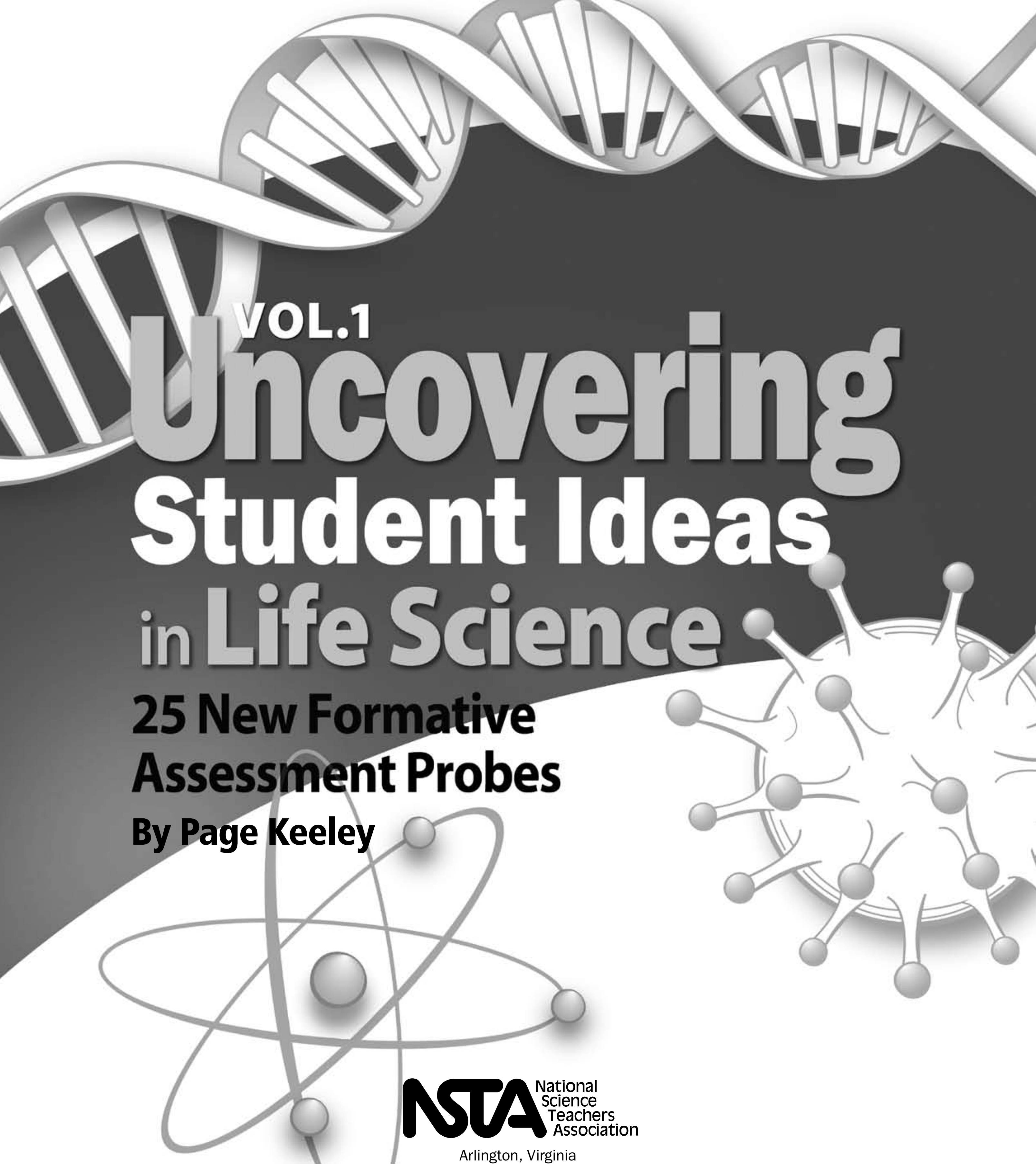
VOL.1

Uncovering Student Ideas in Life Science

25 New Formative Assessment Probes

By Page Keeley

NSTApress
National Science Teachers Association



VOL.1

Uncovering Student Ideas in Life Science

25 New Formative Assessment Probes

By Page Keeley

NSTA National Science Teachers Association

Arlington, Virginia

NSTA press®
National Science Teachers Association

Claire Reinburg, Director
Jennifer Horak, Managing Editor
Andrew Cooke, Senior Editor
Judy Cusick, Senior Editor
Wendy Rubin, Associate Editor
Amy America, Book Acquisitions Coordinator

ART AND DESIGN
Will Thomas Jr., Director
Cover, Inside Design, and Illustrations by Linda Olliver

PRINTING AND PRODUCTION
Catherine Lorrain, Director

NATIONAL SCIENCE TEACHERS ASSOCIATION
Francis Q. Eberle, PhD, Executive Director
David Beacom, Publisher

14 13 12 11 4 3 2 1

LIBRARY OF CONGRESS CATALOGING-IN-PUBLICATION DATA
Keeley, Page.
Uncovering student ideas in life science / by Page Keeley.
p. cm.
Includes bibliographical references and index.
ISBN 978-1-936137-17-6 (v. 1)
1. Life sciences—Study and teaching. 2. Educational evaluation. I. Title.
QH315.K37 2011
570.71--dc22
2010052477

eISBN 978-1-936137-51-0

NSTA is committed to publishing material that promotes the best in inquiry-based science education. However, conditions of actual use may vary, and the safety procedures and practices described in this book are intended to serve only as a guide. Additional precautionary measures may be required. NSTA and the authors do not warrant or represent that the procedures and practices in this book meet any safety code or standard of federal, state, or local regulations. NSTA and the authors disclaim any liability for personal injury or damage to property arising out of or relating to the use of this book, including any of the recommendations, instructions, or materials contained therein.

