probes to gather evidence of misconceptions but then proceed with their lesson plans despite their students' responses to the probes. There is little point in gathering data from formative assessment if the data are not used to fashion what comes next—"only when such refashioning occurs does the assessment become formative assessment" (Atkin and Coffey 2003, p. 6). Furthermore, the use of probes can extend beyond "refashioning" instruction. It can update the teachers' science content and pedagogical content knowledge and result in transformative teacher learning. Unlike additive learning, in which teachers acquire a new activity or strategy to add to their

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instructional repertoire, transformative learning results in changes in deeply held beliefs, knowledge, and habits of practice (Thompson and Zueli 1999).

Probes and Transformative Learning for Teachers

Using the probes as a transformative teacher learning experience fits with Thompson and Zueli's five requirements for transformative learning (Loucks-Horsley et al. 2003). A transformative learning experience should

1. *Create a high level of cognitive dissonance.*

That is, new information, whether it is the content of the probe or the students' ideas as seen in students' written work or probe discussions, should reveal a "disconnect" between what the teacher thought he or she knew about the content (or about his or her students' ideas) and what is actually revealed through the probe. For example, a teacher might take the probe before using it with students and find that he or she has the same misconception that was revealed in the research. Or a high school teacher might believe that her chemistry students understand very basic matter concepts and be surprised to learn that her students have misconceptions about fundamental ideas.

2. *Provide sufficient time, structure, and support for teachers to think through the dissonance they experience.* Study groups, mentoring, coaching sessions,

and professional learning communities give teachers a vehicle to make sense of the probe content, of the curricular and instructional implications of students' responses, and of their students' ways of reasoning.

3. *Embed the dissonance-creating and dissonance-resolving activities in teachers' actual situations.* For example, it is wise to use probes that relate to a learning goal in the teacher's curriculum and use his or her students' work to examine students' ideas and consider adjustments to instruction.

4. *Enable teachers to develop new ways of teaching that fit with their new understanding.* It is not enough for teachers to improve their own understanding of the content of a probe or to become aware of the misconceptions their students have. Teachers must consider how they will make the content accessible to their students and how they will change their teaching practices or lessons to help students develop conceptual understanding.

5. *Engage teachers in a continuous process of improvement.* Regular examination of student work from the probes (as well as the Teacher Notes that follow each probe) brings to light new problems related to teaching and learning, develops new understandings about content and pedagogy, and encourages teachers to make modifications to their lessons or try new instructional strategies.

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Nine Suggestions for Using Probes as Assessment for Teacher Learning

Volume 2 in this series addressed ways to use probes as assessment *for* learning to *promote* student learning and *inform* instruction. It also provided a variety of suggestions for embedding probes in instruction. Here, we offer suggestions for ways to use the probes in this book and in Volumes 1 and 2 as assessments *for teacher learning*.

- 1. Always do the probe yourself.** Before giving the probe to your students, take it yourself and think about your prior experiences in school and in everyday situations that may be contributing to your response. Think about when and how you learned the content of the probe and whether you once had misconceptions or still have them. Note any difficulties you had responding to the probe. Being metacognitive about your own knowledge and experiences can help you understand what your students or other teachers might have thought or have experienced while taking the probe. It also points out areas of conceptual difficulty in which you may be helped by further professional development, university courses, or the support of a knowledgeable colleague or university partner.
- 2. Use the Teacher Notes.** The Teacher Notes section that follows each probe contains a wealth of information that can deepen your understanding of the content of the probe and its curricular and instructional implications. Examine the Teacher Notes *before* looking at the student work to sharpen your analytical lens and to anticipate what you might find when you examine students' thinking. Use the Teacher Notes as references in your discussion of student work with other teachers in order to move beyond opinion and speak from a common knowledge base.
- 3. Examine student work in collaborative structures.** Collaborative learning environments are good settings in which to examine the student work from the probes and to discuss the accompanying Teacher Notes. Structures that promote collegial learning include professional learning communities (PLCs), study groups, mentoring, instructional coaching, teacher research teams, and inquiry and reflective practice groups. The ongoing nature of these structures allows teachers to reconvene after making modifications or trying out new strategies and receive feedback from their colleagues on the formative decisions they made.
- 4. Embed the probes into existing professional development.** Using the probes for teacher learning does not have to be a stand-alone professional learning experience. The probes can be used to examine student thinking within a

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variety of content-focused workshops and institutes as well as within embedded professional development strategies, such as lesson study (Lewis 2002), teacher research (Roberts, Bove, and Van Zee 2007), curriculum topic study (Keeley 2005), study groups (Murphy and Lick 2001), and curriculum implementation, content immersion, and demonstration lessons (Loucks-Horsley et al. 2003).

