Uncovering
STUDENT IDEAS About ENGINEERING and TECHNOLOGY

32 NEW Formative Assessment Probes

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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

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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

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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

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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

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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.

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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

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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

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