Uncovering STUDENT IDEAS About ENGINEERING and TECHNOLOGY

32 NEW Formative Assessment Probes

PAGE KEELEY
CARY SNEIDER
MIHIR RAVEL

nsta Press
National Science Teaching Association

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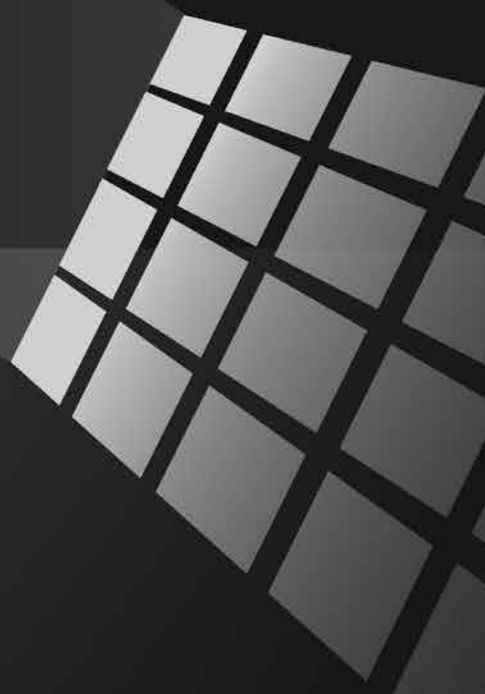

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Foreword

Classroom formative assessment is the most powerful form of assessment that teachers have at their disposal to elicit and analyze evidence of student thinking and, consequently, to use this evidence to adjust learning strategies accordingly. When used properly, formative assessment provides the teacher with a constant source of information that can be used during the course of and at the point of instruction. Similar to a GPS device, formative assessment is a means to keep the learner "on the path" by using student feedback as information to guide and adjust instruction. The probes detailed within *Uncovering Student Ideas About Engineering and Technology: 32 New Formative Assessment Probes* provide opportunities for students to engage in self-assessment and feedback from their peers in the areas of engineering and technology.

This book is especially timely, since 43 states and the District of Columbia have now adopted or adapted science standards based on either the *Next Generation Science Standards* (*NGSS*; NGSS Lead States 2013) or *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (the *Framework*; NRC 2012). These new state standards, which provide guidance for the development of curriculum, instruction, and assessment, call for *all students,* "over multiple years of school, [to] actively engage in scientific and engineering practices and apply crosscutting concepts to deepen their understanding of the core ideas," both in the traditional disciplines of science and in the field of engineering (NRC 2012, p. 10).

Uncovering Student Ideas About Engineering and Technology supports the vision of the *NGSS* and the *Framework* by providing educators with a variety of research-based formative assessment probes to uncover their students' prior knowledge and misconceptions in the areas of engineering and technology. This book not only offers tools for teachers to use to uncover their students' thinking, but also provides a foundation to support the importance of engineering and technology in the development of student problem-solving skills and innovative application of science concepts.

The authors of this book represent a "perfect storm" of expertise. Page Keeley is a prolific writer and researcher in the area of science formative assessment. Cary Sneider was a member of the *Framework* and *NGSS* writing teams and has worked extensively with teachers nationwide to bring engineering and design into the classroom. As a distinguished engineer, technologist, and university educator, Mihir Ravel affords his expertise through the creation of authentic, problem-based scenarios and situations addressed through the probes. The product of the collaboration of these talented experts provides the readers of this book with a practitioner-friendly guide to infusing engineering and technology into classrooms through research-based formative assessment prompts and probes.

I am honored to be asked to write the foreword for this book. Supporting educators in the implementation of three-dimensional science and engineering standards is mission critical. Teachers are the key to the positive change we seek in preparing our students to become a STEM literate citizenry. Toward that end, *Understanding Student Ideas About Engineering and Technology* goes far in supporting educators through its teacher-centered approach to engaging students and soliciting evidence of learning within the domains of engineering and technology.

—Peter J. McLaren
Executive Director
Next Gen Education, LLC

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NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states.* Washington, DC: National Academies Press. *www.nextgenscience.org/next-generation-science-standards*.

Preface

This is the 12th book in the *Uncovering Student Ideas in Science* series. Like the other books in this 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 as well as to identify misunderstandings students develop during instruction that may go unnoticed by the teacher. Each probe is carefully researched to develop distracters that mirror commonly held ideas students have about the key ideas or practices. 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 since alternative ideas that go unchallenged often follow students from one grade to the next, right into adulthood.

Engineering and Technology Probes

This book expands on the other 11 books in the *Uncovering Student Ideas* series, whose scope has been the traditional science disciplines, to help teach the emerging STEM areas of Engineering and Technology as exciting complements to Science and Mathematics. The focus is on the disciplinary content of engineering and technology, the use of engineering practices, and connections to crosscutting concepts that support an understanding of engineering and technology. As we discuss later in the book's Introduction, it is both important and empowering that the great majority of skills that students develop through engineering activities are the same as those they develop in science.