Contents

Section 2

Dedication

This book is dedicated to Ray Barber, biology teacher extraordinaire at Pleasant Valley High School in Chico, California. He is a Toyota TAPESTRY awardee, friend, and colleague whom I have had the pleasure to get to know through NSTA and my work on formative assessment.

Ray, your innovation, creativity, and connection to your students truly inspire me! You exemplify what it means to be part of the science education community, a dedicated NSTA member, and a lifelong learner. Thanks for all you do to support students. And a huge thanks for giving NSTA Press authors like me a reason to continue to churn out these books for great teachers like you!

Foreword

Capturing the conceptual knowledge of students on a particular science topic is one of the most important things that science teachers do. With this knowledge, teachers comprehend the depth of understanding among students or their prevailing misconceptions. More important, by having this knowledge, teachers can determine what instructional strategies to use to ensure that students develop a clear understanding of a science topic. These strategies can range from asking students (verbally or in writing) to explain their thinking to having them draw conclusions about various phenomena. Before such instructional strategies can be put into place, however, teachers have to assess their students' knowledge.

Teachers have a multitude of ways to capture student knowledge. Tests, quizzes, questions, and looking at the written work of students are standard methods. A method used less frequently, but one that is equally important, is the formative assessment probe, which is the approach used in this book (and other books by Page Keeley and her coauthors; see p. xviii for a complete list of these books). Probes allow a science teacher to determine the depth of student understanding in specific conceptual areas. Making this determination is essential because even though a student may be able to select the correct answer to a question from several possible answers in a probe, he or she may not have a deep understanding of the topic, as would be demonstrated by the student's explanation for choosing that answer, a step that the probes require.

The probes in this book are simple yet useful indicators of student understanding. Each probe presents a scenario that involves selecting an answer and providing an explanation. The elegant format of the Teacher Notes that accompany each probe includes a discussion of research about student conceptual knowledge in the area targeted by the probe and the related National Science Education Standards (NRC 1996) and Benchmarks for Science Literacy (AAAS 1993, 2009). This connection of research to national science standards tells teachers what students are likely to misunderstand and what level of understanding students can be expected to have within a particular grade span. Few science education assessment resources offer this magic combination of being research-based, standards-linked, and aligned with topics regularly taught in the science classroom.

For me, another important use of these probes can be the connection of research and practice. Although the probes were designed to capture the preconceptions that students have, they can also be used as tools to monitor how students are thinking about a concept during and after classroom instruction. Teachers who monitor the thinking of their students, and draw conclusions about student thinking, are engaged in a research process that is connected to their classroom practices.

This connection of research to practice can even be used by *groups of teachers* to study student thinking before, during, and after instruction. With the probes, groups of science teachers within a school or district can collect data about students' thinking, come together, and compare the data across instructional topics in science and different curricular formats. When teachers work together on collecting and analyzing student data, they form communities that focus on learning about student thinking and understanding and they definitely enhance their practices.

Foreword

All teachers, preservice through experienced, will find these probes valuable. *Preservice teachers* can use the probes to understand students' thinking about natural phenomena. By considering how students think about scientific phenomena, preservice teachers can begin to understand how important it is to tailor their instruction to the preconceptions their students bring to their learning. *Beginning science teachers* who use these probes will build their capacity to examine student thinking and formalize their ability to capture student ideas and modify their instruction accordingly. *Experienced teachers* who use these probes will continue to develop their expertise in using student understandings to create interactive learning environments that are rich in dialogue and student explanations. In terms of these probes, we can safely say that one size does fit all teachers!

This book fills an important void in the *Uncovering Student Ideas in Science* series. Its focus on the topic of life science is timely and needed. Since 2005, Page Keeley and her coauthors have developed 170 successful probes in physical, life, and Earth and space science. Until now, they had not devoted an entire book to life science probes. The probes in this book capture the many dimensions of biology, not just the animal and plant side of the field. Included in the mix of 25 probes are those that focus on the cellular and ecological, as well as the genetics and zoological, domains of life science. Further, the biological ideas that are presented in this book are aligned with the real-life phenomena that students encounter in and outside their classrooms.

As a community of science educators, we are lucky to have Page Keeley and her commitment to the task of capturing student thinking. Her passion in this area has made an important contribution to the field of science education, with both teachers and students gaining tremendously.

Julie Luft
Arizona State University
NSTA, Division Director, Research in Science Education

References

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

American Association for the Advancement of Science (AAAS). 1993/2009. *Benchmarks for science literacy.* Washington, DC: AAAS. Online at *www.project2061.org/publications/bsl/online*

Preface

Series Overview: *Uncovering Student Ideas in Science*

This book is one of a "series of series" of unique K–12 formative assessment resources. The first book in the first series was *Uncovering Student Ideas in Science: 25 Formative Assessment Probes* (Keeley, Eberle, and Farrin 2005). Subsequently, NSTA published three more books of K–12 formative assessment probes.* The four books in the *Uncovering Student Ideas in Science* series cover a wide range of probes in the life, Earth, space, and physical sciences as well as the nature of science and "unifying themes" such as systems and models.

In 2010, NSTA published the first volume in a new physical science series—*Uncovering Student Ideas in Physical Science, Vol. 1: 45 New Force and Motion Assessment Probes* (Keeley and Harrington 2010). The four additional books planned for this series will cover electricity and magnetism, energy, light and sound, and matter and energy.

