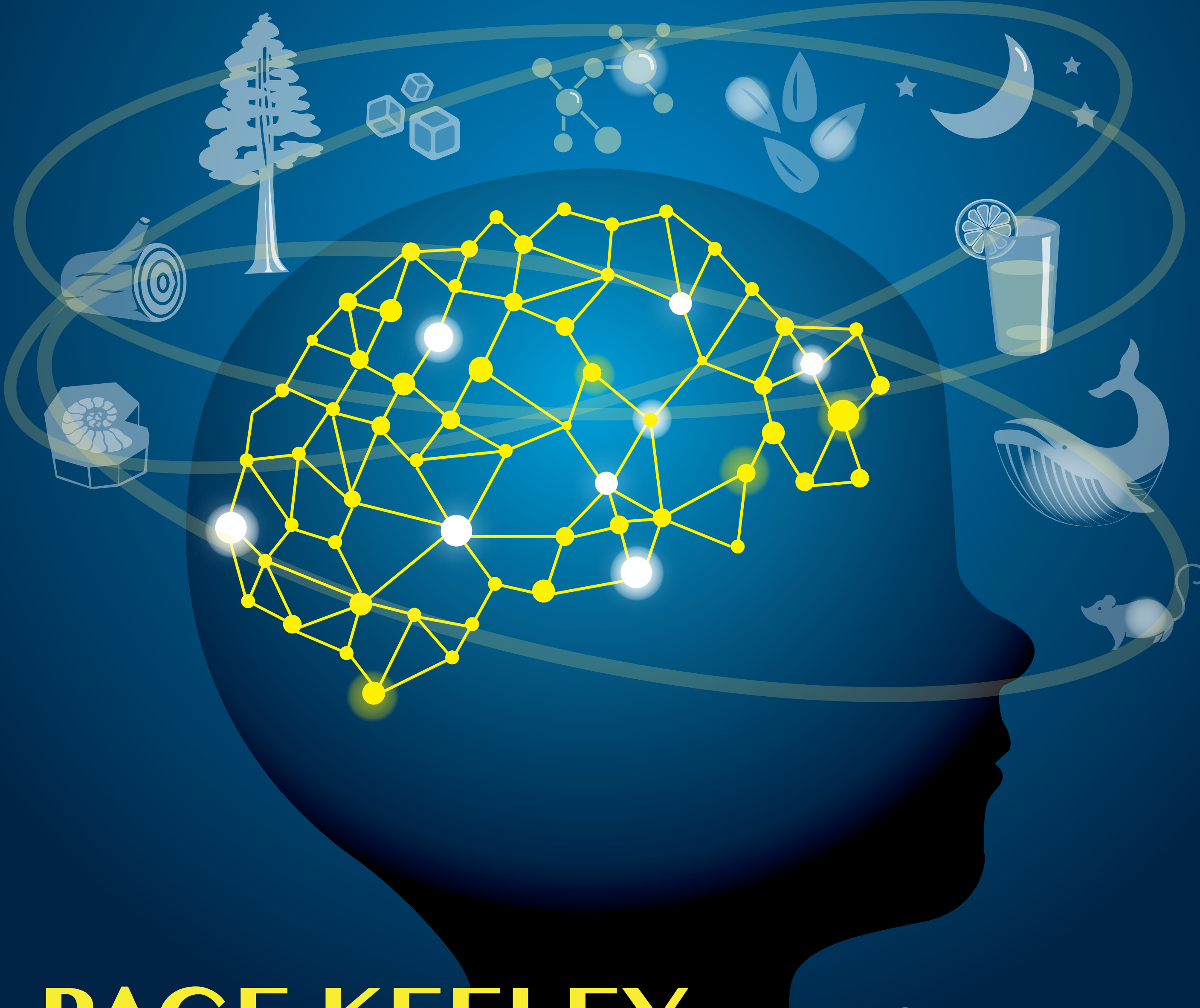
VOL 2. SECOND EDITION

UNCOVERING STUDENT IDEAS IN SCIENCE

25 MORE FORMATIVE ASSESSMENT PROBES



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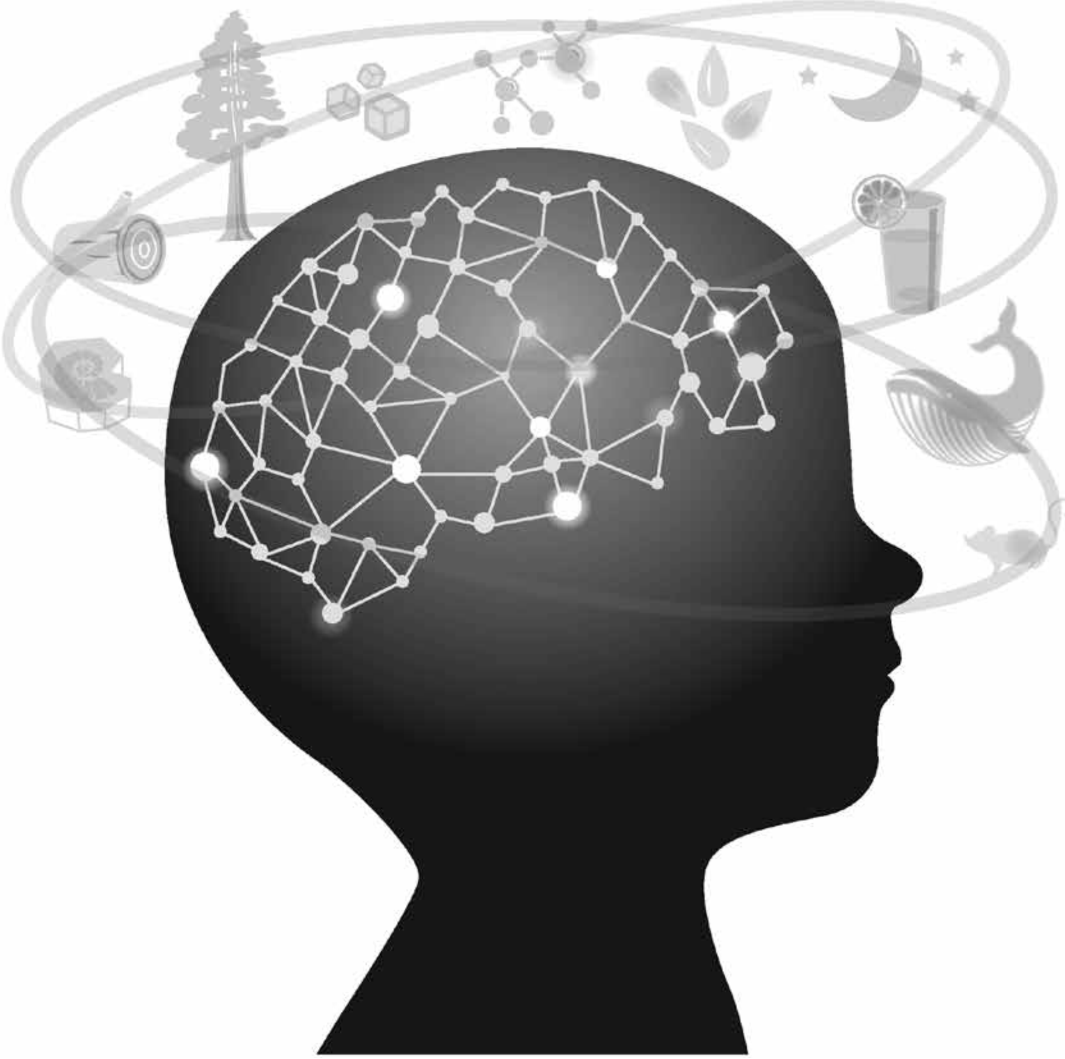

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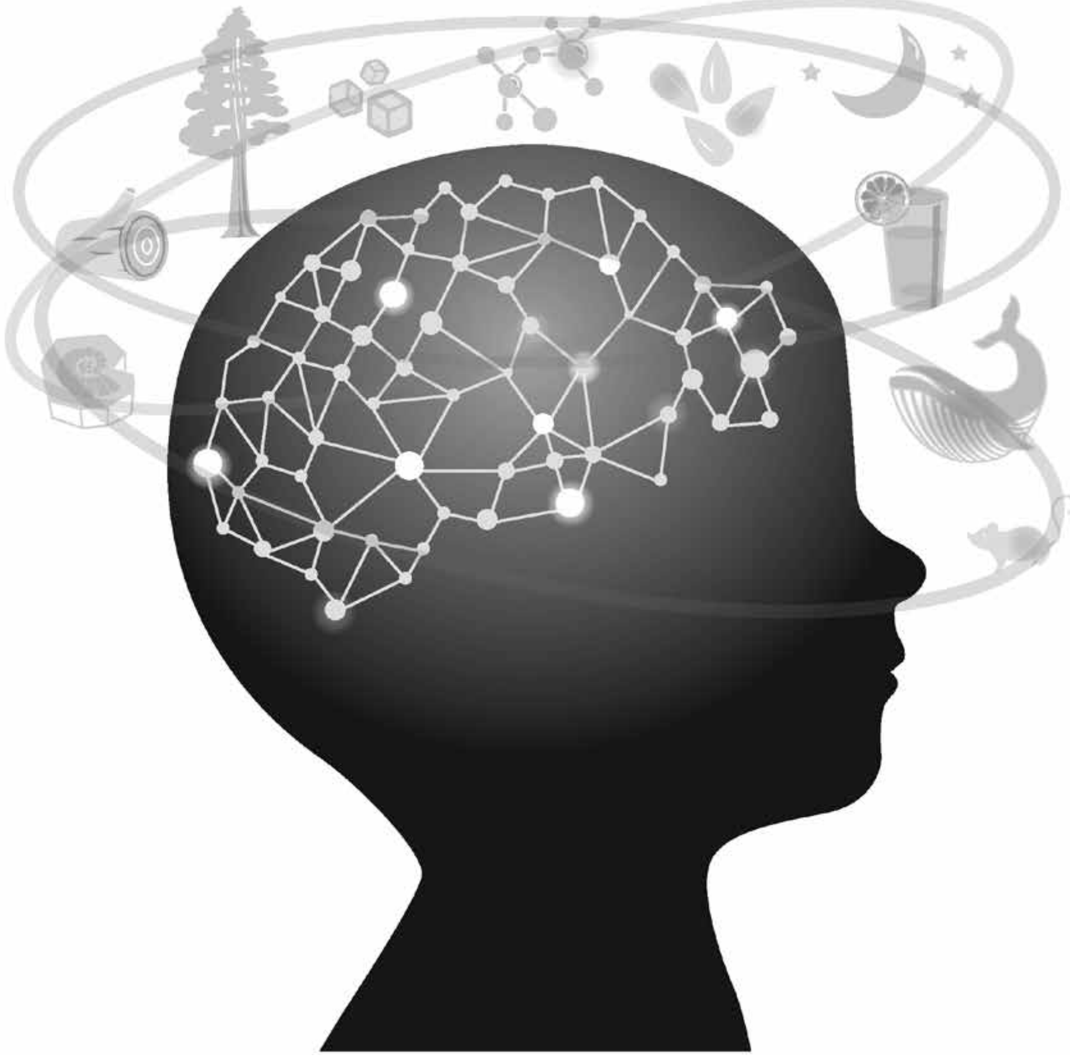

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Foreword

While writing this foreword, I found myself revisiting the 50-odd years of my involvement in science education. I recalled the many ideas, techniques, concepts, and research findings that have passed through my experience and flowed into my teaching repertoire like so much effluent through the filtering rushes in a stream. Some remain vital today and others still cling to the stalks, tried, tested, and found wanting.