Before using the probes, please read the Introduction (pp. 1–6). The Introduction provides information on why a K–12 understanding of engineering and technology is important today not only for producing future engineers, but also for building lifelong creative and systematic problem-solving skills for students in all career paths. It describes how standards and curriculum have changed to reflect this importance. It clarifies the differences between engineering and technology and how they are inextricably linked. It provides information on how to use the probes formatively. Finally, it provides suggestions for additional resources to expand your knowledge of formative assessment as well as engineering and technology.

Four Sections of Probes

Following the Introduction is the collection of 32 formative assessment probes. These probes are organized into four sections: Section 1: What Is Technology (seven probes); Section 2: What Is Engineering? (nine probes); Section 3: Defining Problems (seven probes); and Section 4: Designing and Testing Solutions (nine probes). Each section includes a matrix that lists related key ideas and suggested grade levels for each probe. Following the matrix is a short description of teaching and learning considerations that provide additional information for refining curriculum and instruction.

Two Versions of 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.

Preface

Teacher Notes

Each of the 32 formative assessment probes in this book includes detailed background information for teachers. The Teacher Notes are a vital component of this book and should always be read before using a probe. The features of the Teacher Notes that accompany each probe are as follows:

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 or practice 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 consist of two parts. The first part is a selected answer choice and the second part involves constructing an explanation for the selected answer choice. Similar to the crosscutting concept of structure and function, in which structure often determines function, the format of a probe is related to how a probe is used. The book uses the following probe types:

- *Friendly Talk Probe:* This format uses the context of a group of friends having a conversation. Answer choices are the statements each friend makes. The probe models the importance of sharing ideas through talk and shows how people often have very different ideas.
- *Justified List Probe:* In this format, students select answer choices from a list of examples and non-examples. It shows whether students can transfer what they know or have learned to other examples or contexts and whether they can develop generalizations.
- *Opposing Views Probe:* In this format, two people have opposite or very different ideas. Selecting who to agree with involves carefully examining each statement or argument.
- *Follow the Dialogue Probe:* This format is similar to a friendly talk probe, except students follow a back-and-forth conversation in language typical of ways students converse with others.
- *Always, Sometimes, Never Probe:* This format requires students to evaluate statements to decide if they are always true or apply, sometimes true or apply, or never true or apply and then justify their answer with evidence. Selecting *sometimes* provides an opportunity to consider exceptions.
- *Draw a Picture Probe:* Unlike the format of the other probe types, students do not select a response in this probe. Instead, students draw a picture, which provides insight into their conceptual model or ways of perceiving an object, process, or situation.
- *Sequencing Probe:* This format involves students putting statements, procedures, steps, or ideas into a logical sequence.
- *Quantifying Probe:* This format involves identifying how many examples of a concept, procedure, or practice are in a given scenario.
- *Comparison Chart Probe:* This format presents students with data used to make

comparisons between the different categories of information in the chart.

To learn more about each of these probe types as well as formative assessment classroom techniques (FACTs) that can be used with these formats, see *Science Formative Assessment, Volume 1* and *Volume 2* (Keeley 2016; Keeley 2015), both available through NSTA Press.

Related Key Ideas

Each probe is designed to target one or more related key ideas that develop across multiple grade levels. A key idea represents an important aspect of understanding engineering and technology.

Explanation

The *best* answer choice is provided in this section. *Best answer* is used rather than *correct* or *right answer* because the probes are not 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 engineering as engineers initially share their best thinking about a design or problem situation and modify their ideas and designs as they gather more information.

A brief content explanation is provided to help teachers understand the engineering and technology ideas and practices that underlie the probe and clarify misunderstandings students (and teachers) may have related to the content. The explanations are brief and not meant to give detailed engineering and technology knowledge. They are provided to support teachers' basic knowledge of engineering and technology. Teachers with limited coursework or professional development in technology and engineering design or who are new to teaching engineering should build on these probes to expand their content knowledge. The explanations are carefully written to avoid highly technical language and complex descriptions so that a teacher does not have to specialize in engineering to understand the explanation. At the same time, the challenge is to not oversimplify the engineering concepts, key ideas, and practices. The probe explanations are carefully constructed to provide the concise information a teacher would need to understand and respond to their students' thinking.

Administering the Probe

Intended grade levels for using the probe and suggestions, including modifications, for administering the probe to students are provided. Unlike summative assessments, the probes are not specific to a single grade. They are designed to be used across grade spans even if a key idea was previously taught. Probes help teachers check for understanding of precursor ideas before introducing new ideas. They also activate student thinking by connecting their new learning to prior knowledge as well as engage students in discussions in which previous and new ideas are shared.