The present book, *Uncovering Student Ideas in Life Science, Vol. 1: 25 New Formative Assessment Probes,* addresses K–12 ideas on the topics of life and its diversity; structure and function; life processes; ecosystems and change; reproduction, life cycles, and heredity; and human biology. This volume will be followed by a second life science volume, and possibly a third. It seems there is never a shortage of key science ideas commonly held by students that can be elicited by formative assessment probes. As long as there are interesting and important science ideas to examine—and teachers who want to learn more about how their students' think about these ideas—this series will continue to provide new and informative volumes on additional topics such as astronomy, the nature of science, and Earth science.

Although some diagnostic assessment tools for science teachers do exist, mostly in the physical sciences, there are few diagnostic tools that can be used in grades K–12 in all of the sciences. The importance of identifying and analyzing students' preconceptions (diagnostic assessment) and then using the data on students' preconceptions to inform teaching and learning (formative assessment) was recognized during the 1990s in publications such as *How People Learn: Brain, Mind, Experience, and School* (Bransford, Brown, and Cocking 2000). It became clear to science teachers and educators that there was a need for student- and teacher-friendly probing questions to access students' thinking and prior knowledge in science and to promote learning by involving students in the examination of their own and their peers' ideas. This need led to the development of this popular series.

With the addition of the present book, the *Uncovering* series consists of a total collection of 170 formative assessment probes. These probes are used by thousands of K–12 classroom teachers, university professors, informal educators, professional developers, instructional coaches and mentors, and even parents, and they consistently appear on the NSTA Press list of bestsellers. The series has become a valuable resource not only for improving student learning but also for deepening teachers' understanding of science content and of pedagogical content knowledge (PCK). (PCK is the specialized knowledge of teaching that

* See References, pp. xvii–xviii: Keeley, Eberle, and Tugel 2007; Keeley, Eberle, and Dorsey 2008; Keeley and Tugel 2009.

Preface

teachers—in our case, science teachers—have, including knowledge of the most effective ways of presenting a topic to make it comprehensible to learners. To teach all students according to today's standards, teachers need to have a deep and flexible understanding of subject matter so that they can help students create useful cognitive maps, connect one idea to another, and address misconceptions [Shulman 1992].)

Each book in the original *Uncovering* series begins with a unique introduction to some aspect of formative assessment.

- Introduction to Vol. 1: Offers an overview of formative assessment: what it is and how it differs from summative assessment. Provides background on probes as specific types of formative assessments and how they are developed.
- Introduction to Vol. 2: Describes the link between formative assessment and instruction and suggests ways to embed the probes into your teaching.
- Introduction to Vol. 3: Describes how you can use the probes and student work for teacher learning—either individually or through professional learning communities—to (a) deepen your understanding of students' ideas and their implications for instruction, (b) learn new science content, or (c) even uncover a deeply rooted misconception you might have.
- Introduction to Vol. 4: Describes the link between formative and summative assessment, including reasons why an investment in formative assessment before and throughout instruction can improve students' performance on the summative end.
- *Uncovering Student Ideas in Physical Science, Vol. 1:* The introduction to this book provides an overview of the teaching difficulties and research about students' ideas related to force and motion concepts and strategies for effectively addressing students' ideas.

Collectively, the introductory chapters of the five previous volumes, in addition to the introduction in this volume (p. 1), will expand your assessment literacy and understanding of effective teaching and learning and will deepen your understanding of students' thinking about the important content of science.

About the Probes

A *probe* is a specific type of question designed to reveal more than just an answer. A probe uncovers significant data about students' thinking—for example, about their scientifically correct ideas, misconceptions, partially formed ideas, and the types of reasoning and connections they use to make sense of phenomena or concepts. The probes in the *Uncovering* series are considered two-tiered assessments. The first tier is a forced-choice response where students select from a list that includes the answer and several distracters. The second tier requires students to explain their thinking by explaining why they selected a particular answer.

This two-tiered approach is essential to formative assessment because students may answer a selected response question correctly but have major flaws in their reasoning for choosing that response. Conversely, they may select an incorrect response but show sophisticated reasoning with pieces of correct knowledge that have not been connected in a coherent way. In both cases, all the information is useful to the teacher when determining the learning experiences that he or she will need to provide to move students from where they are in their current thinking to where they need to be to achieve scientific understanding.

The probes in all of the books in the *Uncovering* series were developed using a process that links key ideas in science to children's commonly held ideas as revealed in research about how children learn. This formative assessment probe development process, supported with funding from the National Science

Foundation, is explained in *Science Curriculum Topic Study: Bridging the Gap Between Standards and Practice* (Keeley 2005). Tools, templates, and detailed instructions for facilitating the assessment probe development process are described in *A Leader's Guide to Science Curriculum Topic Study* (Mundry, Keeley, and Landel 2009). Both of these publications are available through NSTA Press (*www.nsta.org/store*) and are highly recommended if you would like to increase your knowledge about the link between science standards, research on learning (including misconceptions), and classroom practice.

About the Teacher Notes

The Teacher Notes that follow each probe provide important information related to the content of the probe, the content's connection to science standards, grade-level considerations, the underlying research on students' commonly held ideas, and suggestions for instruction, including suggestions for addressing the ideas your students have related to the probe and for informing your own professional knowledge. The Teacher Notes that accompany each of the probes are made up of these 11 sections:

1. Purpose

This section begins by describing the general concept elicited by the probe and then states the specific ideas that are targeted by the probe. Before you choose a probe, it is important that you read this section to make sure that the probe is designed to provide the information about students' ideas that you need to inform your teaching.

2. Related Concepts

Each probe is designed to target one or more related concepts that often cut across grade spans, such as the concept of a cell. These concepts are also included on the concept matrix charts on pages 8 and 84. A single concept may be addressed by more than one probe, 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 four probes related to the concept of photosynthesis.