5. Select specific areas to focus on. Looking at student work from the probes can initially be daunting. The responses to the probes provide such a treasure trove of data that it is sometimes hard to know what to focus on. Table 1 shows some of the things you might look for.


6. Examine student thinking across grade spans. An aspect of these probes that distinguishes them from summative assessments is that they are designed to be used across multiple grade levels. Sometimes, a single probe can be used at all levels—elementary, middle, and high school. For example, the “Is It a Solid?” probe shown in Figure 2 (p. 8) may elicit misconceptions about solids that may develop as early as first grade in a unit on solids and liquids and continue through high school if not addressed. Sometimes, the ideas do not change much from one grade span to the next; students just get a lot more “scientific” and their ideas become more muddled with other concepts they are learning as they move up through the grades.

Table 1. What to Look For in Students’ Responses to Probes

Areas for Analysis	What to Look For
Concepts and ideas	Number of students choosing a selected response (use tallies); groups of students using similar explanations
Use of terminology	Confusion of everyday words with their scientific meaning; appropriate use of scientific terminology
Transfer of learning	Ability to apply ideas across contexts or in new situations
Prior knowledge or experience	Ideas that students bring to their learning; experiences students may have had that impact their ideas
Sophistication level	Grade levels at which the students’ ideas are typically developed
Reasoning	Types of rules or justifications students use to support their ideas
Ability to explain	Students’ ability to write or verbalize an explanation

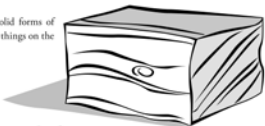
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Figure 2. “Is It a Solid?” Probe

Physical Science and Nature of Science Assessment Probes  **2**

Is It a Solid?

What types of things are solid forms of matter? Put an X next to the things on the list that are solids.



<input type="checkbox"/> rock	<input type="checkbox"/> Styrofoam	<input type="checkbox"/> ice
<input type="checkbox"/> rubber band	<input type="checkbox"/> air	<input type="checkbox"/> wood
<input type="checkbox"/> milk	<input type="checkbox"/> flour	<input type="checkbox"/> soil
<input type="checkbox"/> feather	<input type="checkbox"/> dust	<input type="checkbox"/> melting wax
<input type="checkbox"/> cloth	<input type="checkbox"/> cooking oil	<input type="checkbox"/> salt
<input type="checkbox"/> baby powder	<input type="checkbox"/> sponge	<input type="checkbox"/> iron nail
<input type="checkbox"/> sugar	<input type="checkbox"/> iron nail	<input type="checkbox"/> cotton ball
<input type="checkbox"/> foam rubber ball		

Explain your thinking. What definition, rule, or reasoning did you use to decide whether something is a solid?

Uncovering Student Ideas in Science 25

There is tremendous value in analyzing students’ responses to the same probe with colleagues from other grade levels. Because learning goals become more complex as students progress in school, it is important to take into account the targeted concept and learning goal for the particular grade you teach, including its level of sophistication. Here are some questions to ask yourself before and after you examine student work at various grade levels and read the Teacher Notes:

- How do my district’s curricular learning goals at my grade level match the national learning goals described in the Teacher Notes?

