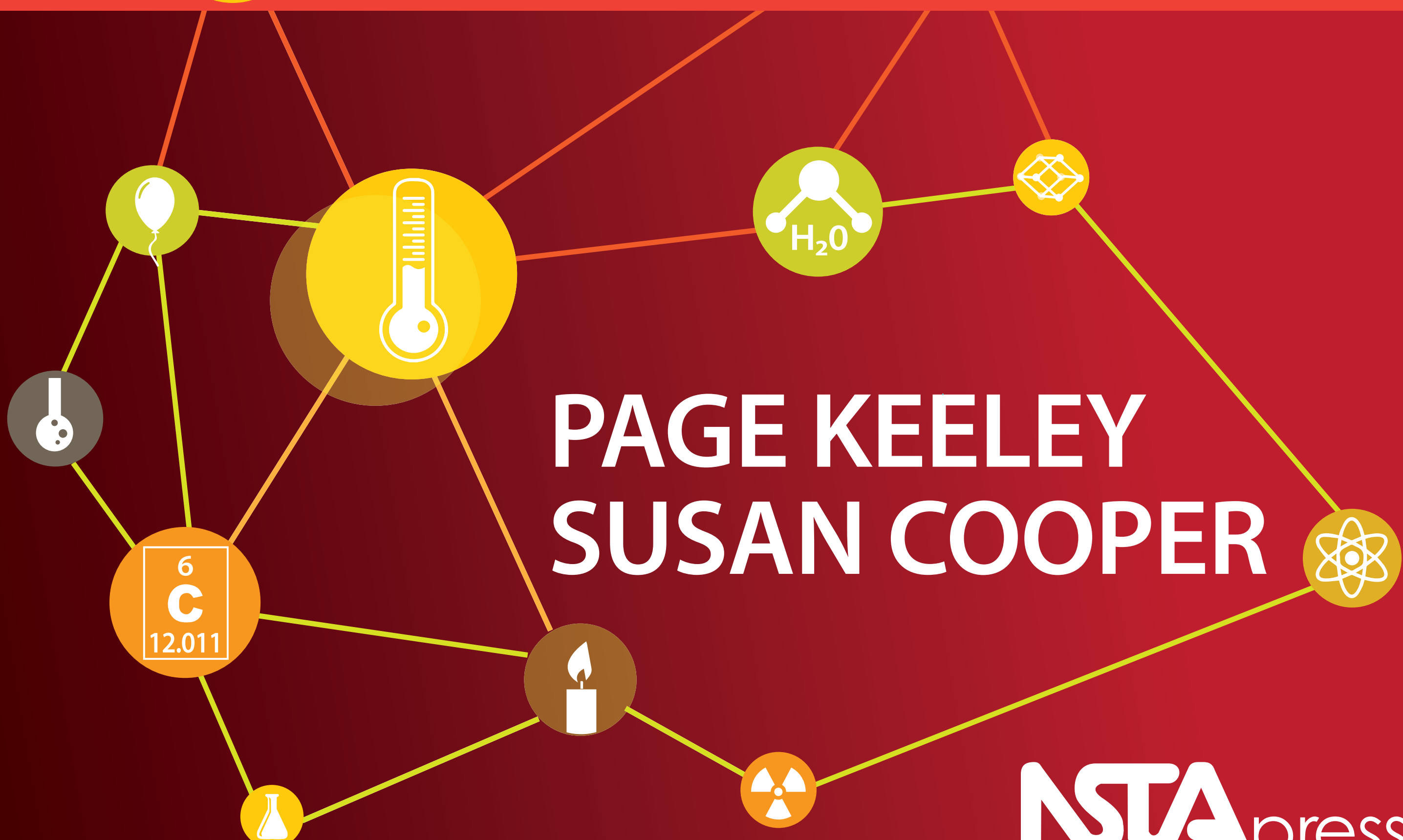
VOL. 3

Uncovering Student Ideas IN PHYSICAL SCIENCE

32 NEW Matter and Energy Formative Assessment Probes



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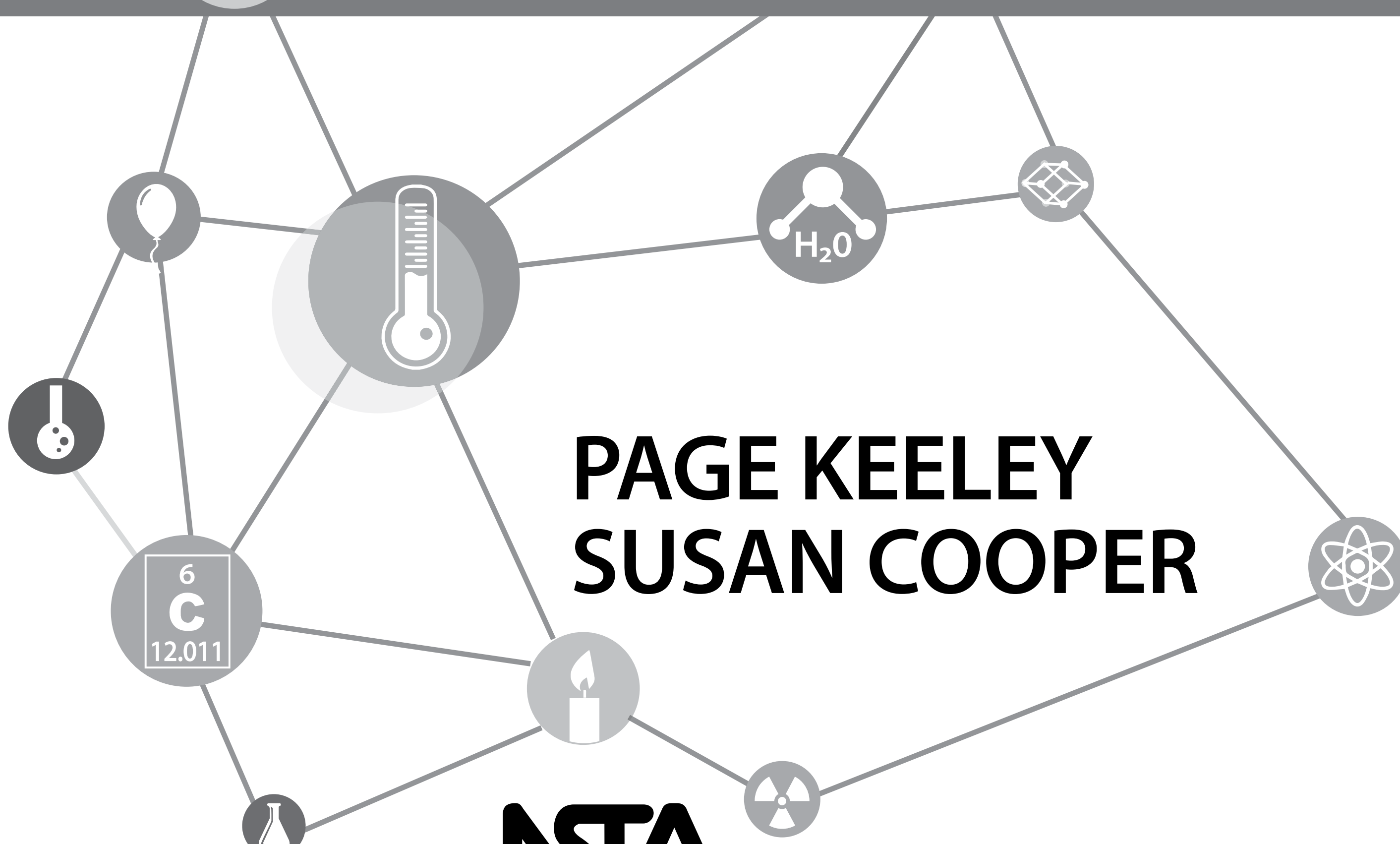