3. Explanation

A brief scientific explanation accompanies each probe and provides clarification of the scientific content that underlies the probe. The explanations are designed to help you identify what the "best" or most scientifically acceptable answers are (sometimes there is an "it depends" answer) and to clarify any misunderstandings you might have about the content. Great care was taken not to oversimplify the content explanations for teachers with biology backgrounds. Conversely, explanations were carefully worded to provide the information that novice life science teachers with little or no formal backgrounds in biology would need to understand the content.

If you need additional background information on the content, please refer to the references and the related NSTA resources that appear at the end of each Teacher Notes.

4. Curricular and Instructional Considerations

Unlike summative assessments, the probes in this book do not target a single grade level. Rather, they provide insights into the knowledge and thinking your students may have regarding a topic as they developmentally progress or move from one grade span (i.e., elementary, middle, or high school) to the next. Some of the probes can be used in K–2, 3–5, 6–8, and 9–12; others address a single grade span, such as 9–12. Teachers from two different grade spans might decide to administer the same probe and then come together to discuss their findings. To do this, it is helpful to know what students typically experience and are expected to know at a given grade span about the ideas elicited by the probe. Because the probes do not typically identify one specific grade level for use, you are encouraged to read the Curricular and Instructional Considerations sections and then decide if your students have sufficient readiness to respond to the probe and whether the information you will get from the probe is likely to be useful in your particular context.

5. Administering the Probe

This section provides suggestions for administering the probe to students, including what the appropriate grade levels are and how various modifications can make the probe more accessible for certain students. For example, the notes might recommend eliminating some of the choices from the list of possible answers for younger students, who may not be familiar with particular words or examples. This section also tells teachers when it is a good idea to establish the context for a probe by showing students various items or props referred to in the probe (e.g., showing students an unopened packet of cucumber seeds or a picture of a seed packet when using the "Cucumber Seeds" probe on p. 9). This section often suggests ways to elicit probe responses when students are working in collaborative groups or engaging in a whole-class discussion.

Most of the probes are not grade-level-specific in the way summative assessments are designed. The suggested grade level is intended to be a guide and depends on your use of the probe and your students' readiness. You might think about these questions:

- Do you want to know what ideas the national science standards expect students at your grade level to learn?
- Are you interested in how preconceived ideas develop and how they are apt to change across multiple grade levels, whether or not they are formally taught?
- Are you interested in whether your students understand previous-grade-level science concepts before you introduce higher-level concepts?
- Do you have students who are ready for advanced concepts that exceed their grade-level expectations?

Weigh the suggested grade levels in the Administering the Probe section against the knowledge you have of your own students and your school's curriculum.

6. Related Ideas in the National Science Standards

This section lists the learning goals stated in the two major documents generally considered to be the national science standards—the most recent version of *Benchmarks for Science Literacy* (AAAS 2009) and *National Science Education Standards* (NRC 1996). Because these are the primary documents on which almost all current state science standards are based, it is important to look at the related learning goals in these documents. In future publications in this series, we plan to include the new Next Generation Science Standards, now under development by the National Research Council.

The learning goals in this section (which are quoted directly from the two primary documents) are not intended to align directly to the probe. Rather they appear in a probe because they are closely related to it in some way. For example, some targeted probe ideas, such as the tropism-related ideas in "Pumpkin Seeds" and "Rocky Soil," although not explicitly stated as learning goals in the national science standards, are clearly related to concepts regarding specific ideas about the behavior of organisms. The topic of tropisms is not included in the standards for the purpose of learning the names and types of different plant responses.

Rather, it serves as a context for important learning goals related to behavioral responses to changes in an organism's environment. Therefore, the two probes that address plants' gravitropic or thigmotropic responses to environmental stimuli (#12 and #13) clearly relate to the National Science Education Standards middle and high school ideas related to the behavioral characteristics of organisms.

Whenever the ideas elicited by a probe *do* appear to be a strong match (aligned) with a national science standard's learning goal, these matches are indicated by a star symbol (★). You may find this information helpful when using probes with lessons and instructional materials that are strongly aligned to a similar goal in your local standards, curriculum materials, and specific grade level.

Sometimes you will notice that an elementary learning goal is included with probes that have been designated for middle and high school use. This is because it is often useful to see the related idea that the probe builds on from a previous grade span. Likewise, a high school learning goal is sometimes included with a probe for grades K–8. This is because it is useful to consider the *next level* of sophistication that students will encounter in their spiraled learning.

7. Related Research

Each probe is informed by related research, where available, or results from the field tests that were conducted during development of the probes. Three sources of comprehensive research summaries readily available to educators were used to describe the commonly held ideas that students have about the life science concepts addressed in this book: Chapter 15 in *Benchmarks for Science Literacy* (AAAS 1993, 2009); the research summaries in the two volumes of the *Atlas of Science Literacy* (AAAS 2001, 2007); and *Making Sense of Secondary Science: Research Into Children's Ideas* (Driver et al. 1994). Available research in the specific field of biology education was also used.

It should be noted that although many of the research articles cited in this section of a probe describe studies that were conducted in past decades and involved children in other countries as well as the United States, most of the results of these studies are considered timeless and universal. Whether students develop their ideas in the United States or other countries, research indicates that many of their preconceptions about living phenomena and life science concepts are similar—regardless of geographic boundaries and societal and cultural influences. Hence the descriptions from the research can help you anticipate the kinds of thinking your students are likely to reveal when they respond to a probe and the factors that may have influenced their thinking. As you use the probes, you are encouraged to explore current and readily available published research. The Curriculum Topic Study website at *www.curriculumtopicstudy.org* has a searchable database where you can access additional current research articles on learning.