I remember so vividly the night of October 4, 1957, when as a nation we were alerted to the beeping of Sputnik as it circled our planet, totally unaware of the influence its presence would have on science education over the next decade. It marked not only the beginning of the space race but the beginning of the rapid and frantic attempts of our nation to "beef up" the science, math, and engineering skills of our students. Science finally had a real place in the school curriculum. The Russians had beaten us to space and we were worried about our future as a nation! The United States responded swiftly with the National Defense Education Act, which allowed teachers like myself to update our content at summer institutes and provided for the development of a different kind of curriculum for school science.

Since then there have been many innovations in our field, including the famed "alphabet soup" curriculum projects of the 1950s and 1960s (e.g., SCIS, SAPA, COPES, Harvard Project Physics) and subsequent curriculum projects such as Insights, GEMS, AIMS, STC, and FOSS.

Then came the advent of the standards decade with Project 2061 and the *Benchmarks for Science Literacy* (AAAS 1993) and the *National Science Education Standards* (NRC 1996). We finally had a guide to what content should be taught and how it should be presented. Many of the states then developed their own versions of the standards, but there was uncertainty about how to use standards on the local level.

In 2005, Page Keeley authored *Science Curriculum Topic Study: Bridging the Gap Between Standards and Practice,* which was the first comprehensive guide to help us bridge the gap between the two sets of national standards, research on student learning, and teaching practice. This was a timely, much-needed book.

Following the development of state standards, each state instituted ways to hold schools accountable for teaching to the standards. For many states, this resulted in "high-stakes" tests, which were enshrined in legislation. Schools gave these tests to students in the spring and received the results sometime during the next school year. The accountability factor was there, but it did little for the teachers who wanted to improve current learning for their students. Many school districts implemented a teaching unit for selected grades entitled "Review for the Test." I thought to myself, "Maybe this really is a good time to retire!"

Many of us believed that teachers needed a way to find out what their students knew, what kind of preconceptions students brought to the classroom, and what teachers could do with this information to improve instruction. Again, Page Keeley and her team from the Maine Mathematics and Science Alliance entered the picture, along with the National Science Teaching Association, with the first volume of *Uncovering Student Ideas in Science: 25 Formative Assessment Probes,* published in 2005. This book focused on helping teachers discern their students' thinking about different science topics. It also helped teachers figure out what to do with this information and where to find help in moving their students to a new and deeper understanding of science concepts.

A workable strategy for formative assessment was now available to the busy teacher. The probes published in the first volume of *Uncovering Student Ideas in Science* were a success, and teachers from all over the country began to find that formative assessment can help them become better teachers. This may indeed have been an example of the "tipping point" that Malcolm Gladwell (2000) talks about in his book *The Tipping Point: How Little Things Can Make a Big Difference.* I knew it was mine. Finding this kind of innovation is exciting to me because teachers once again can be in charge of classroom instruction. The arrival of a truly inquiry-based focus on science education, coupled with assessment, is what I and so many others have been waiting for.

Well, doesn't a successful book deserve a sequel? Here it is, with 25 new probes and accompanying teacher guides. This is the kind of innovation that is enough to keep an old dog like me barking out there in the field for a few more years. Woof!

Dr. Richard Konicek-Moran
Professor Emeritus
University of Massachusetts, Amherst

This foreword was written in 2007 for the first edition of Uncovering Student Ideas in Science, Volume 2.

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It's been said that some people bring a light so great to the world that even after they have gone the light remains. This can certainly be said of Dr. Richard "Dick" Konicek-Moran. Dick's light will forever shine on the thousands of teachers and former students he positively influenced throughout his extraordinary 60+ years in science education. Sadly, my dear friend, mentor, and inspiration passed away on November 10, 2019. He will forever remain in my heart and in my work.

—**Page Keeley,** October 20, 2020

Preface

Uncovering Student Ideas in Science, Volume 2, Second Edition: 25 More Formative Assessment Probes updates the 2007 version by including a Spanish version for each student probe page, adding current research summaries, linking to related disciplinary core ideas (DCIs) in *A Framework for K–12 Science Education* (the *Framework*; NRC 2012) and the *Next Generation Science Standards* (*NGSS*; NGSS Lead States 2013), adding new instructional suggestions and new National Science Teaching Association (NSTA) resources, and making minor changes to a few of the probes.

Similar to the other books in the *Uncovering Student Ideas* series, this book provides a collection of unique questions, called *formative assessment probes,* that are purposefully designed to reveal preconceptions students bring to their learning and to identify misunderstandings students develop during instruction that teachers may not notice. Each probe is carefully researched to develop answer choices that mirror commonly held ideas students have about concepts or phenomena. Although suggested grade levels are provided, the probes are not grade-specific. They are designed to be used across multiple grade spans as well as with adults for professional learning or preservice education, especially because alternative science ideas that go unchallenged will often follow students from one grade to the next, and even into adulthood.

The Probes

This book contains a collection of 25 probes organized into three sections: Physical Science Probes (Section 1), Life Science Probes (Section 2), and Earth and Space Science Probes (Section 3). A concept matrix precedes each section. The matrix lists related concepts addressed by each probe and suggested grade levels for using each probe. There are two versions of each probe included in this book. The first is the English language student page. On the back side of the English language student page is a Spanish language version. This version can be used with English language learners or with students in Spanish language immersion programs.