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Section 1: Concept of Matter and Particle Model of Matter

Section 2: Properties of Matter

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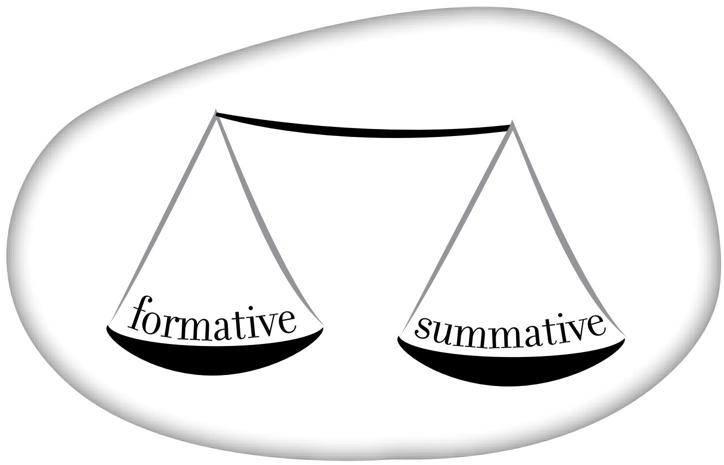
Section 4: Nuclear Processes and Energy

Preface



This is the 11th book in the *Uncovering Student Ideas* series and the third volume in the physical science collection, which includes *Uncovering Student Ideas in Physical Science, Volume 1: 45 New Force and Motion Assessment Probes* (Keeley and Harrington 2010) and *Uncovering Student Ideas in Physical Science, Volume 2: 39 New Electricity and Magnetism Formative Assessment Probes* (Keeley and Harrington 2014). Like the preceding volumes in this series, this book provides a collection of unique questions, called formative assessment probes, designed to uncover ideas students bring to their learning and identify misunderstandings students develop during instruction that may go unnoticed by the teacher. Each probe is carefully researched to identify commonly held ideas students have about the phenomenon or scientific concept targeted by the probe. Each probe includes one scientifically *best* answer along with distracters selected to reveal research-identified alternative conceptions commonly held by children and sometimes adults.

The 32 probes in this book uncover students' thinking about several important ideas regarding matter and energy. Many of the probes are designed to uncover pre-existing ideas that often develop before the concept is even taught. The use of technical terminology is intentionally avoided in most of the probes. Familiar, everyday language is used instead to uncover conceptual understanding, especially since students will sometimes use scientific words without understanding.

It is impossible to cover all matter and energy ideas in one book. For this book, probes were included that focus primarily on concepts and ideas associated with strongly held alternative ideas that can follow students from one grade level to the next and often into adulthood if they have never been surfaced and challenged. Since matter and energy is also a crosscutting concept, there are probes in other books in this series that address matter and energy ideas across the traditional disciplinary content of physics, life, and Earth science. The energy probes in this book focus on energy as it relates to matter. Other books in this series address energy as it relates to forces and motion and energy resources.

Other *Uncovering Student Ideas in Science* Books That Include Matter and Energy–Related Probes

The following is a description of the other books in the *Uncovering Student Ideas in Science* series as of December 2018 that include probes related to matter and energy.

Uncovering Student Ideas in Science, Volume 1 (Keeley, Eberle, and Farrin 2005; Keeley 2018): This first book in the series and its updated second edition, which includes Spanish versions of each student page, contain 25 formative assessment probes in physical, life, Earth, and space science. The introductory chapter of the book provides an overview of what formative assessment is and how it is used. Matter and energy probes in this book, along with suggested grade levels and related concepts, include the following:

- "Ice Cubes in a Bag" (grades 3–12): conservation of matter, mass, matter, change in state, physical change, closed system
- "Lemonade" (grades 3–12): conservation of matter, weight, mass, matter, physical change, dissolving
- "Cookie Crumbles" (grades K–5): conservation of matter, weight, physical change
- "Seedlings in a Jar" (grades 6–12): conservation of matter, mass, chemical change, closed system
- "Is It Melting?" (grades 3–8): melting, dissolving, physical change, change in state, heat
- "Is It Matter?" (grades 3–12): matter
- "Is It Made of Molecules?" (grades 6–12): molecules, atoms, matter
- "The Rusty Nails" (grades 6–12): rusting, chemical change, oxidation, corrosion, mass, open system
- "The Mitten Problem" (grades 3–12): heat, energy, thermal energy, temperature, energy transfer, insulator
- "Objects and Temperature" (grades 6–12): temperature, energy, thermal energy, thermal equilibrium
- "Wet Jeans" (grades 3–12): water cycle, evaporation, water vapor

Uncovering Student Ideas in Science, Volume 2 (Keeley, Eberle, and Tugel 2007): This second book in the series contains 25 formative assessment probes in physical, life, and Earth and space science. The introductory chapter of this book describes the link between formative assessment and instruction. Matter and energy probes in this book, along with suggested grade levels and related concepts, include the following:

- "Comparing Cubes" (grades 6–12): atoms or molecules, characteristic properties, density, extensive properties of matter, intensive properties of matter, mass, melting point, sinking and floating, weight
- "Floating Logs" (grades 5–12): characteristic properties, density, intensive properties of matter, sinking and floating
- "Floating High and Low" (grades 5–8): buoyancy, characteristic properties, density, intensive properties of matter, sinking and floating
- "Solids and Holes" (grades 6–12): Characteristic properties, density, intensive properties of matter, sinking and floating
- "Turning the Dial" (grades 5–12): boiling and boiling point, characteristic properties, change in state, energy, heat, intensive properties of matter, temperature
- "Boiling Time and Temperature" (grades 5–12): boiling and boiling point, change in state, characteristic properties, energy, heat, intensive properties of matter, temperature

- "Freezing Ice" (grades 5–12): characteristic properties, energy, freezing point, intensive properties of matter, temperature
- "What's in the Bubbles?" (grades 3–12): atoms or molecules, boiling and boiling point, change in state, energy
- "Chemical Bonds" (grades 6–12): atoms or molecules, chemical bonds
- "Ice-Cold Lemonade" (grades 6–12): conduction, energy, energy transfer, heat
- "Mixing Water" (grades 5–12): conduction, energy, energy transfer, heat, temperature

Uncovering Student Ideas in Science, Volume 3 (Keeley, Eberle, and Dorsey 2008): This third book in the series contains 22 formative assessment probes in physical, life, Earth, and space science and 3 nature of science probes on hypotheses, theories, and how scientists do their work. The introductory chapter of this book describes ways to use the probes for professional learning. Matter and energy probes in this book, along with suggested grade levels and related concepts, include the following:

- "Pennies" (grades 8–12): atom, properties of matter
- "Is It a Solid?" (grades K–5): liquid, properties of matter, solid
- "Thermometer" (grades 6–12): kinetic molecular theory, thermal expansion, thermometer
- "Floating Balloon" (grades 3–12): density, gas, kinetic molecular theory, mass, properties of matter, weight
- "Hot and Cold Balloons" (grades 6–12): conservation of matter, gas, kinetic molecular theory, mass, properties of matter, weight
- "Earth's Mass" (grades 6–12): closed system, conservation of matter, cycling of matter, decay, transformation of matter
- "Where Did the Water Come From?" (grades 3–12): condensation, evaporation, water cycle, water vapor

Uncovering Student Ideas in Science, Volume 4 (Keeley and Tugel 2009): This fourth book in the series contains 23 formative assessment probes in physical, life, Earth, and space science and 2 probes about models and systems. The introductory chapter of this book describes the link between formative and summative assessment. Matter and energy probes in this book, along with suggested grade levels and related concepts, include the following:

- "Sugar Water" (grades 6–12): dissolving, mixture, physical change
- "Iron Bar" (grades 6–12): atoms, thermal expansion
- "Burning Paper" (grades 6–12): chemical change, closed system, combustion, conservation of matter
- "Nails in a Jar" (grades 6–12): chemical change, closed system, conservation of matter, oxidation
- "Salt Crystals" (grades 6–12): atoms, crystal, crystalline lattice, ionic bond
- "Ice Water" (grades 6–12): energy, phase change, phases of matter, temperature, transfer of energy
- "Warming Water" (grades 6–12): energy, heat, temperature, thermal energy, transfer of energy
- "Is It Food?" (grades 6–12): food, nutrients
- "Camping Trip" (grades 5–12): heat transfer, solar radiation, temperature, weather

Uncovering Student Ideas in Physical Science, Volume 1 (Keeley and Harrington 2010): This fifth book in the series contains 45 probes that address force, motion, weight, and mass ideas. One probe in this book (listed below along with suggested grade levels and related concepts) addresses the difference between weight and mass:

- "Pizza Dough" (grades 6–12): conservation of mass, mass, weight

Preface

Uncovering Student Ideas in Life Science, Volume 1 (Keeley 2011): This sixth book in the series contains 25 life science formative assessment probes. The introductory chapter of this book describes how formative assessment probes are used in a life science context. Although this book focuses on life science concepts, three probes (listed below along with suggested grade levels and related concepts) are related to matter and energy:

- "Atoms and Cells" (grades 6–12): cells, atom, living
- "Food Chain Energy" (grades 6–12): food, flow of energy, food chain, food web, consumer, producer
- "Ecosystem Cycles" (grades 6–12): ecosystem, cycling of matter, flow of energy

Uncovering Student Ideas in Primary Science, Volume 1 (Keeley 2013): This eighth book in the series contains 25 formative assessment probes for K–2 students. The probes are designed for emerging readers as well as English language learners. They can also be used in grades 3–5 to check on students' understanding of precursor ideas. The probes are visual in nature and designed to be used in a talk format. The introductory chapter focuses on how to use the probes to support science talk and how science talk supports students' thinking. Energy is not addressed at the K–2 level in the *NGSS;* therefore, energy probes are not included in this book. Matter probes in this book, along with suggested grade levels and related concepts, include the following:

- "Sink or Float?" (grades K–2): sinking and floating, physical properties
- "Watermelon and Grape" (grades K–2): sinking and floating, physical properties
- "Is It Matter?" (grades K–2): matter, states of matter, solids, liquids, gases
- "Snap Blocks" (grades K–2): weight, conservation of matter, parts and wholes
- "Back and Forth" (grades K–2): physical change, chemical change

Formative Assessment Probes in the Elementary Classroom

Formative assessment is an essential feature of a learning-focused elementary science environment. To help teachers learn more about using formative assessment probes with elementary students to inform instruction and promote learning, NSTA's elementary science journal, *Science and Children,* publishes a monthly column by Page Keeley titled "Formative Assessment Probes: Promoting Learning Through Assessment." Your NSTA membership provides you with access to all of those journal articles, which NSTA has archived electronically. Go to the *Science and Children* web page at *www.nsta.org/elementaryschool*. Scroll down to the journal archives and enter "formative assessment probes" in the keyword search box. This will pull up a listing of all of Keeley's column articles. You can save the articles in your library in the NSTA Learning Center or download them as a PDF.

Table 1 lists the journal issue date, title of the column, and topic of the column for the articles that have been published to date related to matter and energy. Professional developers, facilitators of professional learning communities, and preservice instructors can also use these articles to engage teachers in discussions about teaching and learning related to the probes and the content they teach. In addition, several of the articles are provided in chapter form, along with a link to the probe and discussion questions for professional learning groups in the book *What Are They Thinking?* (Keeley 2014).

Finally, the transformational nature of these formative assessment probes helps teachers break away from teaching and assessing disconnected

Table 1. Matter and Energy Formative Assessment Probes: Promoting Learning Through Assessment (Articles in *Science and Children*)

Issue Date	Article Title and Related Probe	Topic
October 2010	"'More A—More B' Rule" Probe: Floating Logs	Floating and sinking; use of intuitive rules to reason about floating and sinking
March 2011	"The Mitten Problem" Probe: The Mitten Problem	Energy transfer, insulators; teaching for conceptual change and how children's everyday experience affects their thinking
April/May 2012	"Food for Plants: A Bridging Concept" Probe: Is It Food for Plants?	Food, photosynthesis, needs of plants; using bridging concepts to address gaps in learning goals, understanding students' common sense ideas
July 2012	"Where Did the Water Go?" Probe: Where Did the Water Come From?	Using the water cycle to show how a probe can be used to link a core content idea, scientific practice, and a crosscutting concept
January 2013	"Using the P-E-O Technique" Probe: Solids and Holes	Floating and sinking, density; students predict, provide initial explanations for their predictions, then observe the phenomenon and develop a new explanation
July 2013	"Is It a Solid? Claim Cards and Argumentation" Probe: Is It a Solid?	Solids, liquids; technique of claim cards is used to surface students' ideas and engage them in the practice of argumentation using claims and evidence
November 2013	"Is It Melting? Formative Assessment for Teacher Learning" Probe: Is It Melting?	Melting, dissolving; how formative assessment probes can be used in a professional development setting to challenge and address teachers' ideas
December 2014	"Watermelon and Grape: An Intuitive Rule of Quantity and Proportion" Probe: Watermelon and Grape	Sink and float; how the "More A–More B" intuitive rule affects children's ideas about sinking and floating
January 2015	"Ice Cubes in a Bag" Probe: Ice Cubes in a Bag	States of matter, phase change, conservation of matter; uncovering students' ideas about change in state in a closed system
July 2015	"Snap Blocks" Probe: Snap Blocks	Parts and wholes, conservation of matter; do students recognize that an object made of pieces weighs the same as the whole object when it is taken apart?
October 2015	"Wet Jeans" Probe: Wet Jeans	Evaporation, water cycle; using familiar phenomena to uncover students' thinking about evaporation and water vapor
November 2015	"Constructing Cl-Ev-R Explanations to Formative Assessment Probes" Probe: Lemonade	Conservation of matter, dissolving; using claims, evidence, and reasoning to explain what happens to the weight when sugar is dissolved in water
January 2016	"Uncovering Students' Concept of Matter" Probe: Is It Matter?	Matter; uncovering young children's ideas about the types of objects, materials, and substances they consider to be matter
April/May 2016	"Talk Moves" Probe: Watermelon and Grape	Sinking and floating; using talk moves with probes to engage students in productive science discussions
December 2017	"Embedding Formative Assessment Into the 5E Instructional Model" Probe: Lemonade	Conservation of matter, dissolving; how different formative assessment classroom techniques (FACTs) are used throughout an instructional cycle

facts and vocabulary and support conceptual learning of science. Because conceptual change underlies the *Uncovering Student Ideas in Science* series, we highly recommend the book *Teaching for Conceptual Understanding in Science,* which includes chapters on understanding the nature of students' thinking; instructional strategies that support conceptual change; and the link between assessment, instruction, and learning (Konicek-Moran and Keeley 2015).