- Which parts of my district’s learning goals does the probe address?
- How well do my students know the learning goals related to a probe that come before my grade level? Are there learning goals that come after my grade level that they have had opportunities to achieve?
- To what extent does the Curricular and Instructional Considerations section described in the Teacher Notes match my classroom or district context? To what extent are my students familiar with the context of the probe, the correct response, and the distracters (wrong choices)? Should I tell students to ignore some of the distracters?
- Do any of the age-related research findings match the ages of students in my classes?
- When I look at the student work, do I find that any of my students’ ideas are among the research findings in the Teacher Notes?
- What seems to be most problematic for students? Is this indicative of one grade span or is it seen across grades? What patterns do I notice?
- If students hold similar ideas, how do their explanations differ or remain the same across grade spans?
- Taking into account the types of ideas my students have and their reasoning, which points in the Suggestions for Instruction and

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Assessment section in the Teacher Notes might be appropriate for me to use?

- What other curricular or instructional actions might I need to take?

7. **Categorize types of ideas.** Researchers and science educators have categorized students' science ideas in various ways. As you examine your students' ideas, try matching them to the following categories of ideas adapted from *Science Teaching Reconsidered* (NRC 1997):

- **Scientific ideas.** These are the accurate conceptions that a scientifically literate person would have. Scientifically accurate ideas can range from basic, precursor understandings to sophisticated, complex ideas, depending on the developmental level of the student.
- **Preconceptions.** These are popular conceptions based on everyday experiences. Often, they take root even before students have been taught scientific ideas. For example, students think the phases of the Moon are caused by the shadow of the Earth on the Moon. This conception is often rooted in students' everyday experience of seeing how part of an object is shaded when something blocks the light shining on the object.
- **Conceptual misunderstandings.** These misunderstandings arise

when students are taught scientific concepts in a way that does not challenge them to confront their beliefs or in a way that fails to connect disparate pieces of knowledge. For example, even though students have been taught the idea of the water cycle, they may believe that evaporated water moves immediately upward to a cloud. In their minds, they see the water going up to the clouds rather than existing in the air around them. They may correctly use terms like *evaporation* and *condensation* and know that water can exist as water vapor, yet fail to understand that water vapor is in the air around us. Another example is recanting an incorrect definition of matter but not accepting the idea that air is matter. Misrepresentations also lead to conceptual misunderstandings, such as the exaggerated elliptical orbit of the Earth around the Sun that leads to misconceptions about seasons. Overgeneralizations and undergeneralizations—for example, all animals have fur and legs and only shiny or smooth objects reflect light—are also categorized as conceptual misunderstandings.

- **Nonscientific beliefs.** These are views learned by students from nonscientific sources, such as religious or mythical teachings, and

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pseudosciences, such as astrology. For example, in religious instruction, some students learn through literal interpretation of the Bible about the short time in which the Earth and the organisms that inhabit it were created. Scientific evidence, however, shows that the Earth was created about 5 billion years ago and life began with simple, one-celled organisms. The result has been considerable controversy in teaching certain aspects of science, such as the origins of the Earth or life and the Earth's and life's evolution.

- **Vernacular misconceptions.** These arise from the use of scientific words and phrases that mean one thing in everyday life and another in a scientific context. An example is the word *theory*, which means a “hunch” to some people but to scientists means a well-established, thoroughly tested idea. Sometimes the way words are used implies something other than what was intended; for example, “heat rises” and “the Sun moves across the sky” may imply that heat is the physical entity that rises rather than the air or that the Sun is actually the object that is moving around the Earth. Sometimes a scientific word is misused, as in the phrase “a hard candy melts in your mouth.” Melt-

ing is a physical process. The candy does not melt, it dissolves. As a result of the misuse of the word *melt* students have a hard time distinguishing between melting and dissolving. Likewise, misuse of the term *zero gravity*—rather than the correct term, *microgravity*—has led students to think there are instances where there is no gravity acting on an object in space.

- **Factual misconceptions.** These are inaccuracies that may be taught and learned in school or home and are retained unchallenged throughout adulthood. For example, the notions that lightning never strikes twice in the same place, that water in a bathtub drain swirls in the opposite direction in the Southern Hemisphere than it does in the Northern Hemisphere, or that the blood in your veins is blue are all incorrect. Such ideas may remain part of many students' and adults' beliefs because they have been (incorrectly) taught them.