Teacher Notes That Accompany the Probes

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

Purpose

"Deciding what to assess is not as simple as it might appear. Existing guidelines for assessment design emphasize that the process should begin with a statement of the purpose for the assessment and a definition of the content domain to be measured" (Pellegrino, Chudowsky, and Glaser 2001, p. 178). This section describes the purpose of the probe—that is, what you will learn about your students' ideas as you use the probe. It begins by describing the overarching concept the probe elicits, followed by the specific idea that makes up the learning target. Before choosing a probe, it is important to understand what the probe is intended to reveal about students' thinking. Taking time to read the Purpose section will help you decide if the probe will provide the information you need to plan responsive instruction and attend to students' thinking.

Type of Probe

This section describes the format used to develop the probe. All probes in the *Uncovering Student Ideas* series are two-tiered, meaning they are made up of two parts. The first part is a selected answer choice, and the second part involves constructing an explanation to justify the selected answer. Similar to the crosscutting concept of structure and function, in which structure is related to function, the format of a probe is related to how a probe is used. This book uses the following probe types:

- *Friendly Talk Probe:* This format uses the scenario of a group of friends or family members having a conversation. The answer choices are the statements each person makes. The probe models the importance of sharing ideas through talk and shows how people often have very different ideas. "Baby Mice" (p. 127) is an example of a friendly talk probe.
- *Justified List Probe:* In this format, students are presented with a list of things or statements that are examples or non-examples of a concept or principle. Students select multiple answer choices from a list that match the concept or principle. This format is often helpful in finding out whether students can transfer what they learned to different contexts and whether they can develop generalizations. "Is It a Plant?" (p. 91) is an example of a justified list probe.
- *P-E-O Probe (Predict-Explain-Observe):* In this type of probe, students make a prediction, explain the reason for their prediction, and then launch into an investigation to test their prediction. When their observation does not match their prediction, students need to collect more information and evidence to develop a revised explanation. "Solids and Holes" (p. 35) is an example of a P-E-O probe.
- *More A-More B Probe:* This type of probe reveals whether students use a common, intuitive rule, in which they think that an increase in one thing results in an increase in another thing. "Whale and Shrew" (p. 135) is an example of a more A-more B probe.
- *Familiar Phenomenon Probe:* This type of probe uses a familiar, everyday phenomenon to elicit students' ideas. "Ice-Cold Lemonade" (p. 73) is an example of a familiar phenomenon probe.
- *Sequencing Probe:* This format involves putting statements, objects, events, steps, or ideas in a logical sequence. "Emmy's Moon and Stars" (p. 173) is an example of a sequencing probe.
- *Opposing Views Probe:* This type of probe provides an opportunity for students to engage in argumentation over two different points of view. "Freezing Ice" (p. 53) is an example of an opposing views probe.

If you are interested in learning more about each of these probe types and formative assessment classroom techniques (FACTs) that can be used with each of these formats, see *Science Formative Assessment, Volume 1* and *Volume 2,* which are both available through NSTA Press (Keeley 2015, 2016).

Preface

Related Concepts

Each probe is designed to target one or more concepts that develop across a learning progression. A concept is a one-, two-, or three-word mental construct used to conceptually name an object, characteristic, event, or process (Konicek-Moran and Keeley 2015). Concepts make up the DCIs in the *Framework* (NRC 2012) and the *NGSS* (NGSS Lead States 2013). Some examples of concepts addressed in this book include heat, density, inherited traits, transformation of matter, day/night cycle, plants, adaptation, chemical bonds, and weathering. Multiple probes may be used to address a concept. For example, three probes in this book can be used to address the concept of floating and sinking. A concept matrix is included at the beginning of each section (see pp. 14, 90, and 148).

Explanation

The *best* answer choice is provided in this section. *Best answer* is used rather than *correct answer* or *right answer* because the probes are not used to pass judgment on whether students are "right or wrong," nor are they intended to be graded. Instead, they are used to encourage students to reveal their *best thinking so far* without the worry of being "wrong." Sometimes there is no single "right" answer because the probe may uncover different ways of thinking that support an alternative answer choice. In many ways, the "best answer" mirrors the nature of science as scientists initially share their best thinking and modify their explanations as they gather more evidence. Additionally, science is not always black and white, and some students can justify the gray areas.

A brief, simplified scientific explanation is provided for teachers to help them understand the scientific ideas that underlie the probe and clarify misunderstandings students (and teachers) may have related to the content. The explanations do not give detailed scientific background knowledge. They are provided to support teachers' basic understanding of science. Teachers who have limited coursework and few opportunities for professional learning in science, who are new to teaching science, or who are teaching outside their disciplinary major in science can use the explanations to check on and build their understanding. The explanations are carefully written to avoid highly technical language and complex descriptions so that teachers do not have to specialize in an area of science to understand the explanation. At the same time, the challenge is to not oversimplify the science. The probe explanations are carefully constructed to provide concise information anyone can use to understand and respond to students' thinking.

Curricular and Instructional Considerations

The curricular and instructional considerations give insight into how concepts and specific ideas are addressed and how they progress at different grade spans. For example, elementary students may observe similarities between offspring and their parents and develop the idea of inherited traits, but it is not until middle school that students are able to explain the mechanism of inheritance. At the high school level, students learn more complex details about the mechanism of inheritance. Instructional experiences help them develop an understanding of how various gene combinations code for proteins and how the structure and function of proteins results in the expression of traits.

Because the probes are not grade-level specific, this section helps determine where and how a probe fits into teaching and learning. For example, the information about students' initial ideas might be useful for planning instruction when a DCI is a grade-level expectation, or it might be useful at a later grade to find out whether students have sufficient prior knowledge about the concept or idea to move on to the next level in a learning progression. This section is also helpful in determining whether the probe, and its terminology, should be modified to appropriately assess the level of complexity expected at different grade levels.

Administering the Probe

This section provides suggested grade levels for using the probe, including modifications for administering the probe at different grade levels. This section may also include descriptions of response methods, ways to use props or demonstrate the probe scenario, modifications for special needs, and suggestions for extending the probe.

