Uncovering Student Ideas in Astronomy

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By Page Keeley
and Cary Sneider

NSTApress
National Science Teachers Association
Arlington, Virginia

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National Science Teachers Association

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www.nsta.org/store
For customer service inquiries, please call 800-277-5300.

15 14 13 12 4 3 2 1

ISBN 978-1-936137-38-1
eISBN 978-1-936959-82-2

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Cataloging-in-Publication Data is available from the Library of Congress.

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Dedication

This book is dedicated to an astronomy educator, artist, dedicated NSTA workshop presenter, and all-around brilliant and wonderful person—Donna Young. Thank you, Donna, for your tireless efforts in bringing the wonders of the universe to teachers everywhere and supporting the next generation of astronomy educators.

Foreword

There is nothing like astronomy to pull the stuff out of man.
His stupid dreams and red-rooster importance: let him count the star-swirls.
—From the poem "Star-Swirls" by Robinson Jeffers

As the old adage has it: Y*ou can't know where you're going until you know where you've been.* And it's every bit as true in science education as it is in other parts of life. In this intriguing book, Page Keeley and Cary Sneider, two experienced and talented educators, set out to help teachers figure out where their students have been in their thinking about our planet and its place in the universe, so that your teaching and their learning of astronomical ideas can then be as effective as possible.

After many decades of research about learning, today we know that students are not simply blank vessels waiting to be filled with our brilliantly taught lessons. They're more like hot dogs you buy from a street vendor—already full, although not necessarily with material you would approve of. The more you know about what your students' heads are filled with, the better you will be at helping them.

Students of each generation construct their understanding of the world from the best resources they have available—their common sense, their daily experience, the media they are exposed to, conversations with family and friends. Today, the internet plays a much bigger role than it did for the previous generation, but the process by which students absorb a wild mixture of information and approaches in the course of their lives has not changed. And we should always appreciate that students have tried to make the best synthesis of all these influences that they could. After all, their mental constructs—whether scientifically correct or not—show the scientist's urge to make sense of the world and put disparate phenomena into a reasonable context.

This book consists of a series of small but carefully thought-out probes into student thinking about astronomy. Just like a doctor's diagnostic tool provides one chemical or physical indicator of our health, each of Keeley and Sneider's probes measures one or two ideas that lets you know how much surgical repair (if any) might be needed to fix up your students' astronomical ideas.

Astronomy is a great portal to help students solidify their thinking about science and the scientific process. Surveys show that for younger children, astronomy and dinosaurs continue to be the most fascinating entrées into science (and you need only look at popular films for youngsters to see this confirmed). But the study of astronomy has something for students of all ages, from simple observations of everyday sky phenomena to considerations of the origins of all heavier elements in the nuclear crucibles of the stars. The sheer beauty of the images being taken by the Hubble Space Telescope and giant mirrors on Earth is a wonderful entrée for students who are visual learners. And then there is the possibility that one day a large chunk of rock or ice from space may again threaten life on Earth as it did 65 million years ago (in the time of the dinosaurs). If you want to capture the imagination of students for science, astronomical lessons and activities may be your strong suit.

Although I have organized and taught summer workshops for teachers and informal educators for three decades, most of my teaching has been and continues to be for nonscience college students. In my evening classes, I have students ranging in age from 16 to 75 and so I have seen a nice cross section of the adult American public over the years. I can attest to the fact that these older students are often grappling with the very same misconceptions that are highlighted in this book.

Many of my college students firmly believe that the seasons are caused by the Earth being farther away from the Sun in winter, that the changing appearance (phases) of the Moon is the result of the Earth's shadow falling on the Moon, and that shooting stars are stars that die. Some students have also become convinced by internet and TV conspiracy theorists that NASA never landed on the Moon, that UFOs are alien spaceships whose landings on Earth are hushed up by the government, and that the world will end on the winter solstice in 2012 (as supposedly predicted by the ancient Mayans).

In my classes, I do activities that allow students to confront and lay open the preconceptions that they have on many astronomical subjects. Only after we have faced the existence of these ideas can we then do activities to move the students toward finding a new view of astronomical phenomena, based on scientific experiments and observations. Former students who return to speak with me after some time has passed frequently cite these "mind-set"-changing sessions as the highlights of what they remember from my classes.

It is therefore from direct personal experience that I can commend the techniques in this book to your attention and wish you as much pleasure in teaching the wonders of astronomy as I have had over the years.

—Andrew Fraknoi
Chair, Department of Astronomy, Foothill College, Los Altos Hills, California
Former Executive Director, Astronomical Society of the Pacific, San Francisco, California

In addition to the positions listed above, Andrew Fraknoi was founding co-editor of the journal Astronomy Education Review, *and he founded and directed Project ASTRO, a national program that trains and brings volunteer astronomers into fourth- through ninth-grade classrooms. Fraknoi is the lead author of* Voyages Through the Universe, *one of the leading college textbooks for introductory astronomy, and he wrote a colorful children's book called* Disney's Wonderful World of Space. *He was selected California Professor of the Year in 2007 by the Carnegie Endowment for Higher Education and won the Andrew Gemant Award from the American Institute of Physics for his work in making connections between physics and culture. Fraknoi was recently named an honorary member of the Royal Astronomical Society of Canada, a distinction shared by such notables as Stephen Hawking and Harlow Shapley. The International Astronomical Union named Asteroid 4859 Asteroid Fraknoi to honor his contributions to science education and outreach (but he hastens to add that it is a very boring asteroid that is in no danger of hitting the Earth!).*

Preface

When I heard the learn'd astronomer,
When the proofs, the figures, were ranged in columns before me,
When I was shown the charts and the diagrams, to add, divide, and measure them,
When I sitting, heard the astronomer where he lectured with much
applause in the lecture-room,
How soon unaccountable I became tired and sick,
Till rising and gliding out I wander'd off by myself,
In the mystical moist night-air, and from time to time,
Look'd up in perfect silence at the stars.
—Walt Whitman, *Leaves of Grass*

In the classic poem "When I Heard the Learn'd Astronomer," Walt Whitman contrasts the dry and dull delivery of a lecture on the universe with the awe-inspiring experience of going outside and looking up at a star-filled night sky. One can draw a parallel to similar experiences students have in school—being passively filled with facts about astronomy from reading textbooks and listening to teachers talk. Wouldn't it be more interesting if students could contemplate the wonders of the universe through questions that spark interest and curiosity and lead them to observe or model astronomical phenomena firsthand? This book is the first in the *Uncovering Student Ideas in Science* series to focus on astronomy. Coauthored with Dr. Cary Sneider, an esteemed "learn'd astronomer," educator, and researcher, this book aims to not only inform teaching but also inspire students to want to know more about the wonders of the Earth, Moon, Sun, our solar system, and the universe beyond.