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Dedication

This book is dedicated to Luiza Holtzberg and Susan German, two outstanding middle school science teachers who model what it means to uncover students' ideas and use them as springboards for learning. Thank you for all the times you tried out draft probes, provided feedback, and shared student data. And most of all, thank for all you do to support students' and your fellow teachers' learning!

About the Authors

Page Keeley is the primary author of the *Uncovering Student Ideas in Science* series. She is retired from the Maine Mathematics and Science Alliance where she was the senior science program director for 16 years, directing projects and developing resources in the areas of leadership, professional development, linking standards, and research on learning, formative assessment, and mentoring and coaching. She has been the principal investigator and project director of three National Science Foundation (NSF)–funded projects including the Northern New England Co-Mentoring Network, Phenomena and Representations for Instruction of Science in Middle School (PRISMS), and Curriculum Topic Study: A Systematic Approach to Utilizing National Standards and Cognitive Research. In addition to the NSF projects, she has developed and directed statewide projects including Linking Science, Inquiry, and Language Literacy (L-SILL), Teachers Integrating Engineering into Science (TIES), and Science Content, Collaboration, and Conceptual Change (SC4). She also founded and directed the Maine Governor's Academy for Science and Mathematics Education Leadership, a replication of the National Academy for Science and Mathematics Education Leadership of which she is a Cohort 1 Fellow.

Page is the author of 21 national best-selling and award-winning books on formative assessment, curriculum topic study, and teaching for conceptual understanding. Several of her books have been translated and used in countries throughout the world. Currently, she provides consulting services to school districts and organizations throughout the United States and internationally on building teachers' and school districts' capacity to use diagnostic and formative assessment. She is a frequent invited speaker on formative assessment and understanding students' thinking. She also develops formative assessment probes for McGraw-Hill's elementary and middle school science programs.

Page taught middle and high school science for 15 years before leaving the classroom in 1996. At that time, she was an active teacher-leader at the state and national level. She served two terms as president of the Maine Science Teachers Association, was a director of the National Science Teachers Association (NSTA) District II, and served as the 63rd president of the NSTA in 2008–2009. She received the Presidential Award for Excellence in Secondary Science Teaching in 1992, the Milken National Distinguished Educator Award in 1993, the AT&T Maine Governor's Fellow in 1994, the National Staff Development Council's (now Learning Forward) Susan Loucks-Horsley Award for Leadership in Science and Mathematics Professional Development in 2009, the National Science Education Leadership Association's Outstanding Leadership in Science Education Award in 2013, and NSTA's Distinguished Service to Science Education Award in 2018. She has taught as an adjunct instructor at the University of Maine, was a

About the Authors

science literacy leader for the AAAS/Project 2061 Professional Development Program, and served on several national advisory boards for NSF-funded projects. She has a strong interest in global science education and has led science education trips to South Africa in 2009, China in 2010, India in 2011, Cuba in 2014, Peru in 2015, Iceland in 2017, and Panama in 2018.

Prior to teaching, she was a research assistant in immunogenetics at the Jackson Laboratory in Bar Harbor, Maine. She received her BS in life sciences from the University of New Hampshire and her MEd in science education from the University of Maine. She currently divides her time between homes in Fort Myers, Florida, and Wickford, Rhode Island, where in her spare time she dabbles in photography, knitting, and culinary arts.

Dr. Susan Cooper is an assistant professor at Florida Gulf Coast University where she has taught science education as well as other courses for graduate and undergraduate students in curriculum and instruction since 2007. Prior to joining the faculty at Florida Gulf Coast University, Susan taught high school chemistry and physics at LaBelle High School in rural Hendry County, Florida, for 27 years. Susan began her career teaching chemistry and mathematics as a Peace Corps volunteer in Ghana after completing her BS in chemistry from Stetson University and her MA in science education from the University of South Florida. She earned her EdD in curriculum and instruction with a focus on science education from the University of Central Florida.

Since 2002, Susan has authored the content reading guides for *ChemMatters*, a publication of the American Chemical Society. She also wrote the lesson plans for *The Best of ChemMatters: Connecting Science and Literacy* (2016), published by the American Chemical Society. She has made numerous presentations related to reading, writing, and inquiry-based science teaching at national and regional NSTA conferences, the School Science and Mathematics Association annual conventions, Florida Association of Science Teachers annual conferences, and the National Council of Teachers of Mathematics annual conference.

Since 2013, Susan has worked with a faculty team from Florida Gulf Coast University to facilitate week-long Summer STEM Institutes for K–12 Teachers, where many of the formative assessment probes developed by Page Keeley have been implemented. She is a co-principal investigator on a National Science Foundation–Robert Noyce Teacher Scholarship Program grant, "Giving Back and Looking Forward: Enhancing and Diversifying STEM Teaching in Southwest Florida Through Recruitment and Mentorship of Homegrown Talent." Susan lives in LaBelle, Florida, where she enjoys bird-watching, kayaking, and other outdoor activities when she is not traveling to foreign destinations to learn more about the natural world.

Introduction

If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generation of creatures, what statement would contain the most information in the fewest words? I believe it is the atomic hypothesis (or the atomic fact, or whatever you wish to call it) that all things are made of atoms—little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another. In that one sentence, you will see, there is an enormous amount of information about the world, if just a little imagination and thinking are applied.

—Richard Feynman (Feynman, Leighton, and Sands 2011, p. 4)

Introduction to the Format of This Book

If this is your first time using formative assessment probes in the *Uncovering Student Ideas in Science* series, start off by becoming familiar with the content and format of this book. This book contains 32 probes for grades 3–12, organized in four sections. The format is similar to the other 10 volumes in the *Uncovering Student Ideas in Science* series. Each section of probes begins with a concept matrix that lists the major concepts each probe addresses and suggested grade levels they can be used with. After the matrix page, each section also lists the *related* performance expectations from the *Next Generation Science Standards* (*NGSS*; NGSS Lead States 2013) by grade level. *Related* is different from *aligned.* Related means that the probe addresses ideas that can support students' achievement of the performance expectation, either directly or indirectly, even if it is not an exact match. Resources from the National Science Teachers Association (NSTA), such as journal articles, books, science objects, and webinars, are listed at the start of each section for teachers who wish to extend their learning as they use the probes.

Each of the four sections contains a collection of probes related to the section topic(s). The English-language version of each probe is followed on the reverse side by a Spanish version. Detailed background information for teachers (the "Teacher Notes") are provided for each of the probes. The Teacher Notes are one of the most important components of the book and should always be read before using a probe. The subsections that follow describe the components of the Teacher Notes.