8. Suggestions for Instruction and Assessment

A probe is simply diagnostic, not formative, unless you use the information acquired from examining your students' thinking to inform your instruction. After analyzing your students' responses, you will then want to take two important steps: deciding on individual student interventions that differentiate instruction according to the various ideas students may hold and formulating an instructional path that can be used to guide whole-class instruction. You may find that additional probing assessments are needed. Suggestions in this section have been gathered from the wisdom of teachers, the knowledge base on effective science teaching, research on various strategies for learning, and the author's and her colleagues' extensive experience working with students and teachers.

In this section, you will not find detailed descriptions of instructional activities but rather brief suggestions for planning or modifying your curriculum or instruction to help your students cross the bridge that begins with their own preconceptions and leads them toward a scientific understanding. Your role may be as simple as making sure that your students are not limited by the context in which they learned a particular concept. For example, the probe "Eggs" on page 117 may point out the limitations of context when teaching about life cycles or how animals are born. Some students may believe that only organisms that hatch from eggs that develop in the external environment begin their life cycle as an egg. They may not recognize that animals that give birth to live young also started life as an egg. You should also be aware during your teaching that the use of an everyday word such as *animal* can create confusion among students when the teacher is using such a word according to its different, biological meaning—for example, some students may not realize that, in biology, humans are considered animals (see "No Animals Allowed," p. 21).

Learning is a very complex process and no single suggestion will help all students learn. But formative assessment encourages you to think carefully about how to move your students conceptually from where they are initially in their learning to where they need to be. All the while, you are monitoring their progress during the course of instruction and learning. As you become more familiar with the ideas your students have and the many factors that may have contributed to their misunderstandings, you will identify additional strategies to teach for conceptual change.

9. Related NSTA Science Store Publications, NSTA Journal Articles, NSTA Learning Center Resources (SciGuides, SciPacks, and Science Objects)

NSTA Press books and NSTA's journals, SciGuides, SciPacks, and Science Objects are increasingly targeting the ideas students bring to their learning. In this section, I provide suggestions for additional readings and other curricular materials that complement or extend the use of the individual probes and the background information that accompanies them. For example, NSTA Press's *Hard-to-Teach Biology Concepts: A Framework to Deepen Student Understanding* (Koba and Tweed 2009) can clarify biology concepts that teachers and students struggle with. Journal articles from NSTA's elementary, middle school, and high school member journals can provide additional insight into students' misconceptions about food chains and food webs or present effective instructional strategies or activities for deepening student understanding of the ideas targeted by a probe. The NSTA Science Object called *Cell Structure and Function: Cells—The Basis of Life* can be used to deepen a novice life science teacher's content knowledge about cells.

10. Related Curriculum Topic Study Guides

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

The specific CTS guides that informed the development of the probes in this book appear in boxes before the References in the Teacher Notes. Teachers who wish to delve deeper into the standards and research-based findings that were used to develop the probes may wish to use the guides for further information. In addition, the CTS website—*www.curriculumtopicstudy.org*—provides a database of supplemental resources linked to each topic covered in the book. These supplemental resources include new research on students' ideas, videos that address the topic, and professional development materials.

11. References

References conclude each of the Teacher Notes. The references provide the complete citations for publications and other materials cited in the Teacher Notes. Consider reading some of these articles or books to really dig down into a subject that interests you.

Formative Assessment Reminder

Now that you have some background on the older series, this new series, the probes, and the Teacher Notes, let's not forget the formative purpose of these probes. *Remember—a probe is not formative unless you use the information from the probe to modify, adapt, or change your instruction so that students have opportunities to learn certain important life science concepts.*

As a companion to this book and to the others in the *Uncovering* series, NSTA has copublished *Science Formative Assessment: 75 Practical Strategies for Linking Assessment, Instruction, and Learning* (Keeley 2008). This book contains a variety of strategies to use with the probes to facilitate elicitation of student thinking, support metacognition, spark inquiry, encourage discussion, monitor progress toward conceptual change, encourage feedback, and promote self-assessment and reflection. By using the probes and their supporting formative assessment classroom techniques (FACTs), you will create learning environments that acknowledge that all students' ideas are important. Taking the time to make students' ideas visible will help you discover and use new knowledge about teaching and learning and engage your students in the process of conceptual change.

If you have stories to share about your use of the probes or suggestions for future probe topics, please feel free to e-mail me at *pagekeeley@gmail.com.* In addition, if you are interested in planning a workshop or other professional development sessions using the *Uncovering* series and its formative assessment classroom techniques, check out NSTA Press's Authors Speak site—*www.nsta.org/publications/press/authorsspeak*—through which you can arrange to bring an NSTA Press author, such as the author of this series, to your school or district for professional development. Following an introduction to using formative assessment and the assessment probes, many school districts throughout the country, both large and small, are recognizing the importance of using embedded professional development, such as book studies, to build and sustain a collaborative culture of formative assessment in their schools.

References

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

American Association for the Advancement of Science (AAAS). 2001. *Atlas of science literacy.* Vol. 1. Washington, DC: AAAS.

American Association for the Advancement of Science (AAAS). 2007. *Atlas of science literacy.* Vol. 2. Washington, DC: AAAS.

Preface

American Association for the Advancement of Science (AAAS). 2009. Benchmarks for science literacy online. *www.project2061.org/publications/bsl/online*

Bransford, J., A. Brown, and R. Cocking. 2000. *How people learn: Brain, mind, experience, and school.* Washington, DC: National Academies Press.

Driver, R., A. Squires, P. Rushworth, and V. Wood-Robinson. 1994. *Making sense of secondary science: Research into children's ideas.* London: Routledge-Farmer.