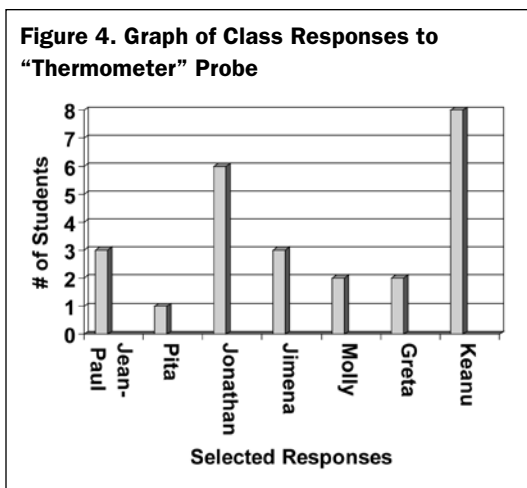
8. **Crunch the data and create classroom profiles and graphs.** Classroom profiles provide a written record of students' misconceptions for the teacher to analyze, share with other teachers, and refer to in monitoring conceptual change over time (Shapiro 1994). The classroom profile breaks each distracter down into the

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Figure 3. Classroom Profile for “Thermometer” Probe (Grade 7)

Response Choices	Students’ Supporting Explanations for Their Choices	# of Students
1. (Jean-Paul) “The hot water pushed it up.”	<ul style="list-style-type: none"> • “The hot water creates a force that pushes the liquid up.” • Repeats the answer choice with no further explanation. 	2 1 Total: 3
2. (Pita) “The mass of the red liquid increased.”	<ul style="list-style-type: none"> • “When the liquid gets hot from the water, it gets heavier and expands.” 	1 Total: 1
3. (Jonathan) “The heat inside the thermometer rises.”	<ul style="list-style-type: none"> • “The red liquid is in the form of heat and it rises.” • Explains how heat rises when it’s warm but doesn’t mention the red liquid. • Repeats the answer choice with no further explanation. 	2 3 1 Total: 6
4. (Jimena) “The air inside the thermometer pulls it up.”	<ul style="list-style-type: none"> • “Air pressure makes it go up.” • “The air gets warm and creates a vacuum, which sucks the liquid up.” • “The warm air creates a force that pulls up on the liquid.” 	1 1 1 Total: 3
5. (Molly) “The molecules of the red liquid are further apart.”	<ul style="list-style-type: none"> • “As the liquid warms up, the space between the molecules increases.” • “The liquid is turning to a gas so the molecules are further apart.” 	1 1 Total: 2
6. (Greta) “The number of molecules in the red liquid increased.”	<ul style="list-style-type: none"> • “The molecules break apart when the liquid gets hot, making more molecules.” • “There is more liquid so there are more molecules.” 	1 1 Total: 2
7. (Keanu) “The molecules of the red liquid are getting bigger.”	<ul style="list-style-type: none"> • “The heat makes the molecules expand [also includes ‘grow’ and ‘stretch.’]” • “Things expand or get bigger when they warm up [but doesn’t mention molecules].” • Gave no explanation—just “that’s how thermometers work.” • Gave no further explanation—left blank. 	4 2 1 1 Total: 8

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kinds of reasoning students use and the number of students who used similar reasoning for that response. The exercise in grouping similar responses is an excellent professional development exercise for teachers that models similar ways that researchers code responses. Teachers can also include an additional column with the names of students who shared each idea. Classroom profiles can be shared with students (with names removed); most students show great interest in knowing what other students think and how the other students' thinking compares to their own. Creating graphs and charts to visually show the tallies of students' responses is another way of sharing data with students; the visual tallies are also useful in teacher collaborative groups. Figure 3 (p. 11) shows a classroom profile for a seventh-grade class's response to the probe “Thermometer” (on p. 33 of this book). Figure 4 shows a graph of the student responses from the probe.

9. Read and discuss professional literature. Further your understanding of the content related to the probe, students' ideas, and effective strategies and activities to use to teach for conceptual change by selecting and reading professional literature from the related NSTA publications list provided for each probe. In addition, you may want to read the references cited, including the full research papers. Also, search www.curriculumtopicstudy.org. This database regularly posts new research articles on students' misconceptions and other resources for teacher professional development related to the topic of each probe.