Series Overview: *Uncovering Student Ideas in Science*

The *Uncovering Student Ideas in Science* series provides science educators with unique sets of versatile formative assessment probes for use in K–12 education, preservice teacher programs, and professional development. This popular series of award-winning books began with *Uncovering Student Ideas in Science, Vol. 1: 25 Formative Assessment Probes* (Keeley, Eberle, and Farrin 2005). That book contains 25 K–12 probes in life, Earth, space, and physical sciences. The introductory chapter provides an overview of formative assessment and a description of the standards- and research-based probe development process. Between that 2005 book and this new volume on astronomy, five other books have been published in the series:

- *Uncovering Student Ideas in Science, Vol. 2: 25 More Formative Assessment Probes* (Keeley, Eberle, and Tugel 2007): This book contains 25 K–12 probes in life, Earth, space, and physical sciences. The introductory chapter describes the link between formative assessment and instruction and suggests ways to embed the probes into your teaching. This book won the Distinguished Achievement Award given by the Association of Educational Publishers (AEP).

- *Uncovering Student Ideas in Science, Vol. 3: Another 25 Formative Assessment Probes* (Keeley, Eberle, and Dorsey 2008): This book contains 22 K–12 probes in life, Earth, space, and physical sciences and 3 nature of science probes. The introductory chapter describes how to use the probes for teacher learning either through individual study or in a variety of professional development formats.
- *Uncovering Student Ideas in Science, Vol. 4: 25 New Formative Assessment Probes* (Keeley and Tugel 2009): This book contains 23 K–12 probes in life, Earth, space, and physical sciences and 2 unifying concepts probes, one on models and one on systems. The introductory chapter describes the link between formative and summative assessment, including why an investment in formative assessment throughout an instructional cycle can improve student performance on summative assessments. This book was also a winner of the Distinguished Achievement Award and a finalist in the Golden Lamp Award given by the AEP.
- *Uncovering Student Ideas in Physical Science, Vol. 1: 45 New Force and Motion Assessment Probes* (Keeley and Harrington 2010). Coauthored with physicist and physics education researcher Dr. Rand Harrington, this book contains 45 K–12 probes organized in the categories of Describing Position and Motion; Forces and Newton's Laws; and Mass, Weight, Gravity, and Other Topics. The introductory chapter provides an overview of the research, teaching, and student ideas related to force and motion, including advice for implementing the probes. Other volumes planned for this physical science series will cover electricity and magnetism, sound and light, and matter and energy. This book was also a winner of the AEP's Distinguished Achievement Award.
- *Uncovering Student Ideas in Life Science, Vol. 1: 25 New Formative Assessment Probes* (Keeley 2011b): This book includes 25 biology/life science probes organized in the categories of Life and Its Diversity; Structure and Function; Life Processes and Needs of Living Things; Ecosystems and Adaptation; Reproduction, Life Cycles, and Heredity; and Human Biology. The introductory chapter describes how formative assessment probes are used in a life science context. Two more books are planned for this life science series.

Collectively, this new astronomy book and the six volumes that preceded it now provide educators with 215 assessment probes. In addition, the introductory chapters of all the books in the series can significantly expand teachers' assessment literacy, understanding of the ideas students bring to their learning, key ideas that make up fundamental topics in science, effective teaching and learning strategies, and access to other related resources.

About the Probes in This Book

The probes in this book, as well as others in the series, are diagnostic assessments designed to uncover students' thinking. Once students' ideas are revealed, the teacher uses the information to make decisions about instruction that will help students give up their misconceptions or incompletely formed ideas in favor of the scientific view or a more coherent and connected understanding of the content. It is this use of the probe to inform instruction that transitions it from being a diagnostic assessment to a formative assessment. If one uncovered students' preconceptions but did nothing with the information, then the probe would be merely diagnostic. It is the formative use of the probes that make them powerful resources for promoting learning and improving teaching.

Although these probes are printed on paper and are often used as written formative assessments, their real value comes through providing opportunities for students to discuss their ideas and formulate scientific arguments to support their thinking while evaluating and challenging the ideas of their peers. Whether used at the beginning of a unit as an elicitation or at checkpoints during various stages of instruction, the probes are designed to draw out ideas commonly held by students. Beyond having students merely select an answer, the real value of the probes emerges when students are asked to explain their thinking. It is this part of the probe that provides many insights into students' ways of thinking and reasoning that draw on their everyday experiences outside of school as well as ideas "learned" in school that failed to come together in a coherent, connected, or accurate way.

All of the probes in this series have common features: a title designed to spark interest; a prompt set in an engaging, familiar context; a set of answer choices to choose from; and an open-ended section where students are asked to provide an explanation. This format is designed for the purpose of making the probe accessible to all students, providing an answer that is most likely to match ideas students have and eliminate the blank stares or "I don't know" responses that often accompany open response formats. The explanation section is also used to promote student thinking and provide opportunities for students to construct explanations to support their thinking. Constructing explanations and defending scientific ideas through talk and argument are key science practices included in *A Framework for K–12 Science Education*, which will inform the Next Generation Science Standards tentatively due to be released in late 2012 (NRC 2011).

In addition to these common features of the probes, there are a variety of formats used throughout the *Uncovering Student Ideas in Science* series to draw out students' ideas in different and sometimes novel ways. These formats and the process for developing these types of probes are described in Page Keeley's National Science Foundation–funded Curriculum Topic Study (CTS) materials (Keeley 2005; Mundry, Keeley, and Landel 2009), and the formats are summarized below:

- *Justified List Probes.* These probes provide a list of items which may or may not match a particular concept or statement in the probe's prompt. Students are asked to choose the items on the list they believe match the concept or statement provided and explain their rule or reason for choosing the items. An example of a justified list probe is Probe 16, "Seeing the Moon."
- *Friendly Talk Probes.* These probes involve a group of people talking about their different ideas. Students choose the name of the person they agree with the most and explain why. The format of these probes make them much more engaging than a traditional multiple-choice question where students choose A, B, C, or D. The statements (answer choices) are written to simulate a conversation between people. There is also a degree of safety in choosing the answer in that students worry less about whether they are wrong because they didn't say it, "so and so" did. An example of a friendly talk probe is Probe 30, "Is It a Planet or a Star?"
- *Thought Experiment Probes.* These probes are set in the context of an imaginary scenario that would be impossible to produce in the real world. Students have to use their imagination to visualize the scenario

and apply their knowledge of science to predict a result and explain their reasoning behind their prediction. An example of a thought experiment probe is Probe 3, "Falling Through the Earth."