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

Keeley, P. 2008. *Science formative assessment: 75 practical strategies for linking assessment, instruction, and learning.* Thousand Oaks, CA: Corwin Press and Arlington, VA: NSTA Press.

Keeley, P., F. Eberle, and C. Dorsey. 2008. *Uncovering student ideas in science, vol. 3: Another 25 formative assessment probes.* Arlington, VA: NSTA Press.

Keeley, P., F. Eberle, and L. Farrin. 2005. *Uncovering student ideas in science, vol. 1: 25 formative assessment probes.* Arlington, VA: NSTA Press.

Keeley, P., F. Eberle, and J. Tugel. 2007. *Uncovering student ideas in science, vol. 2: 25 more formative assessment probes.* Arlington, VA: NSTA Press.

Keeley, P., and R. Harrington. 2010. *Uncovering student ideas in physical science, vol. 1: 45 new force and motion assessment probes.* Arlington, VA: NSTA Press.

Keeley, P., and J. Tugel. 2009. *Uncovering student ideas in science, vol. 4: 25 new formative assessment probes.* Arlington, VA: NSTA Press.

Koba, S., with A. Tweed. 2009. *Hard-to-teach biology concepts: A framework to deepen student understanding.* Arlington, VA: NSTA Press.

Mundry, S., P. Keeley, and C. J. Landel. 2009. *A leader's guide to science curriculum topic study.* Thousand Oaks, CA: Corwin Press.

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

Shulman, L. 1992. Ways of seeing, ways of knowing, ways of teaching, ways of learning about teaching. *Journal of Curriculum Studies* 28: 393–396.

Acknowledgments

I would like to thank the teachers and science coordinators I have worked with for their willingness to field-test probes, share student data, and contribute ideas for assessment probe development. I would especially like to acknowledge Amy Neiman, a teacher at La Center High School in La Center, Washington. Amy's use of the "Let's Keep Thinking!" sticky bars technique was the inspiration for the vignette in the introduction of this book. Thanks, Amy, for sharing such a creative way to use this technique to monitor changes in students' thinking throughout instruction! Also, my special thanks go to Beth Chagrasulis at Bridgton Academy in North Bridgton, Maine. Beth is a talented high school biology teacher who never hesitates to take the time to give me feedback on the probes and a window into how they can be used in creative ways.

I would also like to thank my colleagues at the Maine Mathematics and Science Alliance (MMSA) (*www.mmsa.org*) who support me in this work as well as my professional development colleagues, the Math-Science Partnership directors, and university partners throughout the United States whom I have had the pleasure of sharing the *Uncovering Student Ideas* work with in various projects. I also thank the book's four reviewers for providing useful feedback to improve the original manuscript: Susan Brady, director, Center for Science and Engineering, University of California; A. Daniel Johnson, senior lecturer and Kirby Faculty Fellow, Department of Biology, Wake Forest University; Richard Konicek-Moran, educator, biologist, and professor emeritus, University of Massachusetts-Amherst; and Luke Sandro, biology teacher, Springboro (Ohio) High School.

I especially thank Dr. Julie Luft for taking the time to write the foreword for this first volume in the life science series. Julie is an inspiring researcher and educator who truly walks the talk when it comes to building a bridge between research and practice. And deep gratitude goes to all my friends at NSTA Press—it is a privilege to work with you!

About the Author

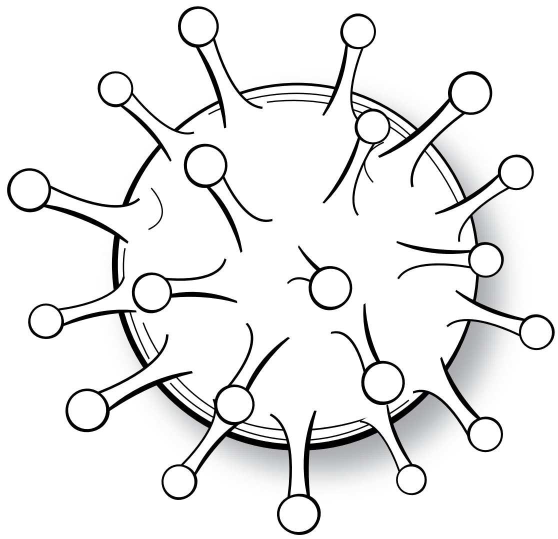
Page Keeley is the senior science program director at the Maine Mathematics and Science Alliance (MMSA) where she has worked since 1996. She directs projects in the areas of leadership, professional development, linking standards and research on learning, formative assessment, and mentoring and coaching, and she consults with school districts and organizations nationally. She was 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. She is the author of 10 books (including this one): four books in the *Curriculum Topic Study* series (Corwin Press); five volumes in the *Uncovering Student Ideas in Science* series (NSTA Press); and *Science Formative Assessment: 75 Practical Strategies for Linking Assessment, Instruction, and Learning* (Corwin Press and NSTA Press).

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. She is frequently invited to speak at national conferences, including the annual conference of the National Science Teachers Association. She led the People to People Citizen Ambassador Program's Science Education delegation to South Africa in 2009 and to China in 2010.

Page taught middle and high school science for 15 years; in her classroom she 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. During her time as a classroom 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 a Milken National Distinguished Educator Award in 1993. She was the AT&T Maine Governor's Fellow for Technology in 1994, 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 was elected the 63rd president of the National Science Teachers Association for the 2008–2009 term. In 2009 she received the National Staff Development Council's Susan Loucks-Horsley Award for her contributions to science education leadership and professional development.