Related Disciplinary Core Ideas (NRC 2012; NGSS Lead States 2013)

A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (NRC 2012) is the primary source document that has informed the development of many recent state standards, including the *Next Generation Science Standards* (NGSS Lead States 2013). The *Framework* will continue to inform the development of most states' standards as their standards come up for revision, regardless of whether those states adopt the *NGSS*. This section lists the DCIs from the *Framework* and the *NGSS* that are related to the probe.

Because the probes are not designed to be summative assessments, this section is not considered an alignment. Instead, it identifies concepts or ideas in the DCI that are related in some way to the probe. Sometimes the DCI is an exact match to the probe at a specific grade level; other times, students may need ideas that surface when using the probe to develop an understanding of the DCI. Seeing a related DCI that precedes a grade level is helpful when using the probe so that teachers know what students were expected to understand at the previous grade level. It is also useful to know what the DCI will be that builds on students' ideas at the next grade level. In other words, teachers can see how the ideas they teach relate to a spiraling progression of understanding as students move from one grade level to the next.

Although this section lists the DCIs that are most related to the probe, keep in mind that the probes also provide opportunities for students to use science practices as well as crosscutting concepts. For example, all of the probes include the practice of constructing scientific explanations because the second part of every probe asks students to explain their thinking. Students can be asked to draw a diagram to support their explanation, which provides an opportunity to use the science practice of developing and using models. Probes used in a discussion format support the practice of argumentation. Teachers can select a crosscutting concept and ask students to use it in their explanation. Additional ways to support the use of the science practices and crosscutting concepts may be included for each probe in the Suggestions for Instruction and Assessment section.

Related Research

Each probe is informed by research, when available. Much of the research on students' "misconceptions" was conducted in the 1980s and 1990s and summarized by Rosalind Driver's group at the University of Leeds in England. The commonly held ideas students have that are not completely consistent with the scientific way of thinking go by a variety of names: misconceptions, partial conceptions, alternative conceptions, naïve conceptions, facets of learning, conceptual misunderstandings, phenomenological primitives, and so on. In the *Uncovering Student Ideas* series, they are referred to as *commonly held ideas.*

Two comprehensive sources of these research summaries that are available to educators and still relevant today are Chapter 15 in the *Benchmarks for Science Literacy* (AAAS 2009), which is available online, and *Making Sense of Secondary Science: Research Into Students' Ideas* (Driver et al. 1994). In addition to drawing upon these sources, recent research from science education journals, such as the *Journal of Research in Science Teaching,* is cited if studies are available. Although many of the research citations describe studies that have been conducted in past decades, as well as studies that include children outside the United States, most of these studies' results are considered timeless and universal. Whether students develop their ideas in the United States or other countries, research indicates that many of these commonly held ideas are pervasive regardless of geographic boundaries and societal and cultural influences.

For some concepts, few or no formal research studies have been conducted to identify and describe commonly held ideas or difficulties students may have related to the concepts or ideas in the probe. For probes that lack formal research studies on commonly held ideas, this section may describe common ideas that were identified during the field testing of the probe or by teachers who have used the probe.

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

Suggestions for Instruction and Assessment

Uncovering and examining the ideas students bring to their learning is considered *diagnostic assessment.* Diagnostic assessment becomes formative assessment when the teacher uses the assessment data in a feedback loop to make decisions about instruction that will move students toward the intended learning target. These probes are intentionally labeled *formative assessment probes,* rather than *diagnostic probes,* because knowing the ideas students bring to their learning is not the primary goal or end point. Thus, for the probe to be used formatively, a teacher needs to think about how to choose or modify a lesson or activity to best address the ideas students bring to their learning or the misunderstandings that surface or develop during the learning process. A probe may also reveal whether students understand a concept or idea, which is a signal to the teacher that he or she can move forward with planned instruction. Making informed decisions about instruction is the essence of formative assessment.

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

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

As you become more familiar with the ideas your students have and the multifaceted factors that may have contributed to their misunderstandings, you will identify additional strategies that you can use to teach for conceptual change and understanding. This section also points out other related probes in the *Uncovering Student Ideas* series that can be modified or used as is to further assess students' conceptual understanding. It may also provide suggestions for ways to include science practices or crosscutting concepts to support three-dimensional learning when using a probe, especially when the probe is used again after the students have had the opportunity to develop their understanding, revisit their initial thinking, and construct a new explanation using scientific ideas. When applicable, this section includes safety notes for the proposed suggestions. These guidelines should be adopted and enforced to provide for a safer learning and teaching experience. Teachers should also review and follow local polices and protocols used within their school and school district. For additional safety information, read NSTA's "Safety in the Science Classroom" article (*http://static.nsta.org/pdfs/SafetyInTheScienceClassroom.pdf*) or visit the NSTA Safety Portal (*www.nsta.org/topics/safety*).

Related NSTA Resources

This section includes updated resources available through NSTA that are related to each probe, including journal articles, NSTA Press books, online NSTA Science Objects, and archived NSTA webinars. If you are an NSTA member, you have online access to all the NSTA journals referenced in this section, regardless of which journal you subscribe to. This list is just a sampling of the many NSTA resources that may be related to each probe. You can search for additional resources on the NSTA website at *www.nsta.org*.

References

The final section of the Teacher Notes is the list of references cited in the Teacher Notes.

Other Formative Assessment Resources

Now that you have the background on the probes and the Teacher Notes in this updated version of *Uncovering Student Ideas in Science, Volume 2,* remember that a probe is not formative unless you use the information from the probe to modify, adapt, or change your instruction so that students have the opportunity to learn the important scientific ideas. As a companion to this book and all the other volumes in this series, NSTA has co-published the books *Science Formative Assessment, Volume 1, Second Edition: 75 Practical Strategies for Linking Assessment, Instruction, and Learning* (Keeley 2016) and *Science Formative Assessment, Volume 2: 50 More Strategies for Linking Assessment, Instruction, and Learning* (Keeley 2015). In those books, you will find a variety of techniques to use along with the probes to facilitate elicitation, support metacognition, initiate investigation, encourage discussion, monitor progress toward conceptual change and understanding, encourage feedback, and promote self-assessment and reflection. In addition, these formative assessment classroom techniques (FACTs) provide opportunities for students to use science practices such as modeling, designing investigations, argumentation, and explanation construction.