- *Word Use Probes.* These probes reveal how students confuse the use of everyday words with scientific words or confuse similar-sounding words. An example of a word use probe is Probe 5, "The Two Rs."
- *Opposing Views Probes.* These probes are similar to friendly talk probes except they involve two people with opposite views. Students select the person whose view most matches their own and explain why. An example of an opposing views probe is Probe 27, "Is the Moon Falling?"
- *Follow the Dialogue Probes.* These probes include back-and-forth dialogue between two people. Students follow the dialogue and defend or critique each person's reasoning. An example of a follow the dialogue probe is Probe 42, "Seeing Into the Past."
- *Familiar Phenomenon Probes.* These probes are based on a phenomenon students are familiar with or may have seen or experienced in real life or vicariously. The probe is designed to reveal their ideas about the explanatory nature of the phenomenon. An example of a familiar phenomenon probe is Probe 34, "Shooting Star."
- *Representation Analysis Probes.* These probes provide students with a choice of representations that visually model a concept, process, event, or object. Students choose the representation that best matches their thinking visually and explain why they chose it. An example of a representation analysis probe is Probe 29, "How Do Planets Orbit the Sun?"

Regardless of what type of format is used, all the probes are designed to engage students in surfacing their astronomy ideas and sharing their thinking with other students as well as the teacher. It is for this reason that you are strongly encouraged not to give students the answer to the probe immediately after responding. If you do, the thinking is over! Provide students with time to think the question through, muddle about in reconsidering their ideas as the discussion yields new evidence, and engage in firsthand observations or modeling to discover the answers for themselves. Merely telling students the answer does little to change deeply rooted conceptions. Students need to be vested in the process of realizing for themselves when their ideas no longer work for them. This often happens through rich classroom discourse that encourages and supports the skills of evidence-based argumentation. Eventually students will come to learn the right answer, whether it is through their own process of constructing new knowledge or they are eventually presented with the scientific explanation. Hanging out in uncertainty for a while is not the same as hanging out in uncertainty indefinitely; there is no harm in holding answers back until students are ready to accept the scientific explanation and discard ideas that no longer provide explanatory power for them.

How the Probes Are Arranged in This Book

The probes are arranged in five sections. Section 1 presents ideas related to the nature of our planet, such as the spherical Earth concept and Earth's gravity. Section 2 presents ideas related to the Sun-Earth system, such as the seasons and the Sun's changing path across the daytime sky. Section 3 addresses the Earth-Sun-Moon system, with an emphasis on modeling the Moon. Section 4 goes beyond Earth's moon to explore the dynamic solar system. Finally, Section 5 takes us beyond the solar system to explore ideas related to stars, galaxies, and the universe.

Each section begins with a concept matrix that identifies the major concepts addressed by each probe and the grade span most appropriate for using the probe. Following the matrix is an overview of teaching and learning considerations for the concepts in that section. Next, there is a list of the CTS guides that are often used to generate the probes by linking key ideas in national standards to research-identified misconceptions. CTS guides can also be used to further examine the curricular topic (Keeley 2005). More information about the CTS process and tools is available at *www.curriculumtopicstudy.org*.

The last part of the introductory material in each section is a list of related resources from NSTA and other sources. These highly recommended resources can be used to further develop teachers' content knowledge or provide suggestions for instructional activities and opportunities to further students' learning.

Teacher Notes

Each probe is accompanied by a set of Teacher Notes. These notes contain valuable information about content, teaching, and learning and should be read before using a probe. The sections of the Teacher Notes are described below.

Purpose

This section describes the purpose of the probe—that is, why you would want to use it with your students or the teachers you work with. It begins by describing the overall concept elicited by the probe, followed by the specific idea the probe targets. Before using a probe, you should be clear about what the probe can reveal. Taking time to read the purpose will help you decide if the probe fits your intended use.

Related Concepts

Each probe is designed to target one or more related concepts that often cut across grade spans. These concepts are also included on the matrix charts. A single concept may be addressed by multiple probes as indicated on the concept matrix. You may find it useful to use a cluster of probes to target a concept or specific ideas within a concept. For example, there are several probes that relate to Earth's orbit around the Sun.

Explanation

A brief scientific explanation accompanies each probe and clarifies 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 an "it depends" answer) as well as clarify any misunderstandings you might have about the content.

The explanations are not intended to provide detailed background knowledge about the content. In writing these explanations we were careful not to make them so technical that only someone with an astronomy background would understand them, since our intended audience includes teachers who have little or no astronomy or physics background. We provide the information a novice teacher would need to understand the content he or she teaches, but we also try not to oversimplify. If you have a need for additional information about the content, refer to the resources list in each section.

Administering the Probe

In this section, we suggest ways to administer the probe to students, including appropriate grade spans and, in some cases, modifications to make a probe intended for one grade span useful for another. The suggested grade span is intended to be a suggestion only. Your decision about whether or not to use a probe depends on why you are using it and your students' readiness. Do you want to know about the ideas your students are expected to learn in your grade-level standards? Are you interested in how preconceived ideas develop and change across multiple grade levels in your school whether or not they are formally taught? Are you interested in whether students achieved a scientific understanding of previous grade-level ideas before you introduce higher level concepts? Do you have students who are ready for advanced concepts? We recommend that you weigh the suggested grade levels against the knowledge you have of your own students, your school's curriculum, and your state standards.

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, 2009) and *National Science Education Standards* (NRC 1996). The learning goals from these two documents are quoted here because almost all states' standards are based on them. Also, since the probes are not designed as summative assessments, the listed learning goals in this section are not intended to be considered alignments but rather ideas that are related in some way to the probe. When the ideas elicited by a probe appear to be a strong match (aligned) with a national standard's learning goal, these matches are indicated by a star (★) symbol. You may find this information useful in using probes with lessons and instructional materials that are strongly aligned to your state and local standards and specific grade level.

Sometimes you will notice that an elementary learning goal is included with middle and high school probes. This is because it is useful to see the related idea that the probe may build on from a previous grade span. Likewise, sometimes a high school learning goal is included even though the probe is designated for grades K–8. This is because it is useful to consider the next level of sophistication that students will encounter in a coherent vertical sequence of learning.