Connections to the Three Dimensions (NRC 2012; NGSS Lead States 2013)

A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (the *Framework*; NRC 2012) is the primary source document, which has informed the development of many recent state standards, including the *Next Generation Science Standards* (*NGSS*; NGSS Lead States 2013), and 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 general disciplinary core ideas (DCIs), science and engineering practices (SEPs), and crosscutting concepts (CCCs) from the *Framework* and *NGSS* that are related to the probe.

Because the probes are not designed to be summative assessments, this section is not considered an alignment, but rather identifies ideas, practices, and concepts that are related in some way to the probe. Additional ways to support the use of the DCIs, SEPs, and CCCs are included in the Suggestions for Instruction and Assessment section.

Related Research

Each probe is informed by research when available. Research on K–12 students' ideas about engineering and technology is relatively new; therefore, there are fewer studies cited in this section compared with other books in the *Uncovering Student Ideas* series. However, consider using these probes to do your own classroom research on commonly held ideas about engineering and technology, and sharing your results with colleagues through presentations or articles in journals published by NSTA, the International Technology and Engineering Educators Association (ITEEA), and other STEM organizations.

One research article frequently cited in this book is "The Informed Design Teaching and Learning Matrix" (Crismond and Adams 2012). This meta-literature review connects research findings on how people design with what K–16 teachers need to understand and do to build student capability in engineering design and support learning through engineering design activities.

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 a 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.

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. 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 might surface or develop during the learning process. A probe may also reveal whether students understand a key idea or use of an engineering practice, which can help the teacher move forward with planned instruction.

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 materials you have available, and the diverse learners you have in your classroom.

The suggestions provided in this section have been gathered from the wisdom of teachers, the knowledge base on effective teaching, research on specific strategies used to address commonly held ideas and conceptual difficulties, and the experiences of the authors. 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 the important ideas, concepts, and practices related to engineering and technology. It may be as simple as realizing that you need to provide a relevant, familiar problem-solving 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 instructional strategies, resources, and 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 understanding.

References

The final section of the Teacher Notes is the list of references. References are provided for the publications cited in the Teacher Notes.

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Dedication

This book is dedicated to the memory of two individuals whose vision and cooperative spirit have helped bring together the worlds of K–12 technology and engineering education with the world of science education:

William E. Dugger, Jr., who led the development of the *Standards for Technological Literacy,* the first set of educational standards for technology and engineering; and

Alan J. Friedman, who helped advance the integration of science inquiry and engineering design in schools and beyond the school day through a lifetime of accomplishment.

About the Authors

Page Keeley is the primary author of the *Uncovering Student Ideas in Science* 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. Page is "retired" from the Maine Mathematics and Science Alliance (MMSA) where she had been the senior science program director since 1996, directing 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 of three National Science Foundation (NSF)–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 providing 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 of 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 numerous journal articles and contributed to several book chapters. She also develops formative assessment probes for McGraw-Hill's middle and elementary school science programs.

Prior to 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 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 (NSELA), 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 Authors

She has led science/STEM education delegations to South Africa (2009), China (2010), India (2012), Cuba (2014), Iceland (2017), Panama (2018), and Costa Rica (2019).

Prior to 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 travel, reading, fiber art, and photography, and 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 Uncovering Student Ideas in Science and Mathematics page.

Cary Sneider is a visiting scholar at Portland State University, and a consultant for the STEM Next Opportunity Fund and the Stephen D. Bechtel Jr. Foundation, both charitable foundations that support STEM education. He also continues to be active as a consulting author for Houghton Mifflin Harcourt's Science Dimensions K–8 series, and other writing and curriculum development projects.

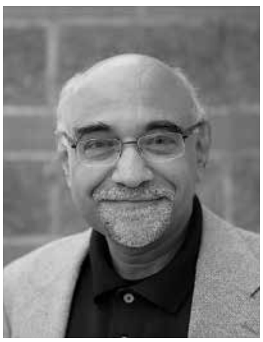
While studying astrophysics at Harvard College in the 1960s, Cary volunteered to teach in an Upward Bound program and discovered his real calling as a science teacher. After teaching middle and high school science in Maine, California, Costa Rica, and Micronesia, he settled for nearly three decades at Lawrence Hall of Science in Berkeley, California, where he developed skills in curriculum development and teacher education.

Starting in 1997, Cary spent 10 years as vice president for programs at the Museum of Science in Boston, where he led development of a high school engineering curriculum, Engineering the Future: Science, Technology, and the Design Process. In 2007, he moved to Portland, Oregon, to take a position as associate research professor at Portland State University, where for the next decade he taught courses in research methodology to more than 80 candidates in a Master of Science Teaching (MST) program. During this period, he led a team in revising science education standards for the state of Washington; served as a consultant to the National Research Council to help create *A Framework for K–12 Science Education: Practices, Core Ideas, and Crosscutting Concepts*; led the engineering team that helped craft the *Next Generation Science Standards: For States, by States*, which were released in 2013; and from 2011 to 2019 served as a member of the National Assessment Governing Board, which sets policy for the National Assessment of Educational Progress (NAEP), also known as The Nation's Report Card.