Purpose

The first section of the Teacher Notes describes the purpose of the probe—that is, what you will learn about your students' ideas if you use the probe. It begins by describing the overarching concept the probe elicits, followed by the specific idea the probe targets. Before choosing a probe, it is important to understand what the probe is intended to reveal about students' thinking. Taking the time to read the purpose will help you decide if the probe will elicit the evidence you need to collect to understand your students' thinking and how their ideas may change throughout a cycle of instruction.

Type of Probe

The *Uncovering Student Ideas in Science* series uses 12 different probe types. This book uses 10 of those types: justified list probes; friendly talk probes; P-E-O (predict-explain-observe) probes; representation analysis probes; concept cartoon probes; opposing views probes; word use probes; data analysis probes; idea choice probes; and thought experiment probes. The type of probe is related to how it is used. For more information about these types of probes, refer to *Science Formative Assessment, Volume 1* and *Volume 2* (Keeley 2016; Keeley 2015).

Related Concepts

Each probe is designed to address one or more concepts that build from one grade span to the next. A concept is a one-, two-, or three-word mental construct used to represent ideas. For example, the concept of matter represents how we think about physical objects, materials, and substances. Most concepts addressed by a probe are embedded within the disciplinary core ideas. The concepts are also listed on the matrix charts that precede the probes for each section.

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 graded or intended to pass judgment. Answers are not always black and white. Probes should be used to encourage students to reveal and share their thinking without the worry of being "wrong." Sometimes there is no single "right" answer because probes often uncover different ways of thinking about a phenomenon or concept that can be legitimate. What is most important is that students feel free to get all ideas out in the open so that they can be considered, eventually discarding ideas that evidence no longer supports. Using the probes in this way mirrors the nature of science. Scientists propose different ideas, eventually discarding the ones that evidence does not support until they agree on a claim and explanation that is best supported by their observations, data, and valid information sources. The *best* answer to a probe is the one that is supported by evidence and scientific facts, theories, or laws.

A brief scientific explanation is given for the *best* answer choice. The explanations are designed to help you understand why the *best* answer is the most scientifically acceptable choice. The explanations are for teachers; however, in some instances, they can be shared as written with upper middle and high school students.

Some teachers, especially at the elementary and middle school level, are generalists, with a minimal background in science. Therefore, the explanations are carefully written to avoid highly technical terminology and detailed descriptions. At the same time, care is taken to not oversimplify the science. Rather, the explanations provide the concise information a science novice would need to understand the content related to the probe. If you need additional background information regarding the content of the probe, refer to the NSTA resources listed at the beginning of each section to build or enhance your content knowledge.

Administering the Probe

Suggestions are provided for administering the probe to students, including response methods, ways to use props or artifacts, clarification of the probe scenario, modifications for different learners, or use of different formative assessment classroom techniques (FACTs). Recommended grade levels are also included.

Related Disciplinary Core Ideas and Crosscutting Concepts From the *Framework* (NRC 2012)

This section identifies the goals for learning that are related to the probe. These learning goals come from the disciplinary core ideas described in *A Framework for K–12 Science Education* (the *Framework;* NRC 2012). Some probes also include a crosscutting concept. These two dimensions, along with the scientific and engineering practices, make up the *NGSS,* which are listed as three-dimensional performance expectations at the beginning of each section. Whether states adopt the *NGSS* or revise their standards based on the *Framework*, this section shows the relationship between the probe and the disciplinary content in the two dimensions. Since the probes are not designed to be summative assessments, the listed learning goals are not considered to be alignments but rather ideas and concepts from the two dimensions that are related in an important way to the probe. Because it is important to assess a learning goal in more than one way, several probes may target the same disciplinary core idea.

Disciplinary core ideas that cut across grade spans are identified for each probe. Although a suggested grade level is provided, the probes are not grade-specific. They can be used within a grade span or across multiple grade spans. It is useful to see the related core idea that precedes your grade level when using the probe as well as seeing the core idea that builds on the probe at the next grade level. In other words, teachers can see how the foundation they are laying relates to a spiraling progression of ideas as students move from one grade level to the next.

You may find that a probe targets an idea at a lower grade span than the one you teach. Often it is necessary to check whether students have sufficient conceptual understanding of prior grade level ideas before introducing new ideas. The nature of misconceptions is such that often a misconception held by students in the elementary grades will follow them into middle school if not surfaced and addressed. That same misconception may then follow students into high school and even into adulthood if teachers are unaware of it and students lack the opportunity to work through and resolve it.

Related Research

Each probe is informed by related research when studies have been conducted and are available through selected professional journals. When available, recent studies are included; however, many of the research citations in this book and others describe studies that have been conducted in past decades. Sometimes the researchers studied children not only in the United States but in other countries. Regardless of when and with whom the research was conducted, most of these studies are considered timeless and universal. Commonly held ideas identified in the research are pervasive regardless of geographic boundaries and societal and cultural influences. Some probes may target the same concept. If so, some research findings may be repeated in the Teacher Notes for different probes.

Although your students may have different backgrounds and experienced different 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 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?* (Keeley 2014).

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 to make decisions about instruction that will move students toward the intended learning target. Thus, for the probe to be considered a formative assessment probe, the teacher needs to think about how to design, choose, or modify a lesson or activity to best address the ideas students bring to their learning or misunderstandings that might surface or develop during instruction. As you carefully listen to and analyze your students' responses, the most important next step is to choose the instructional path that would work best in your particular context according to 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 replace or revise their initial ideas and move toward a more scientific or deeper understanding. It may be as simple as realizing that you need to provide a relevant, familiar context or phenomenon, or there may be a specific strategy, resource, or activity that you could use with your students. For probes that target a similar concept or idea, some of the instructional suggestions may be repeated in the Teacher Notes for those probes.

Learning is a complex process and most likely no single suggestion will help all students learn. But that is what 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. In addition, this section points out other probes in the *Uncovering Student Ideas in Science* series that can be used or modified to further assess students' conceptual understanding and gather additional evidence for making instructional decisions.

This section also includes suggestions that help support three-dimensional teaching and learning. To conceptually understand the disciplinary content the probe targets, students use scientific practices combined with crosscutting concepts. Every probe has a two-tiered structure that supports the use of the scientific practice of constructing explanations. The second part of every probe asks students to explain their thinking either in writing or through talk and discussion. Other scientific practices may also be used with the probes and are suggested in the Teacher Notes when appropriate. For example, students may be encouraged to draw a picture to explain what happens when sugar dissolves in water. Drawing pictures to support an explanation is an example of using a model. Table 2 shows how the formative assessment probes can be used to support the scientific and engineering practices.