At the time this book was written, the National Research Council had just come out with *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC 2011). This conceptual framework is being used to guide the development of the Next Generation Science Standards that are anticipated to be released in late 2012. Since the state-level implementation phase will most likely not phase in until 2013, and the previous standards still are relevant in states, we chose to keep the Benchmarks and the National Science Education Standards in this volume. However, as we developed the probes, we did notice that the core ideas described in the Framework match well with the probes in this book. Once the Next Generation Science Standards are released, there will be a crosswalk for this book (as well as all the previous books in the *Uncovering Student Ideas* series) that describes the link between each probe and the new standards. That crosswalk will be available on the Uncovering Student Ideas website in 2013: *www.uncoveringstudentideas.org*.

Related Research

Each probe is informed by research on students' astronomy misconceptions, including research conducted by coauthor Dr. Cary Sneider. The research summaries can help you better understand the design and intent of the probe and the kinds of thinking your students are likely to reveal when they respond to the probe. Some of the research studies we cite describe studies that have been conducted in past decades, and they have involved children in both the United States and other countries. Most of the results of these studies are considered timeless and universal. Whether students develop their ideas in the United States or in other countries, research indicates that many of these astronomy ideas are pervasive regardless of geographic boundaries and societal and cultural influences. Teachers who use the probes are encouraged to conduct their own classroom action research with the probes. An example of using probes for action research is described in the *Science and Children* article "Formative Assessment Probes: Is It Living?" (Keeley 2011a). Consider a similar action research approach with these astronomy probes.

Suggestions for Instruction and Assessment

A probe remains simply diagnostic, not formative, unless you use the information about students' ideas to inform instruction. After analyzing your students' responses, the most important step is to decide on the student interventions and instructional paths that would work best in your particular context, based on your students' thinking. We have included suggestions gathered from the wisdom of teachers, the knowledge base on effective science teaching, research, and our own collective experiences working with students and teachers. These are not extensive lists of detailed instructional strategies but rather brief suggestions that may help you plan or modify your curriculum or instruction to help students learn ideas that they may be struggling with. It may be as simple as realizing that you need to provide an opportunity for students to directly observe the phenomenon, or there may be a modeling activity you could use with your students (e.g., to demonstrate the positional relationship of the Moon to the Earth and the Sun when explaining what causes the phases of the Moon). Learning is a very complex process, and most likely no single suggestion will help all students learn. But that is what formative assessment encourages—thinking carefully about the variety of instructional strategies and experiences needed to help students learn important ideas in astronomy. 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 understanding.

References

References are provided for the standards, research findings, and some of the instructional suggestions cited in the Teacher Notes. You might want to read the full research summary or access a copy of the research paper or resource cited in the Related Research section of the teacher notes.

Going Formative

Before you begin to use the probes in this book, recall that a probe is not formative unless you use the information from the probe to modify, adapt, or change your instruction so that students have data-informed opportunities to learn the important concepts in astronomy. As a companion to this book, NSTA has copublished *Science Formative Assessment: 75 Practical Strategies for Linking Assessment, Instruction, and Learning* (Keeley 2008). That companion book includes strategies to use with the probes to facilitate elicitation of students' ideas, support metacognition, spark inquiry, encourage discussion and argumentation, monitor progress, give and obtain feedback, improve quality of questions and responses, and promote self-assessment and reflection. In addition, please visit the Uncovering Student Ideas website (*www.uncoveringstudentideas.org*) for additional formative assessment resources and strategies shared by users of the probes. And please look for "Uncovering Student Ideas in Science" sessions offered by NSTA Press at NSTA's area and national conferences and web seminars. We hope to see you there and learn about your (and your students') successes in using these 45 astronomy probes!

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Acknowledgments

We would like to thank all the teachers and science coordinators who tried out the probes with their students, gave us feedback on them, or contributed ideas for further probe development. We especially would like to thank the following educators who carefully reviewed this book, and in many cases pilot tested the probes with their students: Susan Duncan, Beaverton, Oregon; Andrew Fraknoi, San Francisco, California; Nicole Holden, Beaverton, Oregon; Neil Kavanagh, Portland, Oregon; Jaylee Scott, Mesa, Arizona; Haley Candista, Dallas, Texas; and Taryn Devereaux, York, Maine.

We are grateful to our excellent reviewers for providing us with very useful feedback to improve the original manuscript of this book: Ted Willard, Timothy Slater, and Llama Maynard. We especially want to thank Andrew Fraknoi for taking the time to write such a thoughtful and inspirational foreword.

We also appreciate the assistance over the years of the following collaborators and fellow researchers who contributed so much to the research and practice of astronomy education: Jane Abel, Paul Ammon, Varda Bar, William Brewer, Al Byers, Cathy Clemens, Supriya Chakrabarti, David Cudaback, John Dobson, Alan Friedman, Alan Gould, Claudine Kavanagh, Anne Kennedy, Gary Kratzer, Will Kyselka, William Liller, Marcia Linn, Ramon Lopez, Larry Lowery, Gerry Mallon, Cherilynn Morrow, Yossi Nussbaum, Steven Pulos, Philip Sadler, Dennis Schatz, Dwight Sieggreen, Elizabeth Stage, William Waller, and David White.

And finally, we can't say enough about the outstanding support from NSTA Press staff in helping us bring this book to fruition.

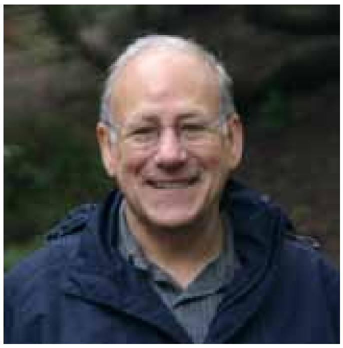
About the Authors

Page Keeley is the senior science program director at the Maine Mathematics and Science Alliance (MMSA), where she has worked since 1996. She has directed projects in the areas of leadership, professional development, linking standards and research on learning, formative assessment, and mentoring and coaching, and she consults with school districts and organizations nationally. She has authored 12 books and has been the principal investigator on three National Science Foundation grants: the Northern New England Co-Mentoring Network; Curriculum Topic Study: A Systematic Approach to Utilizing National Standards and Cognitive Research; and PRISMS: Phenomena and Representations for Instruction of Science in Middle School. Most recently she has been consulting with school districts, Math-Science Partnership projects, and organizations throughout the United States on building teachers' capacity to use diagnostic and formative assessment.

Page taught middle and high school science for 15 years and used formative assessment strategies and probes long before there was a name attached to them. Many of the strategies in her books come from her experiences as a science teacher. Page was an active teacher leader at the state and national level. She received the Presidential Award for Excellence in Secondary Science Teaching in 1992 and the Milken National Distinguished Educator Award in 1993, and she was the AT&T Maine Governor's Fellow for Technology in 1994. She has served as an adjunct instructor at the University of Maine, is a Cohort 1 Fellow in the National Academy for Science and Mathematics Education Leadership, and serves on several national advisory boards.