In 1997, Cary received the Distinguished Informal Science Education award from the National Science Teaching Association (NSTA). In 2003, he was named National Associate of the National Academy of Sciences, and in 2018 he received the Robert H. Carleton Award, NSTA's highest recognition.

Over his career, Cary has directed more than 20 federal, state, and foundation grant projects. He has coauthored two books on STEM education, edited the three-volume

Go-To Guide to Engineering Curricula; authored *Jake and the Quake*, a work of historical fiction for middle school students; and authored several book chapters and numerous articles. He earned a BA in astronomy at Harvard College, and a California Secondary Teaching Credential, MA, and PhD in science education at the University of California, Berkeley.



Mihir Ravel is a noted technology leader in high-performance electronic systems and ultrafast scientific measurements, and a pioneer in design-centric approaches to integrated STEM education.

After a fortunate corporate research and development (R&D) career, Mihir now divides his time between public service in K–12 engineering and science education and advising entrepreneurs and innovators focused on emerging opportunities for social good. He has traveled extensively in developed and developing countries as a speaker and strategic adviser to both public and private institutions. He has been an international advisor to various federal and state agencies on STEM and design education; has served on the advisory boards for EDN magazine, the Austin Technology Council, the Massachusetts Institute of Technology (MIT) Enterprise Forum, and The Indus Entrepreneurs (TiE); and is an adviser to various early stage private ventures and nonprofit educational initiatives and foundations.

Mihir has been an invited faculty collaborating on design-centric learning methods with leading universities in Europe, Asia, and the United States, with a special emphasis on exposing students to the power of engineering design and entrepreneurship for making a better world. A highlight of his university collaborations was helping incubate the Affordable Design and Entrepreneurship (ADE) program at Olin College of Engineering, which was recently recognized alongside MIT as one of the top two global leaders in engineering education. The ADE program is a transformational educational initiative aimed at the problems of global poverty, and immerses student teams in creating social ventures using an engineering design process as a critical tool for improving the daily lives of the world's poor.

To build on his lessons learned in advancing university education, Mihir has recently been applying those experiences toward design-based approaches to K–12 STEM education. He has partnered with school districts, universities, and foundations in the Pacific Northwest to develop engineering and design–integrated STEM curricula at the high school level. He is a coauthor with Cary Sneider and others of the second edition of *Engineering the Future: Science, Technology, and the Design Process,* developed in collaboration with the Boston Museum of Science and Activate Learning, as an introduction to engineering design for *all* students, not just those interested in engineering careers. He is also an adviser to Houghton Mifflin Harcourt on K–12 science.

Complementing his university experience, Mihir's STEM education work builds on lessons learned from three decades of leading high-tech R&D organizations in a range of technologies spanning ultrafast electronics, optical and wireless communications, digital multimedia, environmental monitoring, and smart sensor networks. He has led research collaborations with leading university and government labs with support from the National Science Foundation, Department of Energy, and Department of Defense. He served as the first vice president of technology for National Instruments, a global pioneer in tools for measurement, machine automation, and system design. Previously, he was a Technology Fellow and head of Strategic Technologies for Tektronix, a global leader in high performance instrumentation and electronic design. His perspective that STEM education should be a combination of both creative and structured thinking has been shaped by his early training in physics, electrical engineering, and computer science at MIT.

Introduction

What Are Formative Engineering and Technology Probes?

The subject of *Uncovering Student Ideas About Engineering and Technology: 32 New Formative Assessment Probes* highlights the biggest change in the content of K–12 science education in more than a century—that engineering be taught alongside the traditional disciplines of life, physical, and Earth and space science. Although initially it may seem like technology and engineering are two different subjects, they are actually two sides of the same coin. Technology is the designed world—everything around us that has been created by people; engineering is the process of inventing and improving technologies.

Readers who are familiar with the other 11 books in the *Uncovering Student Ideas* series will already know how to use these probes. If not, you'll catch on as soon as you try one with your students. Each probe is a conversation-starter, designed to uncover your students' pre-existing ideas. They become formative when you use the information about your students' thinking to make informed instructional decisions that will help them modify or refine their initial ideas.

Why Technology and Engineering Design Are Essential for ALL Students

There are very good reasons why technology and engineering have risen to prominence in K–12 education. In 1950, the global population was about 2.5 billion people, by 2015 it had more than tripled to 7.3 billion, and estimates project it to be about 10 billion by 2050 (United Nations Population Division, *https://population.un.org/wpp*). How will future generations meet the growing needs of this population? All students must understand that engineering and technology are powerful tools to meet our escalating needs for affordable health care and housing, clean energy, efficient transportation, nourishing food, and clean water. Just as learning how the natural world functions (science) is critical to understanding these problems, equally so is the process of solving them through engineering.