If you are interested in developing your own formative assessment probes, the second edition of *Science Curriculum Topic Study: Bridging the Gap Between Three-Dimensional Standards, Research, and Practice* (Keeley and Tugel 2019) describes the process for developing probes that mirror research-identified commonly held ideas. Additionally, the sections of the Teacher Notes in this book are summaries of a curriculum topic study. This book is available through NSTA, and there is a website for further information: *www.curriculumtopicstudy2.org*.

A primary purpose of formative assessment is to break away from teaching and assessing disconnected facts and overemphasizing activities that do not take into account students' ideas. Formative assessment supports conceptual learning of science by helping teachers understand what students are thinking before, during, and after instruction. Because conceptual understanding is the underpinning of the *Uncovering Student Ideas* series, the NSTA book *Teaching for Conceptual Understanding in Science* (Konicek-Moran and Keeley 2015) is highly recommended as a resource to extend your learning. The book includes chapters on understanding the nature of students' thinking; instructional models and strategies that support conceptual change; and ways to link assessment, instruction, and learning. Also, check the NSTA website for opportunities for professional learning. Page Keeley and her colleagues frequently present sessions at NSTA conferences on using formative assessment probes, and they conduct professional learning workshops for NSTA and for school districts throughout the United States and internationally. Page can be contacted at *pagekeeley@gmail.com* and followed on Twitter (@CTSKeeley). You can find current information on the *Uncovering Student Ideas* series and professional learning opportunities at *www.uncoveringstudentideas.org*.

And finally, before you use the probes in this book, be sure to read the introduction (p. 1). Each book in this series includes an introduction that focuses on an aspect of using formative assessment probes. The introduction in this book focuses on linking instruction and assessment. It has been updated to reflect current shifts in instructional practice and formative assessment.

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About the Author

Page Keeley is the primary author of the *Uncovering Student Ideas* series. Her assessment probes and FACTs (formative assessment classroom techniques) are widely used by K–12 teachers, university professors, and professional development and science specialists throughout the United States and internationally. In 2013, Page retired from the Maine Mathematics and Science Alliance (MMSA), where she had been the senior science program director since 1996. At MMSA, she developed and directed projects in the areas of instructional leadership, coaching and mentoring, linking standards and research, and science and literacy. She has been a principal investigator and project director for three National Science Foundation–funded projects: the Northern New England Co-Mentoring Network (NNECN), Curriculum Topic Study (CTS), and Phenomena and Representations for Instruction of Science in Middle School (PRISMS). Today, she works as an independent consultant, speaker, and author and provides professional development to school districts and organizations in the areas of formative assessment, understanding student thinking, teaching science for conceptual understanding, and designing effective instruction.

Page is a prolific author and has written 22 national bestselling and award-winning books in science and mathematics education. Several of her books have received national distinguished awards in educational publishing. She has authored more than 50 journal articles and contributed to several book chapters. She also develops formative assessment probes for McGraw-Hill's middle and elementary school science programs.

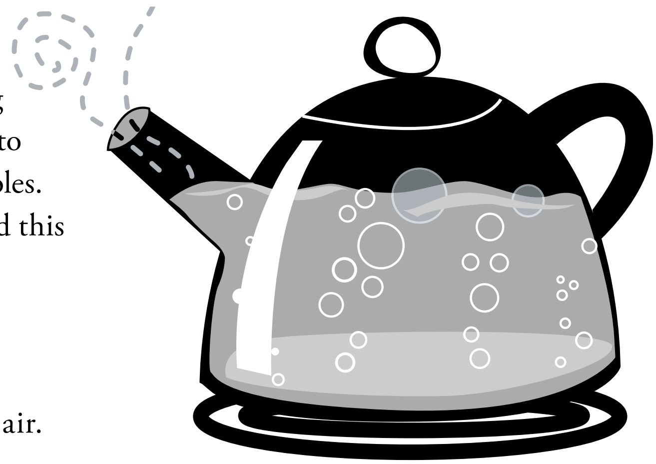
Before joining MMSA in 1996, Page taught middle and high school science for 15 years. At that time, she was an active teacher leader at the state and national levels, serving as president of the Maine Science Teachers Association and the National Science Teaching Association (NSTA) District II Director. She received the Presidential Award for Excellence in Secondary Science Teaching in 1992, the Milken National Distinguished Educator Award in 1993, and the AT&T Maine Governor's Fellowship in 1994. Since leaving the classroom in 1996, her work in leadership and professional development has been nationally recognized. In 2008, she was elected the 63rd president of NSTA. In 2009, she received the National Staff Development Council's (now Learning Forward) Susan Loucks-Horsley Award for Leadership in Science and Mathematics Professional Development. In 2013, she received the Outstanding Leadership in Science Education award from the National Science Education Leadership Association, and she received the NSTA Distinguished Service to Science Education Award in 2018. She has served as an adjunct instructor at the University of Maine, was a Cohort 1 Fellow in the National Academy for Science and Mathematics Education Leadership, was a science literacy leader for the AAAS/Project 2061 Professional Development Program, and has served on several national advisory boards.

About the Author

She has led science and STEM education delegations to South Africa (2009), China (2010), India (2012), Cuba (2014), Iceland (2017), Panama (2018), and Costa Rica (2019). Before entering the teaching profession, Page was a research assistant for immunogeneticist Dr. Leonard Shultz at the Jackson Laboratory of Mammalian Genetics in Bar Harbor, Maine. She received her BS in life sciences and pre-veterinary studies from the University of New Hampshire and her MEd in science education from the University of Maine.