Prior to teaching, she was a research assistant in immunology at the Jackson Laboratory of Mammalian Genetics in Bar Harbor, Maine. She received her BS in life sciences from the University of New Hampshire and her MEd in secondary science education from the University of Maine. Page served as the 63rd President of the National Science Teachers Association. In 2009 she received the National Staff Development Council's Susan Loucks-Horsley Award for her contributions to science education leadership and professional development. Page is a frequent invited speaker at national conferences and led the People to People Citizen Ambassador Programs Science Education delegation to South Africa in 2009, China in 2010, and India in 2011.

About the Authors



Cary Sneider is an associate research professor at Portland State University in Portland, Oregon, where he teaches research methods in a master's degree program for prospective teachers and leads a National Science Foundation–supported project to bridge the gap between high school and college physics. His research interests have focused on helping students unravel their misconceptions in science and on new ways to link science centers and schools to promote student inquiry. He recently served as design lead for technology and engineering on the National Research Council's effort to develop *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Cary has been involved in the development of framework documents for the National Assessment of Educational Progress (NAEP) in Science and in Technology and Engineering Literacy, and he is currently a member of the National Assessment Governing Board. He is also a leader of the writing team at Achieve, Inc., which is managing the development of the Next Generation Science Standards for the states.

From 1997 to 2007 Cary was vice president for educator programs at the Museum of Science in Boston, where he led development of a high school engineering curriculum, Engineering the Future: Science, Technology, and the Design Process. Prior to that he served as director of astronomy and physics education at the University of California Lawrence Hall of Science. He has taught science at the middle and high school levels in Maine, California, Costa Rica, and Micronesia. In 1997 he received the Distinguished Informal Science Education award from the National Science Teachers Association, and in 2003 he was named national associate of the National Academy of Sciences.

Over his career Cary has directed more than 20 federal and state grant projects, mostly involving curriculum development and teacher education. He earned a bachelor of arts in astronomy from Harvard College and a teaching credential and doctorate from the University of California at Berkeley. He attributes his lifelong passion for astronomy to clear skies in southern Maine, where he spent his formative years, and to his parents and sister Sharon, who put up with the noise and messiness of telescope building.

Introduction

“I don’t get it,” he said, passing me in the hall one day. Pointing out the window he continued, “Look, there’s the Moon. I can see the curved shadow of the Earth on the Moon. But the Sun is still up, so the Earth’s shadow must be behind us somewhere. How can Earth’s shadow fall on the Moon in the daytime?”

My friend had graduated from an Ivy League school. He had always done well in school and he loved science. As director of a major science education program he certainly had a good formal background in science. But that day I realized he did not understand the modern scientific explanation for Moon phases.

To his credit, at that moment my friend realized that he’d had it wrong all these years. It is likely that he first learned about Moon phases in elementary school, when his spatial reasoning skills had not yet developed. And since he never studied Moon phases again, he never had an opportunity to learn the real reason for phases.

A great many people of all ages make this same mistake. They learn about Moon phases and eclipses, but what really sticks is the explanation for an eclipse of the Moon, also called a lunar eclipse (derived from the Latin word for moon, *luna*). A lunar eclipse occurs when the Moon passes through the Earth’s shadow. A lunar eclipse happens about twice a year. Since you have to be on the side of Earth facing the Moon when it is in Earth’s shadow, chances are about 50-50 that you’ll get to see it. So at any one location it is common to see a lunar eclipse about once a year.

Once we both recognized why he was confused, it was easy to help my friend understand why Moon phases occur. I took a hard-boiled egg out of my lunch bag and we walked outside. I handed him the egg and asked him to hold it up next to the Moon in the sky and pay attention to which part is lighted and which part is in shadow. He figured it out himself. Here’s more or less what he said:

“Oh! I see now. The egg and the Moon are both lit up by the Sun. I knew that before. But the shadow on the egg is the same as the shadow on the Moon—and the lighted part is the same, too. In fact, I’m looking at a ‘crescent egg’! The dark part is the shadow of the egg on itself, just like with the Moon—the dark part of the Moon is the shadow of the Moon on itself.”

For good measure I took a moment to explain to my friend why he had been confused. It’s easier to learn the explanation for a lunar eclipse than for Moon phases, and if it is presented too early and then never revisited it’s not surprising that someone would remember just one explanation and apply it to both phases and eclipses—even though the explanation for Moon phases is different. Today, thanks to science education research, the concept of Moon phases is more appropriately placed at the upper elementary or middle school level, where many students still find it challenging.

—Cary Sneider, 2011

Introduction

Why Are Probes Useful for Teaching Astronomy?

The 45 astronomy probes in this book can help you provide the kind of experience in your classroom that Cary and his friend experienced in the exchange described above. Each probe presents a situation that will engage your students' interests while assessing their current level of understanding (or misunderstanding). Although it may not always be easy to help your students untangle mistaken ideas, knowing what your students' preconceptions are is an excellent start.

One way to think about what these probes can do that other assessments often fail to do is to reveal your students' mental models of the world. We all have many such models and we use them all the time. For example, envision in your "mind's eye" the house or apartment building where you live. Imagine you are standing across the street from the front door. What color is the building? How many windows does it have? Is there a mailbox in view? If the mailbox is not in front of the building, can you envision where it is? Now imagine walking across the street, picking up the mail, and entering the building. "Walk around" inside, looking into the different rooms, to become aware of just how detailed this mental model happens to be.

Your mental model of the place you live does much more than provide mild entertainment when reading about science teaching—it provides a map of the world that you follow when you pick up the real mail, walk into your actual house, put away the groceries in the correct cupboards, and find your glasses in the place where you usually leave them. Mental models are such an important part of our lives that we rarely think of them; but without them we could not function in the world. They also color new information that we receive.

Stella Vosniadou and William Brewer (1992, 1994) conducted a series of influential studies on children's mental models in astronomy. They interviewed first-, third-, and fifth-grade students, and found that the children's understanding of the day-night cycle depended on their mental models of the Earth. For example, students whose mental model of the Earth was a flat surface with an absolute "down" in space explained that the Sun would literally go "up" in the daytime and "down" at night. Older students, who held a more advanced spherical Earth concept, understood that the Earth is a ball in space. Those students held different misconceptions. For example, some thought that day and night were caused when the Sun went around the Earth once a day.

Without understanding your students' mental models about the Earth in space, it will be very difficult to help them understand anything that you may want to teach them about astronomy.