In today's modern society, in which we are all surrounded by complex technologies and expected to make technological decisions on a daily basis as consumers, workers, and citizens, it is essential for everyone to become technologically literate and to be able to apply user-centered design approaches to solving problems in their daily lives. That is why technology and engineering education are important for ALL students, not just those who will become tomorrow's engineers.

Changes in Science Education Standards

The International Technology and Engineering Educators Association (ITEEA) has been a pioneer in developing K–12 standards for ***all students*** to learn about engineering and technology. *Standards for Technological Literacy: Content for the Study of Technology* (ITEEA 2007) identified 20 standards: seven on the nature of technology and its relationship to society; six on technology and engineering abilities; and seven on modern civilization's major technological systems, including medical, agricultural, transportation, and energy systems.

Introduction

Each standard includes benchmarks for grades K–2, 3–5, 6–8, and 9–12, to guide the work of teachers and curriculum developers. Many of these ideas and capabilities have since been incorporated in *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (the *Framework*; NRC 2012) and the subsequent *Next Generation Science Standards* (*NGSS*; NGSS Lead States 2013).

At the time this book was being written, a great number of states in the United States have adopted or adapted science education standards that include engineering as a core subject at the same level as life science, physical science, and Earth and space science. In addition to having its own set of core ideas and performance expectations in the new standards, engineering as a practice is to be fully integrated with the other science disciplines. Although engineering has long been a part of science standards and curricula, in the past it has usually been seen as a way to reinforce science concepts by expecting students to apply what they learned in more traditional science classes. Also, it has been used primarily to teach topics in physics, such as force and motion, energy, and waves, and only rarely applied to other fields of science. In contrast, the vision of engineering in the *Framework* (NRC 2012) and the *NGSS* (NGSS Lead States 2013) is that students are expected to be able to apply an engineering design process to all fields of science, to understand how science and engineering drive each other forward, and to solve real-world problems by considering the ways that science, technology, and engineering interact with society and the natural world. As explained in volume 2 of the *NGSS* (NGSS Lead States 2013, p. 3):

> *The rationale for this increased emphasis on engineering and technology rests on two positions taken in the* Framework. *One position is aspirational, the other practical.*
>
> *From an aspirational standpoint, the* Framework *points out that science and engineering are needed to address major world challenges such as generating sufficient clean energy, preventing and treating diseases, maintaining supplies of food and clean water, and solving the problems of global environmental change that confront society today. These important challenges will motivate many students to continue or initiate their study of science and engineering.*
>
> *From a practical standpoint, the* Framework *notes that engineering and technology provide opportunities for students to deepen their understanding of science by applying their developing scientific knowledge to the solution of practical problems. Both positions converge on the powerful idea that by integrating technology and engineering into the science curriculum, teachers can empower their students to use what they learn in their everyday lives.*

Not surprisingly, it is taking time to integrate engineering into school curricula. Results from the *Report of the 2018 National Survey of Science and Mathematics Education* highlight this issue (Banilower et al. 2018). Among elementary teachers, most feel well prepared or very well prepared to teach life science (75%), Earth science (71%), and physical science (59%). However, only 9% feel well or very well prepared to teach engineering. And although middle school and high school science teachers are generally more confident than elementary teachers, only 6% of middle school teachers and 7% of high school science teachers are very confident in their abilities to teach engineering. Keeping in mind that the *NGSS* includes engineering as a fourth discipline, note that only 46% of high schools offer engineering courses, compared with 97% that offer biology, 94% that offer chemistry, 84% that offer physics, and 59% that offer Earth science. On the other hand, that is a big improvement since the last survey in 2012, when only 24% of high schools offered courses in engineering (Banilower et al. 2013).

This book is intended to speed and deepen the process of integrating engineering into the school curriculum by providing teachers with tools to assess their students' understanding of technology and engineering, using the method of "assessment probes" exemplified in the *Uncovering Student Ideas* series. This introduction provides a brief orientation to this set of probes by explaining the authors' perspective on the meaning of technology and engineering (and why technology and engineering are essential for all students to learn), how the probes are organized into four sections, and additional NSTA resources to extend your learning.

The Meaning of Technology and Engineering

Technology and engineering are intimately related, but they are not the same. The *Framework* describes the relationship between these terms as follows:

> *In the K–12 context, science is generally taken to mean the traditional natural sciences: physics, chemistry, biology, and (more recently) earth, space, and environmental sciences. … We use the term engineering in a very broad sense to mean any engagement in a systematic practice of design to achieve solutions to particular human problems. Likewise, we broadly use the term technology to include all types of human-made systems and processes—not in the limited sense often used in schools that equates technology with modern computational and communications devices. Technologies result when engineers apply their understanding of the natural world and of human behavior to design ways to satisfy human needs and wants. (NRC 2012, pp. 11–12)*

Since many teachers who use these probes are likely to be science teachers, it is important to point out that the great majority of skills that students develop through engineering activities are the same as those they develop in science. The eight science and engineering practices identified in the *Framework* and *NGSS* are the same, whether students are exploring the natural world or improving the designed world. The major difference is in the goal of the two activities. The aim of science is to understand the natural world, while engineering aims to solve a problem or meet a need. When engaged in solving a problem, it is essential for students to learn about people's needs and desires that require and inspire the development of new and improved technologies. Doing so requires persistence and logical thinking, coupled in equal measure with imagination and compassion for the people in need. Engineering is more than applied science. It is a creative art grounded in compassion for serving society and protecting the natural world.