In her spare time, she enjoys traveling, reading, making fiber art, and photography. She also dabbles in modernist cooking and culinary art. A Maine resident for almost 40 years, Page and her husband now divide their time between homes in Fort Myers, Florida, and Wickford, Rhode Island. You can contact Page through her websites at *www.uncoveringstudentideas.org* and *www.curriculumtopicstudy2.org* or via e-mail at *pagekeeley@gmail.com.* You can follow her on Twitter at @CTSKeeley or on Facebook through her *Understanding Student Thinking Through Formative Assessment* page.

What's in the Bubbles?



Hannah is boiling water in a glass tea kettle. She notices bubbles forming on the bottom of the kettle that rise to the top and wonders what is in the bubbles. She asks her family what they think, and this is what they say:

Dad: They are bubbles of heat.

Calvin: The bubbles are filled with air.

Grandma: The bubbles are an invisible form of water.

Mom: The bubbles are empty—there is nothing inside them.

Lucy: The bubbles contain oxygen and hydrogen that separated from the water.

Which person do you most agree with and why? ______________________
Explain your thinking.

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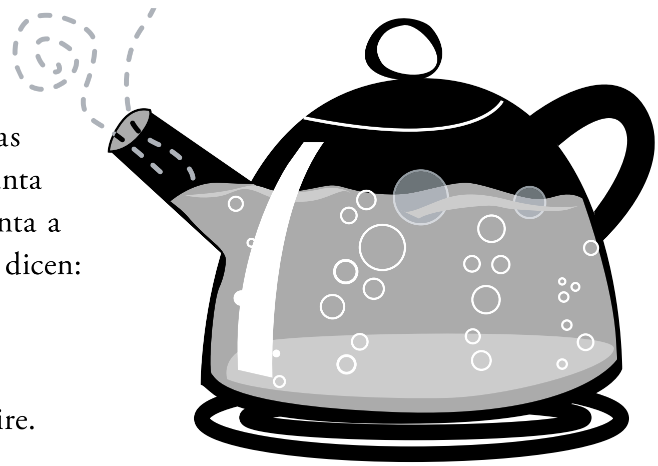
¿Qué hay en las Burbujas?



Hannah está hirviendo agua en una tetera de vidrio. Ella ve burbujas formándose en el fondo de la tetera. Las burbujas suben a la cima. Ella se pregunta qué hay en las burbujas. Ella le pregunta a su familia qué piensan y esto es lo que dicen:

Papá: Son burbujas de calor.

Calvin: Las burbujas se llenan de aire.

Abuela: Las burbujas son una forma invisible de agua.

Mamá: Las burbujas están vacías, no hay nada dentro de ellas.

Lucy: Las burbujas contienen oxígeno e hidrógeno que se separan del agua.

¿Con qué persona estás más de acuerdo y por qué? ___________________ Explica lo que piensas.

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What's in the Bubbles?

Teacher Notes

Purpose

The purpose of this assessment probe is to elicit students' ideas about particles during a phase change. The probe is designed to find out if students recognize that the bubbles formed when water boils are the result of liquid water changing into water vapor.

Type of Probe

Friendly talk

Related Concepts

Phase change, boiling, water vapor, gas, properties of matter

Explanation

The best answer is Grandma's: The bubbles are an invisible form of water. This invisible water is called water vapor, a gaseous form of water that is not visible. Sometimes it is called *steam.* However, steam can contain very small droplets of liquid water, which allows it to sometimes be visible. When water is heated, the energy supplied to the system results in an increase in molecular motion. If heated enough, the molecules have so much energy that they can no longer remain loosely connected and thus start to slide past one another. The increased energy now allows the attractive forces between water molecules to be overcome, and they form an "invisible" gas in the form of water vapor. Because the molecules in the gas phase are so much farther apart than in the liquid phase, they have a much lower density, are more buoyant (causing them to "bubble up"), and escape into the air. The bubble is the invisible water vapor that rises to the surface and escapes from the liquid.

Curricular and Instructional Considerations

Elementary Students

At the elementary level, students have experiences observing changes in state. The idea of change is connected to physical properties of materials by subjecting materials to heating and cooling. Water is often used as a familiar substance for observing phase changes. In the primary grades, the focus is primarily on solids and liquids. Elementary students describe change in states of water from the solid to liquid to gas phase and vice versa, although the change from liquid to gas phase is an abstract idea developed more fully in upper elementary grades. Children develop ideas about bubbles early on through their everyday experiences, so it is not too early to ask students their ideas about particles and bubbles. However, it is best to hold off on expecting a scientific explanation until middle school when students learn about kinetic molecular theory.

Middle School Students

In middle school, students use the kinetic molecular theory to explain what happens at the particle level during phase changes. They compare evaporation of a liquid under ordinary ambient conditions as well as in situations where increased application of heat is involved, such as boiling water. They are encouraged to use models to explain everyday phenomena such as the water boiling in a kettle.

High School Students

At the high school level, students connect ideas about energy to phase change. They develop the idea that the continuous addition of energy during the heating of a liquid overcomes the attractive forces between molecules of a liquid during the liquid-to-gas transition. They understand that a chemical change in which the water molecules break down into simpler substances does not take place.

Administering the Probe

This probe can be used with students in grades 3–12. If used with elementary students, remove the last answer choice. You may wish to use visual props for this probe. Bring a beaker (or some other clear, boiling-safe container) of water or to a full boil so that students can see the bubbles forming and rising to the surface. Be sure students are wearing safety goggles and are not too close to the heat source if they are observing the boiling up close. Continue to heat the boiling water as students respond to the probe and explain their thinking.