Mental Models and the Evolution of Astronomy

Astronomy is sometimes called the "mother of all sciences" because it was the first field to which modern scientific thinking was applied. Although the term *scientist* had yet to be invented, the term might well be applied to Aristotle, the ancient Greek philosopher and teacher of Alexander the Great. Aristotle was born approximately 2,500 years ago in Stagira in what is today northern Greece. He wrote about his ideas on astronomy in a book called *On the Heavens* (see Guthrie 1939 for one of several English translations).

Aristotle's mental model of the Earth in space was remarkably modern in some ways. He described the Earth as a huge sphere (giving proper credit to philosophers of earlier periods) and as evidence of Earth's shape he correctly referred to the appearance of Earth's shadow on the Moon during a lunar eclipse. He noted that as travelers journeyed far to the north or south they would see different stars gradually come into view.

Aristotle's mental model was not entirely modern. He imagined that people could live in many different places on Earth without falling off because in his view Earth was located in the center of the universe. Everything heavy would naturally fall to the center of the universe, while things that were light, such as fire, would go away from the center of the Earth. To explain day and night, he posited that the Sun circled the Earth once a day. Aristotle's writings survived the Middle Ages, and his mental model of the Earth and Sun was taught in the best schools for thousands of years, until it was finally challenged by Copernicus in the 16th century.

Copernicus agreed with Aristotle that the Earth is a sphere. However, he disagreed that the Earth is immovable in the center of the universe. Instead, he proposed that the Sun is immovable, in the center of the universe, and the Earth orbited around it once a year. In his mental model—which is closer to our own—day and night were caused by the Earth spinning once a day as it orbited the Sun once per year.

Since Copernicus worked a couple of centuries before Newton came up with his theory of gravity, Copernicus must have had difficulty explaining why people—and everything else—clung to Earth's surface rather than flying off into space as the Earth spun around. So he envisioned that the Earth, the Moon, and other large bodies each had its own center to which everything would fall.

The process of continually modifying a mental model of Earth's position among other bodies in space continues today in the work of modern astronomers. Astronomers cannot "experiment" with objects in space. However, they can observe the light from distant stars and galaxies to see how they move and how they relate to one another, and then build a mental model (often translated into a more precise mathematical model) that is consistent with what they see. It is not unusual for a new observation—or a new way of thinking about old observations—to cause astronomers to change their mental models of stars, galaxies, moons, planets, or even the Earth itself.

Your Students' Mental Models

One of the greatest resources you can tap into as a teacher is the different mental models held by your students. By engaging them in discussing their ideas related to these probes, students will have an opportunity to learn about other mental models besides their own. That realization—that there may be a different way to think about a situation—is a tremendously powerful way to get your students to question their own thinking.

A set of instructional materials that used a similar approach but predated the *Uncovering Student Ideas in Science* series was *Earth, Moon, and Stars* in the GEMS (Great Explorations in Math and Science) series (Sneider 1986). Students were given "thought experiments," using diagrams and questions similar to some of the probes in this book. The focus of the GEMS unit was the Earth's spherical shape and a simple idea of gravity. The students started by writing their answers to the probes, and then they met in small groups to discuss their ideas. Without the teacher having to explain the correct concepts, these discussions alone moved the students much closer to the scientific mental model of the Earth in space (Sneider and Pulos 1983; Sneider et al. 1986).

The *Earth, Moon, and Stars* curriculum was rigorously tested in a study by 17 teachers from 10 states who agreed to give pretests and posttests to students who participated in their classes (Sneider and Ohadi 1998). The study included 539 students in grades 4–9. Although all groups significantly increased their test scores, the youngest students, in grades 4 and

5, made the greatest gains. Students in control groups, who did not engage in these activities, did not increase their scores. In other words, students *can* change their mental models of the Earth's shape and gravity concept by discussing their ideas with each other. And that is what we want you to do with these probes—use them to stimulate discussion that can help your students change their mental models of the universe.

Learning From Probes and the New Science Education Standards

In July 2011, the National Research Council (NRC) released a report entitled *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC 2011). This Framework is expected to provide a blueprint for new science standards that states will eventually adopt. It describes core ideas in the major fields of science, including astronomy, and also describes important capabilities that all students should acquire during their K–12 experience. Among these are the crosscutting concepts of systems and models, stability and change, and cause and effect, and the practices of developing and using models, constructing explanations, and arguing from evidence. All of these capabilities can be supported by engaging students in discussions around the probes. Eventually the Next Generation Science Standards (NGSS) will be developed, based on the Framework; the NGSS will also embody these concepts and abilities. Although the NGSS are not yet available, the probes and Teacher Notes in this book will very likely be consistent because we have taken into account the practices, core ideas, and crosscutting concepts described in the 2011 *Framework* report.

Stepping-Stones

The word *misconception* has been used a number of times in the preface and introduction. It's important to point out that from the perspectives of the students their ideas about the world are not "wrong." As Vosniadou and Brewer (1992, 1994) and many others have pointed out, the students' explanations for phenomena such as night and day or phases of the Moon are entirely consistent with their mental models of the Earth in space, among a host of other objects that they cannot directly see or handle. Some researchers have suggested using the term *preconception* or *alternative conception* rather than *misconception* to avoid labeling the students' ideas as "wrong."

We prefer to keep the term *misconception* and use it in a general way to indicate that it is an idea that is contrary to the modern scientific thinking that we want to promote. However, we emphasize that expressing these ideas—even though they may be wrong from a modern scientist's point of view—is a very important part of the learning process. In many cases your students will progress through a sequence of misconceptions before getting it right. As suggested by researcher Philip Sadler (1998), misconceptions might best be thought of as stepping-stones that are absolutely essential for helping our students gradually change their mental models, so they can share the modern scientific view of the universe.

With this book you now have a powerful set of tools to uncover the astronomy-related ideas your students bring to the classroom. Through students' writing and talk you will be able to follow their efforts to make meaning out of their everyday encounters with the natural world and concepts presented to them in school. Every student has his or her own unique approach to creating meaning in a learning situation. Whether or not a student's ideas change depends on the willingness of the student to accept new ways of looking at his or her natural world.

In other words, you cannot "fix" your students' misconceptions. However, by using these probes to formatively assess your students' current thinking, you will be in a much better position to create a path that moves students from where they are to where they need to be scientifically. We hope the probes in this book, along with the information in the Teacher Notes, will help you create a classroom environment that makes it safe and interesting to surface and discuss all students' ideas, so that they can reach for the next stepping-stone in their understanding of astronomy.