Organization of This Book

The probes in this book are divided into the following four sections.

- **Section 1: What Is Technology?** Before students learn about engineering, they must recognize that they are surrounded by technologies that have been designed and improved by engineers. This section will reveal your students' understanding of the nature and purpose of technologies and how technologies change over time. Other probes in this section focus on technological processes and the critical idea of systems.

- **Section 2: What Is Engineering?** This section begins with a series of probes about students' initial ideas concerning who can become an engineer and what motivates engineers. Other probes reveal students' ideas about how engineers work together in teams, the similarities between science and engineering, and the nature of engineering—spanning the range from creative to logical, imaginative to systematic, and scientific to mathematical.
- **Section 3: Defining Problems.** Beginning with a very important foundational probe about the basics of an engineering design process (EDP), this group of probes is designed to reveal your students' understanding of the critical importance of defining a problem before beginning to solve it. Probes include the practice of defining the problem, determining who really needs the solution, whether or not the problem can be solved through engineering, and how to define the problem in terms of criteria and constraints. It ends with a probe about the value of research to take advantage of prior successes and user feedback.
- **Section 4: Designing and Testing Solutions.** Once your students have defined the problem, how do they go about designing a solution? The first part of this section includes probes intended to help you refine instruction to address your students' current thinking about the process of brainstorming new ideas, drawing ideas from nature, considering the affordability and sustainability of designs, and the process of sorting through initial ideas to choose the one that is most promising, making trade-offs, and using science and math to design a successful solution.

  Designs can only be improved and verified to work when they've been tested—testing is actually the phase of an EDP where engineers (and students!) often learn the most about a design: what's working, what isn't working, and why. The second part of this section begins with a sequence of probes concerning the different kinds of models used in comparing and developing designs, from sketches and technical drawings, to computer simulations and physical prototypes. Other probes concern the process of choosing the best solution, the pervasive role of science and math in engineering design, and iterating and optimizing the design to make it better.

Although the probes in this book do not cover every aspect of engineering and technology, the entire collection should provide sufficient scope to help you develop a fairly in-depth understanding of your students' current vision of engineering design—not only as a school subject that they are expected to learn, but also to learn the skills of systematic problem solving and teamwork needed to solve the challenges facing our world, as well as ones that may arise in their own lives.

Additional NSTA Resources

NSTA has numerous resources to support your use of the probes in this book. In addition to the NGSS@NSTA Hub (*https://ngss.nsta.org*), the following resources may also be useful.

Formative Assessment Resources

Keeley, P. 2014. *What are they thinking? Promoting elementary learning through formative assessment.* Arlington, VA: NSTA Press.

Keeley, P. 2015. *Science formative assessment, volume 2: 50 more strategies for linking assessment, instruction, and learning.* Thousand Oaks, CA: Corwin Press (a co-publication with NSTA Press).

Keeley, P. 2016. *Science formative assessment, volume 1: 75 practical strategies for linking assessment, instruction, and learning.* 2nd ed. Thousand Oaks, CA: Corwin Press (a co-publication with NSTA Press).

Keeley, P. 2019. Guest editorial: Formative assessment in the science classroom: What it is and what it is not. *Science and Children* 56 (9): 8–9.

Keeley P. *Uncovering Student Ideas in Science Series. www.nsta.org/publications/press/uncovering.aspx.* These probes can be used to assess students' ideas about disciplinary content knowledge used in an engineering problem.

Science and Children Journal (2010–present). Page Keeley writes a monthly column titled "Formative Assessment Probes: Promoting Learning Through Assessment." While written for the elementary journal, the suggestions in the column apply to K–12. There are more than 60 articles in this collection (*www.nsta.org/elementaryschool*).

To learn more about professional development support for formative assessment, visit the *Uncovering Student Ideas* website at *www.uncoveringstudentideas.org.*

Engineering and Technology Resources

Kanter, D. E., and D. P. Crismond. 2017. Core idea ETS1: Engineering design. In *Disciplinary core ideas: Reshaping teaching and learning,* ed. R. Duncan, J. Krajcik, and A. Rivet, 245–262. Arlington, VA: NSTA Press.