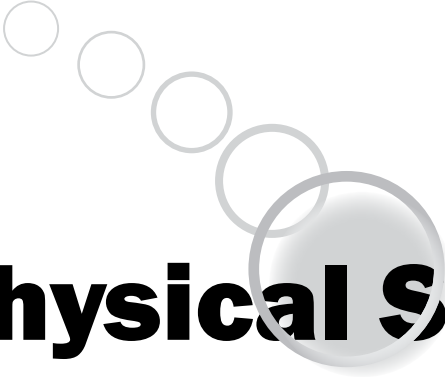
Whatever probe or probes you decide to use in your classroom, remember the outcomes will be threefold. First, you will learn a lot about your students; this new information will lead to modifications in how and what you teach. Second, you will learn a lot about standards and research-based teaching and learning that applies to all students. And third, you will learn the value in sharing the probes, your student data, your inquiries into practice, and your new learning with other teachers.

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**Physical Science
and Nature of
Science
Assessment
Probes**
Concept Matrix

**Related
Science
Concepts**

	Physical Science										Nature of Science		
	Pennies	Is it a Solid?	Thermometer	Floating Balloon	Hot and Cold Balloons	Mirror on the Wall	Batteries, Bulbs, and Wires	Apple on a Desk	Rolling Marbles	Dropping Balls	Is it a Theory?	Doing Science	What is a Hypothesis?
Acceleration										✓			
Atom	✓												
Balanced Forces								✓					
Circular Motion									✓				
Complete Circuit							✓						
Conservation of Matter					✓								
Density				✓									
Electric Circuit							✓						
Electricity							✓						
Experiment												✓	
Force								✓	✓	✓			
Gas				✓	✓								
Gravity								✓		✓			
Hypothesis											✓		✓
Inertia									✓				
Kinetic Molecular Theory			✓	✓	✓								
Liquid		✓											
Mass				✓	✓					✓			
Mirrors						✓							
Nature of Science											✓	✓	✓
Newton's First Law									✓	✓			
Properties of Matter	✓	✓		✓	✓								
Reflection						✓							
Scientific Inquiry												✓	✓
Scientific Law											✓		
Scientific Method												✓	✓
Solid		✓											
Theory											✓		
Thermal Expansion			✓										
Thermometer			✓										
Weight				✓	✓					✓			

Doing Science

Four students were having a discussion about how scientists do their work. This is what they said:



Antoine: "I think scientists just try out different things until something works."

Tamara: "I think there is a definite set of steps all scientists follow called the scientific method."

Marcos: "I think scientists use different methods depending on their question."

Avery: "I think scientists use different methods but they all involve doing experiments."

Which student do you most agree with? _____

Explain why you agree with that student and include why you disagree with the other students.

Doing Science

Teacher Notes



Purpose

The purpose of this assessment probe is to elicit students' ideas about scientific investigations. The probe is designed to find out if students recognize that scientists investigate the natural world in a variety of ways depending on the question they pose and that there is no fixed sequence of steps called the "scientific method" that all scientists use and follow rigidly.

Related Concepts

experiment, nature of science, scientific inquiry, scientific method

Explanation

The best answer is Marcos's: I think scientists use different methods depending on their question. Doing science is generally a logical, systematic process, unlike Antoine's response,

which implies that the approach to science is random rather than methodical. Sometimes creative, divergent thinking and approaches have led to scientific discovery but they usually involve a systematic approach. Fundamentally, the various scientific disciplines are alike in their reliance on evidence, the use of hypotheses and theories when appropriate, the kinds of logic used, and more; however, scientists differ greatly from one another in what phenomena they investigate and in how they go about their work (AAAS 1988, p. 4). The scientific method correctly implies a methodical approach; however, Tamara's response implies that there is one method that includes a definite sequence of steps that all scientists follow. "There simply is no fixed set of steps that scientists always follow, no one path that leads them unerringly to scientific knowledge" (AAAS 1988, p. 4). Sci-

entists move back and forth among processes and do not follow a recipe.