Table 2. Probes and Practices

Scientific and Engineering Practice	When presented with a probe, students will ...
Asking Questions and Defining Problems	• Ask further questions about the phenomenon or concept • Turn the probe into a question for investigation • Turn the probe into a question for obtaining information • Turn the probe into a problem to be solved
Developing and Using Models	• Use drawings to support their explanation • Describe a model they could use to explain the concept or phenomenon to someone • Critique models used to explain the concept or phenomenon
Planning and Carrying Out Investigations	• Make predictions or hypotheses and launch into an investigation to observe the outcome • Design and carry out an investigation to test predictions or hypotheses
Analyzing and Interpreting Data	• Compare predictions or hypotheses to what is actually observed • Look for patterns or relationships in data to answer the probe question
Using Mathematics and Computational Thinking	• Use mathematics to describe a pattern or explain an answer choice • Use measurement or number sense to choose the best answer choice
Constructing Explanations and Designing Solutions	• Explain initial answer choice based on experiences or prior knowledge • Revise answer choice and initial explanation and construct new (scientific) explanation using evidence from investigation or valid information sources • Use knowledge of science concepts and principles to design a solution to a problem posed by the probe
Engaging in Argument From Evidence	• Construct an argument with evidence to explain and defend an answer choice • Evaluate the arguments of others as they defend their answer choices
Obtaining, Evaluating, and Communicating Information	• Use text or other information sources to support or construct an explanation or solution to a probe • Use tables, charts, and graphs to support or construct an explanation or solution to a probe • Describe what type of information is needed to explain the phenomenon or solve the problem

The probes are two-dimensional as designed. To make them three-dimensional, teachers can encourage students to use crosscutting concepts in their explanation. Suggestions for using crosscutting concepts are provided for some of the probes. For example, teachers may ask students to use proportional relationships in their explanation of a density-related phenomenon as part of the crosscutting concept of scale, proportion, and reasoning.

References

The final section of the Teacher Notes is the list of references. References are provided for the information cited in the Teacher Notes, including the original article cited in the research summaries.

Matter and Energy Topics

There is little doubt that matter and energy topics present difficulties for both students and their teachers. Students have daily interactions with matter and energy both in and outside of school. Ideas about matter and energy form from their everyday experiences in the natural world; conversations with their family and friends; and interpretations of things they see, hear, or read in books, television, and other media. No wonder teaching science is challenging! Students often come to class with fully or partially formed ideas about matter and energy that may not be consistent with scientific ideas. These ideas are described in the research as naive ideas, alternative conceptions, partially formed ideas, facets of understanding, and misconceptions. Regardless of how they are labeled, these are ideas that make sense to students and therefore it is important for teachers to be aware of them. When teachers take the time to uncover these ideas, understand where they came from, and make instructional decisions that will help students give up their strongly held ideas in favor of scientific ways of thinking, they are taking an important first step in teaching for conceptual understanding.

There are too many matter and energy–related concepts to include in one book. For this book, we decided to focus on topics that students may have already formed initial ideas about before being introduced to them in school. For example, students have already formed ideas about heat long before they are introduced to the concept of transfer of energy; therefore, probes have been included that will uncover these ideas. The periodic table is something that students do not encounter during their everyday experiences; therefore, probes about the periodic table are not included in this book. Some probes address ideas developed in middle school that research indicates are not well understood by students or may be interpreted through students' own conceptual lens. For example, when the idea of molecules is introduced, students may form their own alternative ideas about molecules. Probes that address concepts introduced in school are provided when it is important for teachers to check on prior understanding of concepts and ideas that were part of the taught curriculum. Topics chosen for this book are organized in four sections:

- Section 1: Concept of Matter and Particle Model of Matter (six probes)
- Section 2: Properties of Matter (eight probes)
- Section 3: Classifying Matter, Chemical Properties, and Chemical Reactions (nine probes)
- Section 4: Nuclear Processes and Energy (nine probes)

Section 1: Concept of Matter and Particle Model of Matter

"Often in the course of science teaching, we tend not to pay enough attention to the very basic and fundamental concepts or ideas" (Stavy 1991, p. 244). Matter is one of the broadest concepts in the K–12 physical science curriculum. As a basic concept, it seems self-evident that students understand the matter concept. However, this is often not the case. Leaving this basic concept unattended may have consequences for understanding more advanced concepts, theories, and laws related to matter.

The concept of matter appears in numerous places throughout standards and the K–12 curriculum. Disciplinary core idea "PS1: Matter and Its Interactions" appears in the *Framework* and the *NGSS*. Students learn about states of matter, properties of matter, and conservation of matter. A keyword search for *matter* in the NSTA *NGSS* Hub Keyword Search Engine at *https://ngss.nsta.org/keywordSearchResults.aspx* reveals the word appears 17 times in the performance expectations, 52 times in the disciplinary core ideas, 15 times in the crosscutting concepts, and 50 times in the related resources. Clearly it is a central concept.

Even though the concept of matter by itself,is not explicitly addressed in standards, it is important to understand how students think about this concept when they encounter the word *matter*. Therefore, probes are included in this section that reveal strongly held ideas students have about this concept and how sensory experiences tend to dominate students' thinking about matter, especially matter that is not visible or tangible. For example, in phenomena where a liquid changes to a gas, some students fail to recognize that the matter still exists since they can no longer see or feel it. Stavy (1991) suggests that prior to teaching the particulate nature of matter, teachers should discuss and clarify the meaning of the concept of matter with their students.

The particle model of matter is central to understanding physical and chemical phenomena. Probes that elicit students' ideas about particles and the models they use to explain phenomena are included in this section. Five basic ideas about particulate matter compose this section:

1. All matter, living and nonliving, is composed of very small particles (atoms and molecules) that are too small for us to see with our eyes or with ordinary microscopes.
2. Matter exists in different states and can change.
3. There is empty space between particles of matter.
4. Particles of a gas in an enclosed space are evenly distributed.
5. A particle model can be used to describe and explain phenomena.

Atomic theory explains that all matter is made up of atoms that are too small to be seen. The transition from particles to atoms and molecules is developed in middle school after students have had the opportunity in elementary grades to develop models about very small particles that cannot be seen with our eyes. Piaget's early interviews of children revealed that they had a notion of matter being made up of "tiny bits." However, the characteristics and behaviors of these "tiny bits" conceptualized by children are often very different from those attributed by scientists, especially when it comes to gases (Driver et al. 1994).

Elementary and middle school students may hold a "continuous view" of matter. Even when they recognize that matter is made up of smaller particles, they fail to recognize that there is empty space between the particles. This is another example of how visuality affects students' thinking about microscopic matter. For example, when students look at a wooden desk, they do not see mostly empty space. They see wood that appears to be continuous throughout. This section includes several probes that uncover students' ideas about particles and the models they use to explain the characteristics and behavior of matter.

Section 2: Properties of Matter

Elementary students describe observable properties of objects and materials, transitioning to substances and matter at the atomic and molecular level during middle and high school. Sensory experiences of some objects feeling heavy or light, or being large or small, often interfere with their understanding of different properties. For example, some students think gases have no mass or weight. The intuitive rule "more A equals more B" has a strong effect on how they think about intensive properties such as density and boiling point (Stavy and Tirosh 2000). When students compare two different amounts of the same substance, they may think that an intensive property increases or decreases, depending on the quantity of the substance. For example, students may believe that a larger cube of aluminum ("more A") has a greater density ("more B") that a smaller cube of aluminum.

The probes in this section address both intensive and extensive properties of matter. Extensive properties depend on the amount of matter; intensive properties do not. Until students understand that matter has weight (or mass when they get to middle school), they will struggle with the difference between extensive properties of matter (e.g., weight, volume) and intensive ones such as density (Smith and Plumley 2016). "Children's initial concept of weight is felt weight, which conflates weight and density. Because the concepts of weight and density are components of a theory of matter and prerequisites to the atomic-molecular theory, differentiating them from each other is crucial" (Smith et al. 2006, p. 325).