Keeley, P., and J. Tugel. 2019. *Science curriculum topic study: Bridging the gap between three-dimensional standards, research, and practice.* 2nd ed. Thousand Oaks, CA: Corwin Press. This book includes several curriculum topic study (CTS) guides for understanding disciplinary core ideas about engineering; engineering practices; and connections to science, technology, and society.

Schwarz, C. V., C. Passmore, and B. J. Reiser, eds. 2017. *Helping students make sense of the world using next generation science and engineering practices.* Arlington, VA: NSTA Press.

Sneider, C. 2012. Core ideas of engineering and technology. *The Science Teacher* 79 (1): 32–36.

Sneider, C. 2017. Core idea ETS2: Links among engineering, technology, science, and society. In *Disciplinary core ideas: Reshaping teaching and learning,* ed. R. Duncan, J. Krajcik, and A. Rivet, 263–277. Arlington, VA: NSTA Press.

Willard, T. 2020. *The NSTA atlas of the three dimensions.* Arlington, VA: NSTA Press. This resource includes several conceptual mapped progressions of the disciplinary core ideas and practices related to engineering and technology.

NSTA Press books on engineering. Go to the NSTA Store at *www.nsta.org/store* and enter "engineering" in the search bar. NSTA has several books on engineering and engineering design challenges in its STEM collection.

NSTA Web Seminar: Engineering Design as a Core Idea, presented by Cary Sneider. *www.youtube.com/watch?v=dTh_kTfOsDA.*

Science and Children elementary school journal articles. Go to *www.nsta.org/elementaryschool* and enter "engineering and technology" in the Journal archives search bar.

Science Scope middle school journal articles. Go to *www.nsta.org/middleschool* and enter "engineering and technology" in the Journal archives search bar.

The Science Teacher high school journal articles. Go to *www.nsta.org/highschool* and enter "engineering and technology" in the search bar.

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Banilower, E. R., P. S. Smith, K. A. Malzahn, C. L. Plumley, E. M. Gordon, and M. L. Hayes. 2018. *Report of the 2018 National Survey of Science and Mathematics Education (NSSME+).* Chapel Hill, NC: Horizon Research, Inc.

Banilower, E. R., P. S. Smith, I. R. Weiss, K. A. Malzahn, K. M. Campbell, and A. M. Weis. 2013. *Report of the 2012 National Survey of*

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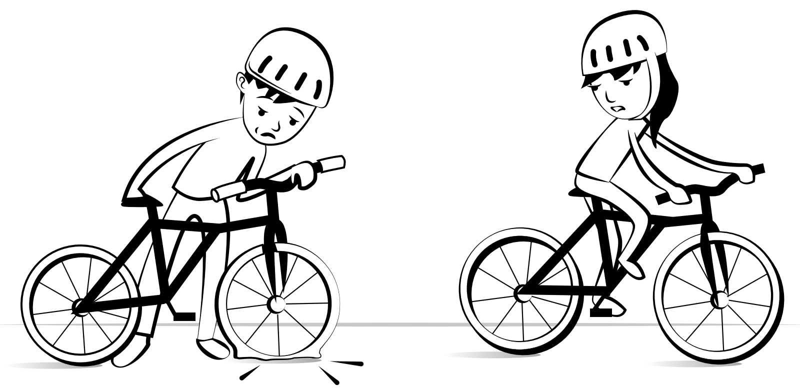
NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states.* Washington, DC: National Academies Press. *www.nextgenscience.org/next-generation-science-standards*.

What's the Problem?



Daniella and her friend Tyson are about to leave for school. Tyson finds out his bicycle has a flat tire. He's worried he will be late for school. Daniella and Tyson have different ideas about what is the most important problem to solve first:

Tyson: We need to figure out how to fix my tire.

Daniella: We need to figure out how to get to school on time.

Who identified the problem that should be solved first? ___________________ Explain your thinking.

____

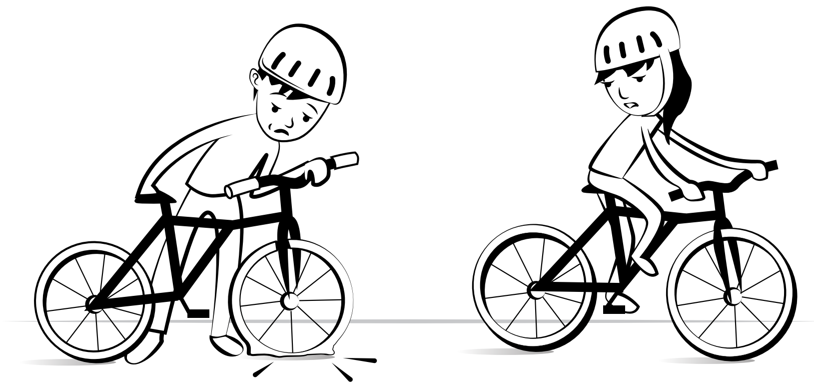
____

____

____

____

¿Cuál Es el Problema?