Experimentation is a process in which scientists control conditions in order to test their hypotheses. Unlike Avery's response, not all scientific investigations involve experiments. An experiment is a type of investigation that involves testing cause-and-effect relationships between variables—manipulated (independent) and responding (dependent). Astronomy, field studies in nature, and paleontology are some of the examples of areas of science in which it would be difficult or unfeasible to manipulate and control experimental conditions. In these types of investigations, scientists rely on a wide range of naturally occurring observations to make inferences about organisms, objects, events, or processes. For example, the link between smoking and lung cancer was actually established through correlational research designs as opposed to classic experiments.

Curricular and Instructional Considerations

Elementary Students

From their very first day in school, young students should be actively engaged in using science to investigate the world around them. They should be encouraged to ask questions about familiar phenomena and objects and to seek answers, collect things, count and measure things, make qualitative observations, organize collections and observations, and discuss findings in a systematic way. These early experiences with inquiry are precursors to un-

derstanding how science is done in a variety of ways and how it relies on gathering data to use for evidence. By directly experiencing a variety of ways that questions can be answered in science through simple investigations, students will begin to develop the idea that there is no one fixed way to go about answering scientific questions. However, this will only happen if students are asked to reflect on what they have done and instruction explicitly addresses the understandings of inquiry. At this level, students develop the notion of a "fair test" when designing experiments, but caution should be used at this early stage to not imply that all scientific investigations are experiments.

Middle School Students

By middle school, students should understand that science is guided by the question posed. The question and the particular content of the inquiry determine the method used to investigate. Caution is taken to ensure that students do not develop the idea that there is one "scientific method" that involves a prescribed set of linear steps that all scientists follow. At this level, students progress beyond the notion of a fair test to include a formal understanding of experimentation as a way of testing ideas that involves identifying and controlling variables. Often, the scientific method is taught and used in the context of doing experiments. However, at this grade level students need to experience and understand that science is systematically carried out in a variety of ways, including doing experiments, but not limited to that. Students should also become aware of how different do-



mains of science use different methodologies (e.g., in astronomy, observations are made using remote technologies).

High School Students

In high school, students develop more sophisticated abilities and understandings of scientific inquiry. They are able to design and carry out more complex experiments as a way to systematically test their ideas. At this level, they should also engage in using a variety of other methods to investigate their questions, including field studies, observations of remote or microscopic phenomena using technology, modeling, specimen collections, and so on. This is the time when students should have opportunities to read and analyze peer-reviewed published scientific papers that show the variety of methodologies scientists use to do their work.

Administering the Probe

This probe is best used as is at the middle school and high school levels, particularly if students have been previously exposed to the term *scientific method* somewhere in their K–12 science education. However, the language of the probe can be modified as a simpler version for K–5 students. Be sure to emphasize that students should explain not only why they agree with the choice they selected from the four responses, but also why they did not select the other choices. The last selected response (Avery) can be expanded to include “...they all involve developing hypotheses and doing experiments.”

Related Ideas in *National Science Education Standards (NRC 1996)*

K–4 Understandings About Scientific Inquiry

- ★ Scientists use different kinds of investigations depending on the questions they are trying to answer. Types of investigations include describing objects, events, and organisms; classifying them; and doing a fair test (experimenting).

5–8 Understandings About Scientific Inquiry

- ★ Different kinds of questions suggest different kinds of investigations. Some investigations involve observing and describing objects, organisms, or events; some involve collecting specimens; some involve experimenting; some involve seeking more information; some involve discovery of new objects and phenomena; and some involve making models.
- Current scientific knowledge and understanding guide scientific investigations. Different scientific domains employ different methods, core theories, and standards to advance scientific knowledge and understanding.

5–8 The History and Nature of Science

- Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.

★ Indicates a strong match between the ideas elicited by the probe and a national standard’s learning goal.

9–12 Understandings About Scientific Inquiry

- Scientists usually inquire about how physical, living, or designed systems function. Conceptual principles and knowledge guide scientific inquiries. Historical and current scientific knowledge influence the design and interpretation of investigations and the evaluation of proposed explanations made by other scientists.

Related Ideas in *Benchmarks for Science Literacy (AAAS 1993)*

K–2 Scientific Inquiry

- People can often learn about things around them by just observing those things carefully. Sometimes they can learn more by doing something to the things around them and noting what happens.