The Virus Debate



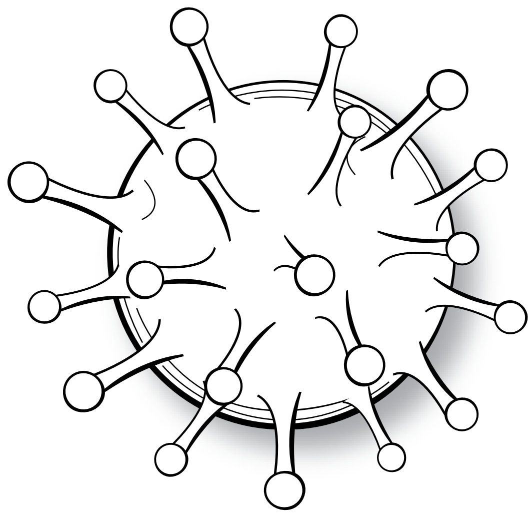
The students in Mrs. Oliver's biology class were having a debate about viruses. Half of the class thought viruses were considered living things. The other half of the class did not think viruses were considered living things. Which side are you on?

Circle the word you think best describes a virus: living nonliving

Explain your thinking. What rule or reasoning did you use to decide whether viruses are living or nonliving?

The Virus Debate

Teacher Notes



Purpose

The purpose of this assessment probe is to elicit students' ideas about characteristics of life. Viruses are used as a context to uncover students' ideas about what determines whether something is considered a living or a nonliving thing.

Related Concepts

Living, virus, cells, characteristics of life

Explanation

There is no absolutely right answer to this question, although the best answer leans toward nonliving. "Are viruses living?" is still an open-ended question in the scientific community and either answer is acceptable depending on students' reasoning. Viruses fall into a gray area between living and nonliving things. A virus is not a cell. It is just a piece of DNA or RNA (never both), surrounded by a protein coat called a capsid. Viruses are a thousand times smaller than even a bacterium and can exist in a wide variety of shapes and forms. They are often described as obligate intracellular parasites because they must be inside a living cell to reproduce and the relationship with its host is parasitic (the guest benefits at the expense of the host).

The reason the best answer leans toward nonliving is that when the characteristics of viruses are compared to a standard list of the characteristics of life, there are many more things they are *not*. Viruses are *not* made of cells, they do *not* obtain or use energy to run metabolic activities (they do *not* have a metabolism because they are just particles and not cells). They do *not* grow in size or develop over a lifetime from a juvenile virus to a mature virus. They do *not* have the ability to respond to a stimulus in their environment, and they do *not* maintain homeostasis as living cells do when they exchange gases, expel waste, or take in food and water.

So, why the debate? Well, viruses *do* have genes that can mutate and give the virus a new characteristic that might allow it to have an advantage in its environment. Natural selection then "chooses" the viruses better able to infect new cells and thus "survive," which results in evolution of the virus population over time.

Also, viruses *do* "reproduce," but they are not capable of doing this independently, and they do not divide as cells do using mitosis or binary fission. Making more viruses is called replication rather than reproduction because they take over a living cell and use the cell's existing machinery to make copies of themselves by assembling more pieces of nucleic acids and protein coats. These new virus particles leave the host cell either one at a time or all at once to go infect a new host cell and make more copies. Whether a virus is living or nonliving, an organism or not an organism, leads to a lively debate during which students may conclude that viruses are at the borderline of life.

Curricular and Instructional Considerations

Elementary Students

In elementary grades, students learn about a variety of living things and some of the characteristics and needs that all living things have in common. They may be familiar with viruses as things that cause disease, but an understanding of the characteristics of a virus should wait until middle school when students have a deeper understanding of cells and life processes.

Middle School Students

In the middle grades, students develop a deeper understanding of the characteristics of life and know that the cell is the fundamental unit of structure and function that carries out the processes essential to all living things. Middle school students can understand the characteristics that define life and apply them to a variety of organisms. When viruses are introduced, they present a conundrum to students that challenges their conceptions of living versus nonliving. Middle school students develop a basic understanding of viruses and viral infection, but details about the types, structures, and replication of viruses can wait until high school.

High School Students

In high school, biology students learn about the history that led to the discovery of viruses. Their deeper knowledge of DNA, RNA, and proteins helps them understand the structural characteristics of viruses and the details of viral infection and replication, including several viruses of importance to human and plant health. Their understanding of the characteristics that define life at the cellular level deepens as they extend their knowledge to the level of cell organelles and biomolecules.

Administering the Probe

This probe is most appropriate for middle and high school students. Before giving the probe, make sure that students have some basic knowledge of what a virus is, its structure, and what it does when it enters a cell. After students have this basic information, use this probe to engage students in thinking about whether viruses are living. The probe leads to a lively debate among students, encouraging them to draw upon their prior knowledge of characteristics that define life.

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

K–4 Characteristics of Organisms

- Organisms have basic needs. For example, animals need air, water, and food; plants require air, water, nutrients, and light. Organisms can survive only in environments where their needs can be met.

5–8 Structure and Function in Living Systems

- ★ All organisms are composed of cells—the fundamental unit of life.
- ★ Cells carry out the many functions needed to sustain life. They grow and divide, therefore producing more cells. This requires that they take in nutrients, which they use to provide energy for the work that cells do and to make the materials that a cell or an organism needs.

5–8 Reproduction and Heredity

- ★ Reproduction is a characteristic of all living systems.

9–12 The Cell

- Cells have particular structures that underlie their functions. Every cell is surrounded by a membrane that separates it from the outside world. Inside the cell is a concentrated mixture of different molecules that form a variety of specialized structures that carry out such cell functions as energy production, transport of molecules, waste disposal, synthesis of new molecules, and the storage of genetic material.
- Cells store and use information to guide their functions. The genetic information stored in DNA is used to direct the synthesis of the thousands of proteins that each cell requires.
- Cell functions are regulated. Regulation occurs through both changes in the activity of the functions performed by proteins and through the selective expression of individual genes. This regulation allows cells to respond to their environment and to control and coordinate cell growth and division.