Daniella y su amigo Tyson se están preparando para ir a la escuela. Tyson nota que su bicicleta tiene una rueda pinchada. Le preocupa llegar tarde a la escuela. Tyson y Daniella tienen ideas diferentes sobre cuál es el problema más importante que deben resolver primero:

Tyson: Necesitamos descifrar cómo arreglar mi llanta.

Daniella: Necesitamos descifrar cómo llegar a la escuela a tiempo.

¿Quién identificó el problema que se debería resolver primero? ___________________
Explica lo que piensas.

____

____

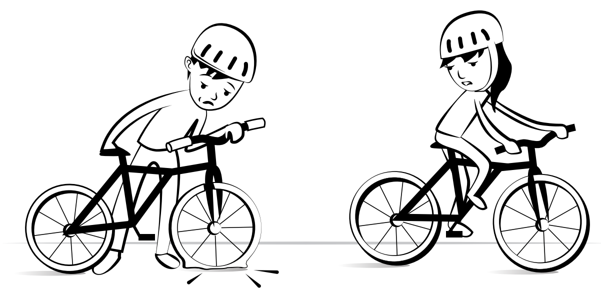
____

____

____

What's the Problem?

Teacher Notes



Purpose

The purpose of this assessment probe is to elicit students' initial response to an ill-defined problematic situation. The probe is designed to reveal whether students recognize that in a problem situation, there is sometimes a more important problem that needs to be solved first.

Type of Probe

Opposing views

Related Key Idea

- It is important to analyze a situation to determine the problem that needs to be solved.

Explanation

The best answer is Daniella's: "We need to figure out how to get to school on time." It is likely that many students will focus on the image of the bicycle, and immediately assume that the problem is the flat tire. However, the more important and immediate problem to be solved is how to get to school on time. Stopping to repair the bicycle will likely make them even later. This kind of situation can also happen with seemingly straightforward engineering problems in which a problem situation needs to be more clearly defined. Sometimes an important or immediate problem needs to be addressed first, before the more obvious problem can be solved.

Administering the Probe

This probe is best used with grades 3–12. The probe can be extended by having students describe what they would do to solve the problem.

Connections to the Three Dimensions (NRC 2012; NGSS Lead States 2013)

- DCI: ETS1.A. Defining and Delimiting Engineering Problems
- SEP: Asking Questions and Defining Problems

Related Research

- Crismond and Adams' (2012) review of several hundred studies of how students solve problems found that "beginning designers feel that understanding the design challenge is straightforward, and a matter of comprehending the basic task and its requirements. By perceiving the design task as a well-structured problem and believing there is a single correct answer, they can act prematurely and attempt to solve it immediately. Informed designers start by trying to learn as much as they can about the problem and delaying design decisions until they understand the problem fully. They set out to learn through research, brainstorming, and doing technological investigations of what the critical issues are in order to frame the problem effectively. They will later return to assess this framing after attempting to solve the challenge in case they need to modify the problem definition" (p. 747).

- Watkins, Spencer, and Hammer (2014) had fourth graders use fictional texts as a basis for identifying, scoping, and designing solutions for an engineering problem that the characters face. In contrast to Crismond and Adams' findings, the investigators found that the students did not treat design problems as well-defined straightforward tasks. Rather, they demonstrated promising beginnings of the ability to define a problem.

Suggestions for Instruction and Assessment

- Lead an all-class discussion as a follow-up to this probe. It is likely that students will disagree about what needs to be done. In that case, encourage more discussion.
- If all students believe the tire needs to be fixed, you can guide students to consider the other problem—getting to school on time. For example, you can ask students what happens when they are late for school, especially if they have been late several times before. How would their experience with being late for school inform how they would approach this problem?
- If most students say that the tire should be fixed first, ask them if they ever fixed a bicycle tire or watched someone do it. What is involved in fixing the tire? How long might it take to fix the tire? Then ask if they still think Tyson and Daniella could fix the tire and still get to school on time.
- Have the students share information about how they come to school in the morning. Do they ride the bus? Does a parent take them? Do they walk or ride a bicycle to school? What would they do if their usual means for getting to school failed? How would they solve the problem of getting to school?
- Have students come up with their own examples of a problem that at first seemed straightforward and easy to solve, but, on further examination, there were underlying problems that needed to be addressed first.
- Ask students to compare how this problem situation might be similar to problems that engineers encounter. Encourage them to guess about a situation, as any answer is a good start.
- Once students have completed this probe, have them discuss the problems involved in this situation. Initially, they may think that fixing a tire is an engineering problem and getting to school is not. However, a more accurate description is the reverse. Fixing tires is simply a step-by-step mechanical task that does not require design skills. However, solving how to get to school on time could be an engineering problem as students will need to define the problem, brainstorm multiple solutions, compare them, and select the best solution.

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