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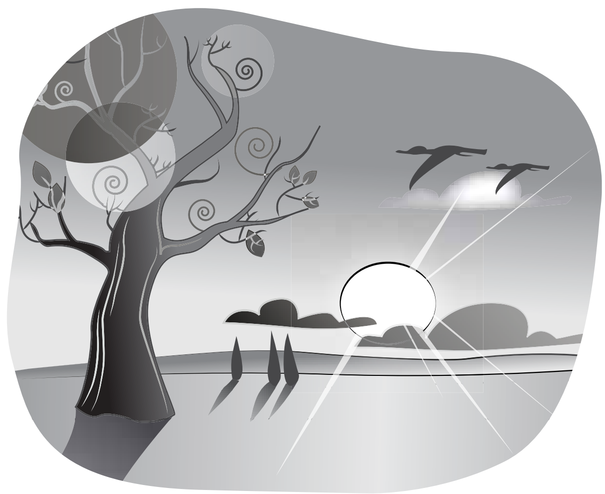
Shorter Days in Winter



Mrs. Moro's students checked the newspapers every morning for the times of sunrise and sunset. They used this information to determine the number of hours of daylight. The class started this project in September, and by November they could see that the days were getting shorter and shorter. The students asked their families and neighbors to explain why days get shorter as winter approaches in the North. Here are the ideas they came to class with the next day:

Frank: "My mom says it's because of daylight saving time."

Jubal: "My sister said Earth's tilt causes the Sun to be farther away in winter."

Sybil: "My father thinks the angle of sunlight must be the cause."

Carter: "My brother says the Sun moves across the sky faster in winter."

Wendy: "My neighbor thinks the Sun's path in the sky gets shorter in winter."

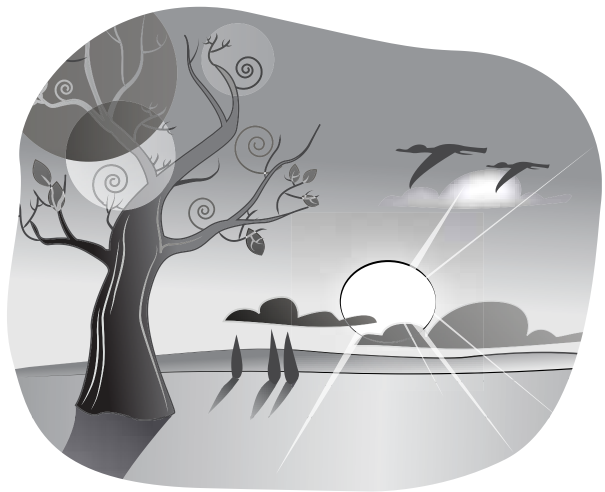
Which student came to class with the best idea? _______________ Explain why you think that is the best idea.

____

____

Shorter Days in Winter

Teacher Notes



Purpose

The purpose of this probe is to elicit students' ideas about the changing length of daylight with the change in seasons. The probe is designed to find out if students can relate the apparent path of the Sun as seen from Earth to the length of daylight.

Related Concepts

Seasons: cause, length of day
Solar system objects: spin
Sun: path in the sky

Explanation

Wendy has the best answer: "My neighbor thinks the Sun's path in the sky gets shorter in winter." Her neighbor describes an accurate observation that the Sun makes a shorter and lower arc in the sky in winter. A shorter arc means the Sun spends less time above the horizon, so days are shorter. Here are problems with the answers given by the other students:

- Frank: "My mom says it's because of daylight saving time." Daylight saving time is a consequence of shorter days, not a cause.
- Jubal: "My sister said Earth's tilt causes the Sun to be farther away in winter." While it's true that Earth's axis is tilted, the tilt does not change the distance between the Earth and Sun. So that part of her sister's response is incorrect. However, the tilt of Earth's axis does cause the path of the Sun in the sky to appear to become shorter in winter and longer in summer. So this answer is partially correct.
- Sybil: "My father thinks the angle of sunlight must be the cause." It is true that as winter approaches not only does the path of the Sun grow shorter but also the Sun does not rise as high into the sky. The changing angle of the Sun results in cooler—but not shorter—days.
- Carter: "My brother says the Sun moves across the sky faster in the winter." Since

the apparent movement of the Sun across the sky is due to Earth's daily rotation on its axis, the rate of travel does not change.

Shorter days are one reason that it is colder in winter in the temperate and polar zones. When the Sun is above the horizon longer it has more time to heat up the land, and there is less time for the land to cool off at night. Also when the Sun is lower in the sky the energy we receive from the Sun is spread out over a larger area, so it is less intense, and the land absorbs less thermal energy.

Administering the Probe

This probe is best used at the middle and high school level. It can be combined with Probes 14, "Changing Constellations," and 15, "Why Is It Warmer in Summer?" to assess students' ideas about the seasons. If you are planning to use the probes to begin a unit of study, it is best to use this probe first, since it is important for your students to be able to explain why it is warmer in summer and cooler in winter from their own viewpoint, here on Earth, before taking the space view.

When you examine students' responses don't be surprised if most of them agree with Jubal, since the tilt of Earth's axis is related to a complete explanation of seasons. If that is the case facilitate a discussion in which students justify and argue their opinions.

Related Ideas in *Benchmarks for Science Literacy* (AAAS 2009)

K–2 The Universe

- The Sun, Moon, and stars all appear to move slowly across the sky.

3–5 The Earth

- The rotation of the Earth on its axis every 24 hours produces the night-and-day cycle. To people on Earth, this turning of the planet makes it seem as though the Sun, Moon, planets, and stars are orbiting the Earth once a day

6–8 The Earth

★ The number of hours of daylight and the intensity of the sunlight both vary in a predictable pattern that depends on how far north or south of the equator the place is. This variation explains why temperatures vary over the course of the year and at different locations.

9–12 The Earth

- Because the Earth turns daily on an axis that is tilted relative to the plane of the Earth's yearly orbit around the Sun, sunlight falls more intensely on different parts of the Earth during the year. The difference in intensity of sunlight and the resulting warming of the Earth's surface produces the seasonal variations in temperature.

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

5–8 Earth in the Solar System

★ Seasons result from variations in the amount of the Sun's energy hitting the surface, due to the tilt of the Earth's rotation on its axis and the length of day.

Related Research

- A review of 41 research studies on people's understanding of the seasons (Sneider, Bar, and Kavanagh 2011) found that

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

although understanding of seasons tended to increase with age, misconceptions were widespread even among college students and educated adults. For example, many people learn in school that seasons are due to Earth's tilt, but have the misconception that the tilt causes Earth to be closer to the Sun in summer. (In fact Earth is closest to the Sun in January, which is winter in the Northern Hemisphere.) The review article suggests a sequence of instruction beginning in elementary school, leading to full understanding of seasons in high school.