9–12 The Molecular Basis of Heredity

- In all organisms, the instructions for specifying the characteristics of the organism are carried in DNA, a large polymer formed from subunits of four kinds (A, G, C, and T). The chemical and structural properties of DNA explain how the genetic information that underlies heredity is both encoded in genes and replicated.

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

K–2 The Cell

- Most living things need water, food, and air.

3–5 The Cell

- Microscopes make it possible to see that living things are made mostly of cells.

6–8 The Cell

- ★ All living things are composed of cells, from just one to many millions, whose details usually are visible only through a microscope.
- ★ Within cells, many of the basic functions of organisms—such as extracting energy from food and getting rid of waste—are carried out.
- Cells repeatedly divide to make more cells for growth and repair.

9–12 The Cell

- Within the cells are specialized parts for the transport of materials, energy capture and release, protein building, waste disposal, passing information, and even movement.

Related Research

- Children have various ideas about what constitutes "living." Some may believe objects that are "active" are alive; for example, fire, clouds, or the Sun. As children mature, they include eating, breathing, and reproducing as essential characteris-

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

tics of living things. People of all ages use movement and, in particular, movement in response to a stimulus, as a defining characteristic of life (Driver et al. 1994).

- Elementary and middle school students use observable processes such as movement, breathing, reproducing, and dying when deciding if things are alive or not. High school and college students use these same readily observable characteristics to determine if something is alive. They rarely mention ideas such as "being made up of cells" or biochemical aspects such as "containing DNA." Many educators suggested that the learning of facts has contributed little toward understanding. Students may be able to quote the seven characteristics of life but may not be able to apply them when determining if something is living (Brumby 1982).
- Carey (1985) suggested that progression in the concept of *living* is linked to growth in children's ideas about biological processes. Young children have little knowledge of formal concepts in biology, including criteria that define characteristics of life.

Suggestions for Instruction and Assessment

- Combine this probe with "Is It Living?" and "Is It Made of Cells?" in *Uncovering Student Ideas in Science, Vol. 1: 25 Formative Assessment Probes* (Keeley, Eberle, and Farrin 2005). Consider adding *virus* to the list of distracters in each of these probes.
- This probe can also be used with the "agreement circle" formative assessment classroom technique (FACT) (Keeley 2008). Students are asked several questions about viruses while standing in a large circle. Those who agree with the statement step to the inside of the circle. Those who disagree stay on the outside of the circle. Then students from inside and outside the circle are matched up in groups to argue their ideas. After using several questions about viruses, use this probe as the culminating question for debate.
- Use graphic organizers such as Venn diagrams or compare-and-contrast charts to compare characteristics of viruses to characteristics of living cells.
- Miller and Levine (2006, p. 480) use an interesting analogy to describe lytic infection by viruses. Challenge students to compare viral infection to an outlaw in the American Wild West—the virus being the outlaw and the cell being the town. First, the outlaw rides into town and then eliminates the town's existing authority (the sheriff), which is analogous to the host cell's DNA. Then the outlaw demands to be outfitted with new weapons, horses, and equipment by terrorizing the local people, which is analogous to using the host cell to make viral proteins and viral DNA. Finally, the outlaw forms a gang that leaves the town and goes on to attack new towns, which is analogous to the host cell bursting open and releasing hundreds of virus particles that go on to infect new cells.
- Ask students if viruses are parasites. Compare viruses to parasitic organisms. How are they alike and how are they different? How can a virus be considered a parasite, yet not be considered an organism?
- Compare and contrast how viruses are classified with how living organisms are classified.

Related NSTA Science Store Publications, NSTA Journal Articles, NSTA SciGuides, NSTA SciPacks, and NSTA Science Objects

Dubois, S., K. Moulton, and J. Jamison. 2009. Collaboration at the nanoscale: Exploring viral genetics with electron microscopy. *The Science Teacher* 76 (4): 32–39.

Jones, M., M. Falvo, A. Taylor, and B. Broadwell. 2007. *Nanoscale science: Activities for grades 6–12.* Arlington, VA: NSTA Press.

Diamond, J., with C. Zimmer, E. Evans, L. Allison, and S. Disbrow. 2006. *Virus and the whale: Exploring evolution in creatures large and small.* Arlington, VA: NSTA Press.

Related Curriculum Topic Study Guide (in Keeley 2005)
"Characteristics of Living Things"

References

American Association for the Advancement of Science (AAAS). 2009. Benchmarks for science literacy online. *www.project2061.org/publications/bsl/online*

Brumby, M. 1982. Students' perceptions of the concept of life. *Science Education* 66 (4): 613–622.

Carey, S. 1985. *Conceptual change in childhood.* Cambridge, MA: MIT Press.

Driver, R., A. Squires, P. Rushworth, and V. Wood-Robinson. 1994. *Making sense of secondary science: Research into children's ideas.* London: RoutledgeFalmer.

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

Keeley, P. 2008. *Science formative assessment: 75 practical strategies for linking assessment, instruction, and learning.* Thousand Oaks, CA: Corwin Press and Arlington, VA: NSTA Press.

Keeley, P., F. Eberle, and L. Farrin. 2005. *Uncovering student ideas in science, vol. 1: 25 formative assessment probes.* Arlington, VA: NSTA Press.

Miller, K., and J. Levine. 2006. *Biology.* Upper Saddle River, NJ: Prentice-Hall.

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

Index

Note: Page numbers in *italics* refer to charts.

Index

Index

Index

Index

Index