3–5 Scientific Inquiry

- ★ Scientific investigations may take many different forms, including observing what things are like or what is happening somewhere, collecting specimens for analysis, and doing experiments.

6–8 Scientific Inquiry

- ★ Scientists differ greatly in what phenomena they study and how they go about their work. Although there is no fixed set of steps that all scientists follow, scientific investigations usually involve the collection of relevant evidence, the use of logical rea-

soning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence.

9–12 Scientific Inquiry

- Investigations are conducted for different reasons, including to explore new phenomena, to check on previous results, to test how well a theory predicts, and to compare different theories.
- ★ Sometimes scientists can control conditions in order to obtain evidence. When that is not possible for practical or ethical reasons, they try to observe as wide a range of natural occurrences as possible to be able to discern patterns.

Related Research

- The idea that there is a common series of steps that is followed by all scientists is likely to be the most common myth of science (McComas 1998).
- Students generally have difficulty with explaining how science is conducted because they have had little contact with real scientists. Their familiarity with doing science, even at older ages, is “school science,” which is often not how science is generally conducted in the scientific community (Driver et al. 1996).
- Despite over 10 years of reform efforts in science education, research still shows that students typically have inadequate conceptions of what science is and what scientists do (Schwartz 2007).

★ Indicates a strong match between the ideas elicited by the probe and a national standard’s learning goal.

Suggestions for Instruction and Assessment

- The scientific method is often the first topic students encounter when using textbooks, and this can erroneously imply that there is a rigid set of steps all scientists follow. Often the scientific method described in textbooks applies to experimentation, which is only one of many ways scientists conduct their work. Embedding explicit instruction of the various ways to do science in the actual investigations students do throughout the year as well as in their studies of investigations done by scientists is a better approach to understanding how science is done than starting off the year with the so-called scientific method in a way that is devoid of a context through which students can learn the content and process of science.
- Use caution when referring to the scientific method. It may be better to refer to *a* scientific method rather than *the* scientific method in order not to imply that there is one, fixed method.
- Be aware that even though scientists may refer to the term *scientific method*, they use this term to generalize the systematic process of doing science, not a rigid, fixed set of steps all scientists follow.
- Use caution when asking students to write lab reports that use the same format regardless of the type of investigation conducted. The format used in writing about an investigation may imply a rigid, fixed process or may erroneously misrepresent aspects of science, such as the idea that hypotheses are developed for every scientific investigation.
- Be careful how the word *experiment* is used. Students and some teachers use *experiment* as a general term for investigation rather than a specific type of investigation that involves variables or fair testing. Consistently remind students to consider, and explicitly point out, that all experiments are investigations but not all investigations are experiments.
- A technique to help students maintain a consistent image of science as inquiry throughout the year by paying more careful attention to the words they use is to create a “caution words” poster or bulletin board (Schwartz 2007). Important words that have specific meanings in science but are often used inappropriately in the science classroom and through everyday language can be posted in the room as a reminder to pay careful attention to how students are using these words. For example, words like *experiment*, *hypothesis*, and *scientific method* can be posted as a caution to be careful in their use.
- Opportunities to experience a variety of ways science is conducted is not enough for students to develop deep understandings about inquiry. For students to understand that science can be carried out in a variety of ways, students need to be given time to reflect on what they have done. Like the nature of science, these understandings need to be explicitly addressed.

- Provide students with a variety of ways to investigate scientific questions, including experiments, field observations, modeling, collecting specimens, making remote observations, and so on. Point out how each has its own methodologies depending on the question being asked and the domain of study. For example, an astronomer cannot control conditions in space but can make observations using technology to help understand astronomical phenomena. Point out the similarities of the different ways to do science, including use of existing knowledge, an organized or systematic approach, and reliance on evidence.
- Use historical accounts and nonfiction readings from articles and books about scientists doing their work, such as *The Beak of the Finch* (Weiner 1994).
- Ensuring that students develop the abilities to carry out scientific inquiries is an important part of the standards. However, it is just as important for students to develop understandings of inquiry. Students can perform investigations yet not understand why they are done in a particular way.

Related NSTA Science Store Publications and NSTA Journal Articles

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“Understandings About Scientific Inquiry”

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