Both the *Framework* and the *NGSS* use the familiar property of weight in grades K–5, transitioning to mass in middle school. Research supports several reasons for waiting until middle school to use the property of mass. One reason is that mass can become associated with the phonetically similar word *massive,* and as a result students may conflate it with size or volume by observing the bulk appearance (Driver et al. 1994). This section includes two probes that reveal how students think about mass as a property of matter.

Another commonly held idea addressed in this section is how students attribute the properties of substances to the properties of the particles that make up a substance. For example, some students think that molecules of ice are cold or that the atoms that make up a copper penny are hard and shiny. Probes in this section also reveal whether students recognize that some properties can be used to identify a substance.

Dissolving presents a challenge to students in that they have to account for the apparent disappearance of a substance. Much of the research in this area has been carried out with examples of salt or sugar dissolving in water, a phenomenon students can readily observe. When conserving matter in the context of dissolving, such as in the probe "Salt in Water," some students may think the salt or sugar no longer has mass or weight since they cannot visually see it. Even when they recognize that the solute breaks down into smaller particles, some students think those particles have less weight or mass because they are smaller. They conserve the substance but fail to conserve the weight or mass. Students' tendency to use conservation reasoning in physical change contexts increases with age but is still challenging even for high school students.

Section 3: Classifying Matter, Chemical Properties, and Chemical Reactions

Students' ways of classifying matter expand from solids, liquids, and gases in the elementary grades to elements, compounds, and mixtures in the middle and high school grades. Middle school students recognize that each element or compound can be represented by its component units and that these units are held together by forces. Perceptible characteristics may affect how students distinguish between elements and compounds. For example, some students may think compound substances, such as salt, are elements because they look the same throughout or may think elements exist only as solids. Studies have shown that students have difficulty recognizing that the same element can exist in different forms. For example, although the element carbon can exist as graphite or as diamond, high school students may think the forms have a different chemical composition. Furthermore, the misconception that these are two different elements is further compounded by using different common names for the same element. This section includes several probes that reveal how students think about pure substances and how they distinguish between them.

Researchers have identified several difficulties students have with the concept of chemical change and the nature of chemical reactions. Simply put, a chemical change involves the breaking apart and recombination of molecules or ionic substances to form new substances that are chemically different from the original substances. “In order to explain a chemical change, students must understand a variety of facts about the chemical properties of the substances involved, as well as some basic chemical theories, the most important of which is the atomic molecular theory” (Hesse and Anderson 1992, p. 278). This section includes several probes that uncover students’ ideas about whether a chemical change has occurred and what happens to atoms and molecules during a chemical change.

The law of conservation of mass states that the total mass of the products of a chemical reaction is the same as the total mass of the reactants. Many researchers, going all the way back to the early work of Jean Piaget, have found that conserving mass (or matter) is difficult for students at all ages (Piaget and Inhelder 1974). Conservation reasoning starts with phenomena that involve physical changes in which the chemical makeup of the material or substance does not change but its appearance does. By middle school, students can usually conserve mass in transformations that involve a change in shape, such as flattening a clay ball, but still struggle with more complex physical changes such as dissolving when they can no longer see the solute. Conserving mass during chemical reactions poses similar difficulties for middle and high school students when there is a nonvisible reactant or product such as a gas. This is where the crosscutting concept of systems is important as the actual system to be explained may be larger than the system that the student perceives. For example, when steel wool rusts, students may fail to recognize that oxygen from the air is part of the system. This section includes a probe (“What Happens to Atoms During a Chemical Reaction?”) that reveals how students use conservation reasoning to explain how matter changes chemically.

Vogelezang (1987) points out that the concept of substance occupies a central position among chemistry concepts and suggests that teachers should pay careful attention to how they use the word. The word *substance* has a meaning in chemistry that differs from the everyday meaning of the word. To a chemist, a substance is a type of “pure” matter that has a definite chemical composition (elements and compounds). In our everyday broad use of the word, substance may refer to any type of matter, including mixtures. The probe “What Is a Substance?” may be used to reveal how students think about this important chemical concept.

Section 4: Nuclear Processes and Energy

Both the *Framework* and the *NGSS* include the core idea of nuclear processes. Much of the content related to nuclear processes is new to students—they may not come to the science class with ideas formed from their everyday experiences, such as they do with other matter and energy–related concepts. Therefore, we chose to focus on an idea related to experiences they may have had or know something about—irradiation. Many students have experienced x-rays or airport screening machines or heard about irradiated food. The first two probes in this section uncover strongly held ideas students have about irradiation that tend to follow them into adulthood if left unchallenged and unresolved and that are important for public understanding of science.

Energy is the final topic in this book. "Energy is perhaps the most important idea in all of science" (Nordine and Fortus 2017). Energy is a broad, crosscutting concept that appears in all the disciplines of science. To cover energy comprehensively would require a separate book devoted only to uncovering student ideas about energy. For this book we chose to limit the focus to the concepts of energy, heat, thermal energy, and temperature; energy of chemical reactions; and the transfer and conservation of energy.

Researchers have known for decades that students at all grade levels have difficulty understanding energy. Before students ever learn about energy in school they have already formed ideas about energy from their everyday experiences. Energy pervades all aspects of our lives, but the ideas students form about energy are not always consistent with the scientific view of energy. The way we refer to energy and related terms in our everyday language, such as heat and temperature, can affect ideas students have about energy. For example, how many times have you heard someone refer to "using up the energy" or say "close the door, you are letting the cold in"? Definitions students learn in school, such as energy is the ability to do work, can also muddle ideas about energy. Even science teachers' language can cause conceptual misunderstandings, such as the way biology teachers sometimes refer to the release of energy when breaking a chemical bond. The probes in this section can be used to uncover preexisting ideas students have about energy.

Formative Assessment Reminder

Now that you have the background on the probes and the Teacher Notes in this new book, let's not forget the formative purpose of these 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 all students have the opportunity to learn the important scientific ideas about matter and energy. As a companion to this book and all the other volumes, NSTA has co-published the books *Science Formative Assessment, Volume 1* (Keeley 2016) and *Science Formative Assessment, Volume 2* (Keeley 2015). In these books, you will find a variety of formative assessment classroom techniques (FACTs) to use along with the probes to facilitate elicitation, support metacognition, encourage discussion and argumentation, monitor progress toward conceptual change, encourage feedback, and promote self-assessment and reflection—all aspects of the formative assessment process.

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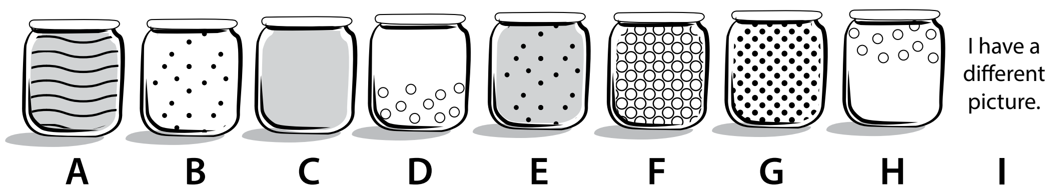
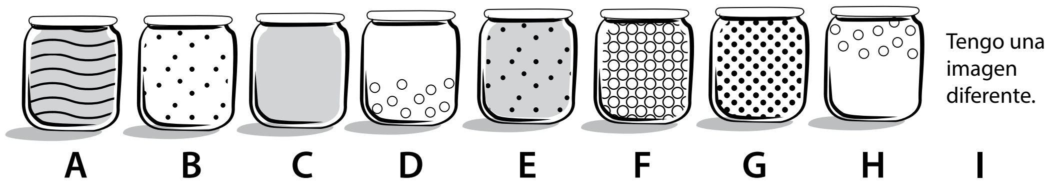
Model of Air Inside a Jar



The drawings show different models of air inside a sealed jar. Circle the drawing that best matches how you would draw a model of air inside a jar.