Related Disciplinary Core Ideas (NRC 2012; NGSS Lead States 2013)

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

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

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

- Gases and liquids are made of molecules or inert atoms that are moving about relative to each other.
- In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide.

9–12 PS1.A: Structure and Properties of Matter

- The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.

Related Research

- Because students cannot observe gases, they often do not think of a gas as being the same type of matter that makes up solids and liquids (Mayer and Krajcik 2017).

- It has been well documented that secondary students think the gas produced from boiling water is a mixture of hydrogen and oxygen gas (Mayer 2011).
- Students' understanding of boiling precedes their understanding of evaporation from surfaces such as dishes and roads. In a sample of students ages 6–8, 70% understood that when water boils, vapor comes from it and that the vapor is made of water. However, the same students did not recognize that when a wet surface dries, the water turns to water vapor (Driver et al. 1994).
- An analysis of middle school students' test results showed that explaining changes of state in molecular terms was among the most difficult tasks for many students. Before instruction, almost none of the students in the study could give molecular explanations of changes of state. After instruction, significantly more students demonstrated understanding, although many students still had difficulties understanding changes of state in molecular terms. For example, one student thought that when molecules are in the water, they move farther apart, they move faster, and then they turn into air (evaporate) (Lee et al. 1993).
- Osborne and Cosgrove (1983) studied New Zealand students ages 8–17. An electric kettle was boiled in front of the students so they could see the bubbles in the boiling water. They were asked what the bubbles were made of. Heat, air, oxygen, hydrogen, and steam were common replies, with the percentage of students answering steam increasing between ages 12 and 17. However, most 17-year-old students thought that water can be split into its component elements by heating, or that heat is a substance in its own right, or that air is contained in water. Osborne and Cosgrove attribute the idea that water molecules break up to knowing the formula of water is H_2O, so naturally it comes apart.

Suggestions for Instruction and Assessment

- Use the phenomenon of bubbles to explain what happens to water molecules during a change in state from a boiling liquid to a gas. Extend the probe by having students use the science practice of developing and using models to explain what is happening at the particle level as the water forms bubbles and bubbles rise to the surface and burst.
- Use the formative assessment classroom technique (FACT) called BDA drawing to explain what is happening as water boils (Keeley 2015). This type of model involves three drawings: *B*-before, *D*-during, and *A*-after. For *B,* have students draw their particle model of matter to show molecules in the liquid state before the water is heated. For *D,* they should show what is happening to the molecules during heating and as bubbles begin to form. For *A*, they should show what is happening when the bubbles rise to the surface and burst. Have students share and explain their representations. As they share, carefully note how students get to the bubble stage—do the bubbles appear spontaneously in their drawings, or does the act of drawing help them make sense of what is happening to the water to form bubbles?
- Extend the probe by asking students to use the crosscutting concept of cause and effect to explain the phenomenon.
- Students may have trouble accepting that water vapor is in the bubbles if they do not understand the idea that water vapor is invisible. Help students contrast the concept of invisible water vapor with visible water

in the air, such as clouds and fog, which are made of tiny suspended droplets rather than water molecules in the form of a gas spread far apart.

- Ask students to observe and describe what happens to the water level as the water boils. Encourage them to explain where the water went. How was it able to leave the glass container? Probe students to consider how the bubbles were involved in decreasing the water level. Challenge students who had the idea that the bubbles were air or nothing to explain how their model could account for the decreased water level.
- Consider how to present phase changes as reversible. Allow students to see heating and cooling cycles for themselves, so they can realize that phase changes do not result in a new substance being formed. This cycle may help them see that the water escapes as a gas in the bubbles and can be recovered again through cooling.
- By fifth grade, students should be using terminology such as *water vapor.* Using the correct terminology combined with an understanding that "invisible" water is in the air may help them overcome the idea that water changes into air rather than remaining the same substance but in a form that you cannot see.
- Be cautious when using the term *steam* with students to describe the gas or vapor form of water. What students are actually seeing over the boiling water when they refer to steam is a wispy mist—it is visible because it is water in a gaseous state that also contains tiny water droplets. Those tiny droplets scatter light at their surfaces, allowing us to "see" the "steam" in much the same way that we can see fog or clouds. The common use of the word *steam* is different from the way scientists or engineers use the word *steam*. To scientists and engineers, steam and vapor are both invisible forms of water in the gaseous state. However, when students (and often teachers) use the word *steam* in the context of this probe, they are usually referring to the visible substance that forms above the boiling water—a gas. Technically, this common use of the word *steam* is incorrect because a gas is invisible. Use the term *water vapor* (not *steam*) to describe the invisible, gaseous form of water. Explicitly point out that clouds and fog are made up of tiny droplets of water in order to distinguish forms of water in the air that we can see from forms we cannot see, such as water vapor. After they have grasped the idea that substances in the gaseous state are not visible, older students may be introduced to the scientific use of the word *steam* and compare it with how it is used in our everyday language.

Related NSTA Resources

Cavallo, A. M., and P. Dunphey. 2002. Sticking together: A learning cycle investigation about water. *The Science Teacher* 69 (8): 24–28.

Dasgupta, A. 2008. Water in disguise: Demonstrations exploring water as a solid, liquid, or gas. *Science and Children* 46 (4): 28–31.

Duncan, R., J. Krajcik, and A. E. Rivet. 2017. *Disciplinary core ideas: Reshaping teaching and learning.* Arlington, VA: NSTA Press.

NGSS Archived Webinar: *NGSS* Core Ideas—Matter and Its Interactions, *http://learningcenter.nsta.org/products/symposia_seminars/NGSS/webseminar27.aspx.*

Pentecost, T., S. Weber, and D. Herrington. 2016. Connecting the visible world with the invisible: Particulate diagrams deepen students' understanding of chemistry. *The Science Teacher* 83 (5): 53–58.

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