- Plummer (2008) interviewed 20 students in each of grades 1, 3, and 8. While she found a general trend toward higher levels of understanding among the older students, students at each grade level held misconceptions about how the Sun appeared to move through the sky during the day and how the Sun's path across the sky changed with the seasons. Many of the children at all ages thought that the Sun was directly overhead at noon every day, even though the Sun was never overhead at noon at the latitude where the children lived. Furthermore, there was no significant difference between third-grade students' and eighth-grade students' understanding of the Sun's apparent motions. However, she did find that students were able to learn about the Sun's changing path in the sky during the year with the help of a small planetarium.
- As part of an evaluation of a new high school course on astronomy, Sadler (1998) tested 1,250 high school students who had taken the course, which included instruction on the reasons for the seasons. One of the questions on the test was as follows: "The main reason for its being hotter in summer than winter is: (a) The Earth's distance from the Sun changes; (b) The Sun is higher in the sky; (c) The distance between the northern hemisphere and the Sun changes; (d) Ocean currents carry warm water north; and (e) An increase occurs in 'greenhouse' gases." Sadler found that most students who did poorly on the test overall chose the common misconception that Earth's distance from the Sun changes during the year. Most students who did moderately well chose a different misconception, that the distance between the Northern Hemisphere and the Sun changes, indicating that they understood that the tilt was somehow related to seasons; but they misunderstood *how* the tilt caused the seasonal variation in temperature. Only the students who did very well on the test overall chose the correct answer: "(b) The Sun is higher in the sky." Sadler concluded that these misconceptions should not be considered failures, but rather stepping-stones toward a full scientific understanding.

Suggestions for Instruction and Assessment

- One of the reasons it is so difficult for students to learn about the causes of Earth's seasons is that the space viewpoint is introduced too early, at the elementary level, before children have an opportunity to make the critical observations of the Sun's changing path in the sky that explain why it is warmer in summer and colder in winter.
- During the upper elementary grades students should have opportunities to observe the changing rising or setting point of the Sun as observed from a fixed location. September–October and March–April are good times to do that because the Sun's path changes most dramatically in the fall and spring. There are also a number of ways to safely measure the altitude of the Sun in the middle of the day, the simplest being to measure the length of a shadow of a fixed

object like a flagpole. Making these observations on a clear day once a week is sufficient to observe changes in the Sun's daily movements. It is also important for the teacher to help the students synthesize their observations to clarify the Sun's changing path in the sky and see that as winter approaches, the arcing path of the Sun becomes shorter, the sun does not travel as high in the sky, and the days grow shorter.

- A visit to a planetarium or use of a classroom planetarium can be very helpful in demonstrating these changes in the Sun's daily path, especially if it comes after students have made measurements of their own.
- Once students understand how the path of the Sun changes with the seasons, they should discuss how such changes affect average daily temperatures in the summer and winter. It should not be difficult for students in grades 4, 5, or 6 to understand that if the Sun is up longer, it will have more time to warm the Earth. That's why it's usually warmer in the afternoon, after the Sun has been up for a long time. It's also why it is coldest shortly before sunrise, because the land has been cooling off all night.
- Ideally this activity should take place after a unit on Earth's shape and gravity so that the students can understand that the Sun's apparent movement is due to Earth's daily spin and the speed of the Sun across the sky does not change. The length of the day is directly related to the length of the Sun's path in the sky.
- If middle school students are to fully understand the reasons for seasons, it is important that they first learn about the Sun's changing path in the sky during the year, before they are expected to explain these changes as a result of Earth's tilted axis.
- There are two reasons why the Sun's changing path in the sky causes it to be warmer in summer and cooler in winter. One reason concerns length of day. A more difficult reason to understand is that the altitude of the Sun in the sky makes a difference in the solar energy that reaches each square meter of ground. This can be addressed at the middle school level in a number of ways. Students can go outdoors to set up a solar cell that lies flat on the ground, connected to an ammeter. They can plot electrical current generated over a full day with no clouds and see that more energy is generated during the middle of the day. Or they can experiment in the lab with a bright incandescent lightbulb and solar cell or liquid crystal thermometer to see how angle of light affects the energy received.
- It should not be assumed that high school students understand the reasons for the seasons just because they studied it during elementary or middle school. This probe will tell you if high school students need to learn about the Sun's changing path in the sky. If they don't agree with Sybil's neighbor, it will be important that they also do activities like those discussed above, so that when they learn about Earth's tilted axis, they will understand that the model of the Earth's tilted axis and its orbit around the Sun is intended to explain what we experience on Earth. It is not simply an explanation to be memorized and repeated on a test.
- The National Science Digital Library's PRISMS (Phenomena and Representations for Instruction of Science in Middle Schools) website, funded by the National Science Foundation, has several representations and phenomena reviewed for their effectiveness in teaching ideas related to the seasons topic and subtopics: *http://prisms.mmsa.org*.

- Although the following Project 2061 AAAS website is still a work in progress, it has much useful information about students' ideas related to the seasons and visualizations that can be used to teach about the seasons: *http://flora.p2061.org/climate/#*.
- The GEMS (Great Explorations in Math and Science) guide, *The Real Reasons for Seasons,* has several activities that can be used to develop ideas related to this probe (Gould, Willard, and Pompea 2000).

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Uncovering Student Ideas in Astronomy

45 NEW Formative Assessment Probes

"You cannot 'fix' your students' misconceptions. However, by using these probes to formatively assess your students' current thinking, you will be in a much better position to create a path that moves students from where they are to where they need to be scientifically."

—From the introduction to *Uncovering Student Ideas in Astronomy*

What do your students know—or think they know—about what causes night and day, why days are shorter in winter, and how to tell a planet from a star? Find out with *Uncovering Student Ideas in Astronomy*, the latest in NSTA's popular *Uncovering Student Ideas in Science* series.

The book is organized into five sections: the Nature of Planet Earth; the Sun-Earth System; Modeling the Moon; Dynamic Solar System; and Stars, Galaxies, and the Universe. The 45 assessment probes provide situations that will pique your students' interest while helping you understand how your students think about key ideas related to the universe and how it operates. The Teacher Notes provided for each probe include the probe's purpose, related concepts, a scientific explanation, advice on how to administer the probe, related research, suggestions for instruction and assessment, and references.

As authors Page Keeley and Cary Sneider note, it's not always easy to help students untangle mistaken ideas. By using this powerful set of tools to identify students' preconceptions, teachers will take an excellent first step toward helping students achieve scientific understanding in astronomy.

Grades K–12

NSTApress
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PB307X
ISBN: 978-1-936137-38-1

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