Explain your thinking. If you chose I, draw your model below and explain it. Describe how it is different from the other models.

Modelo de Aire Dentro de un Frasco

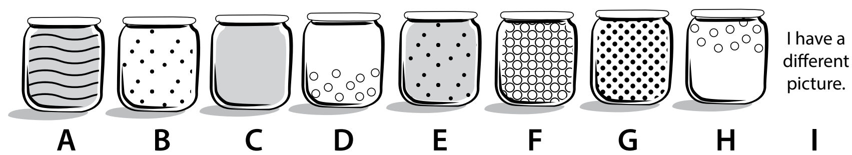


Los dibujos muestran diferentes modelos de aire dentro de un frasco sellado. Marque el dibujo que es más cómo dibujarías un modelo de aire dentro de un frasco.

Explica lo que piensas. Si eliges I, dibuja tu modelo y explícalo. Describe cómo es diferente comparado a los otros modelos.

Model of Air Inside a Jar

Teacher Notes



Purpose
The purpose of this assessment probe is to elicit students' ideas about the particle model of matter. The probe is designed to find out if students recognize that air is made up of particles that are widely spaced with empty space between the particles.

Type of Probe
Representation analysis

Related Concepts
Air, gas, molecule, particle

Explanation
The best representation is B, which represents particles widely and randomly distributed throughout the jar with empty space between them. Air is a gaseous mixture made up of molecules of different gases (nitrogen, oxygen, argon, water vapor, carbon dioxide, and small amounts of other gases). In a gas, the molecules are randomly spaced further apart than in a solid and liquid and are free to move about. The molecules are not arranged as a continuous form of matter; instead, there is empty space between the molecules that does not contain matter. A, C, and E represent a continuous model of matter in which there is something filling the space. A and C may also reveal a non-particle view of matter. E represents both a particle and continuous model of matter. D represents a particle model with nothing between the particles but the particles are not distributed throughout the jar. The particles are at the bottom and there is empty space above them. F shows particles packed tightly with very little space between them. G represents a particle model but the particles have a very orderly, structured arrangement. H is the opposite of D, with empty space at the bottom of the jar. Some students may think the particles float to the top. Some students may choose I and draw their own model. Carefully examine their model, which could be similar to B or reflect a completely different conceptual model.

Under normal conditions, gases are typically considered to be 100 to 1,000 molecular diameters apart. The size of the particles in B is also not to scale. These aspects of a particle model are difficult to portray to scale in the diagrams. It is important to recognize that models cannot always portray all aspects of the real thing.

Administering the Probe

This probe is best used with grades 5–12. Hold up an empty open jar for students to see and seal it with the top. Explain that the jar contains air just like the jars in the diagrams. It may be helpful to explain that the representations are mental models—what someone might visualize in their head if they had a very powerful imaginary magnifier that let them see the air in the jar. Refrain from using the terms *particle* or *molecular model,* as the probe intentionally does not use these words to reveal whether students have the idea that air is composed of particles or molecules. Emphasize that if the pictures do not exactly match a students' mental model of air, they should choose the one that is most like their mental model. You might also point out that models cannot always represent all aspects of the real thing, especially scale size and distance. Let students know that if their mental model of air inside the jar is significantly different, they may choose I and draw their model and explain it. Some students may choose G and provide the explanation that the particles are distributed throughout the jar and there is empty space between them, even though the representation depicts a very orderly, structured arrangement. It is this explanation of particles distributed throughout the jar with empty space between them that may be evident in G or I, even though B may be considered the best representation.

Related Disciplinary Core Ideas and Crosscutting Concepts From the *Framework* (NRC 2012)

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

- Matter of any type can be subdivided into particles that are too small to see, but even then the matter still exists and can be detected by other means. A model showing that gases are made from matter particles that are too small to see and are moving freely around in space can explain many observations, including the inflation and shape of a balloon and the effects of air on larger particles or objects.

3–5 Crosscutting Concept: Energy and Matter

- Matter is made of particles.

6–8 PS1.A: Structure and Properties of Matter

- Gases and liquids are made of molecules or inert atoms that are moving about relative to each other.
- In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations.

Related Research

- Students of all ages show a wide range of beliefs about the nature and behavior of particles. For example, they do not accept the idea that there is empty space between particles (AAAS 2009).
- In a study by Benson, Wittrock, and Bauer (1993), elementary through college age students were asked to imagine they had magic magnifying glasses that would let them see the particles of air in a sealed flask. They drew their mental models. Students

with a continuous view of matter shaded in the flask or drew continuous straight or wavy lines throughout the flask. Students with a particulate view drew dots or circles, some spread out, others packed tightly. The tightly packed drawings indicated a lack of understanding of the amount of empty space between molecules. The study also showed that 30% of college students' drawings of air showed particles in a highly packed and orderly arrangement.

- Students at all grade levels frequently do not believe in the notion that there is empty space between the particles of matter. They often hold on strongly to the presupposition that all empty spaces are filled with air (Talanquer 2009).
- Novick and Nussbaum (1978) studied 13- and 14-year-old students' conceptions of a gas inside a sealed flask containing air. Sixty percent indicated that a gas is made up of particles, 46% mentioned empty space between the particles, and 50% recognized that the distribution of the particles was due to their motion.
- Students do not develop particle ideas equally across all three states. Water and gases seemed to be easier substances for students to make the shift from continuous to particulate or molecular views (Nakhleh, Samarapungavan, and Saglam 2005).
- Researchers have associated the students' misunderstanding of the particulate nature of matter with ineffective instruction (Johnson 1998) as well as misrepresentation of the model in some textbooks (Harrison and Treagust 2002).

Suggestions for Instruction and Assessment

- This probe provides an opportunity for students to evaluate mental models. Develop the idea that mental models are a type of conceptual model and that models can also be physical, mathematical, or symbolic.
- Integrate visual tools into instruction when teaching about the particulate nature of matter. Both static and animated representations should be included with multiple opportunities for students to critique and discuss visual models they develop as well as ones used in instructional materials.
- Extend this probe to ask students to draw their model of the air in the jar after half the air is removed from the sealed jar.
- Extend the probe by asking students to draw their model of air in an open jar.
- For probes such as this one that ask students to visualize the "invisible," have students imagine they have special glasses with unlimited magnification that allows them to see the very smallest things that exist. Ask them to draw what they see through these imaginary glasses.
- Simply telling students that gases are made up of small particles that spread out to fill their container is not enough to change their strong preconceptions. Carefully chosen demonstrations, simulations, and animations are most effective when they stimulate cognitive conflict that enables learners to reconsider their existing ideas.
- Use large veterinary syringes (without needles) to let students explore how to catch air inside and feel the air pushing against their hands when they push the plunger. Ask students to use particle ideas to explain why the air can be compressed into a smaller space.
- Emphasize how models cannot always represent all aspects of the real thing, especially scale size and distance. After students agree on which diagram is the best representation of air in a sealed jar, ask them what would need to be done to improve the model.

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VOL. 3

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