Foreword

I have a dream. Nearly all of our youngsters will graduate high school, and nearly all will be excellent readers, manipulate numbers and estimate easily, be able to argue a point using trustworthy evidence to back it up, make decisions informed by common knowledge, solve complex problems well, understand how scientists and engineers reason and be able to do some of that reasoning themselves, express themselves articulately, work well with others, recognize what they know and when they need to learn more, have passionate opinions backed by knowledge, and appreciate the roles they might take on (and love to engage in) as productive adults.

By middle school, students will begin to have some idea of the kinds of employment they might want to engage in as adults, and as a result of the experiences they are having in school and at home, they will evolve their interests over time and develop mature passions as they move through high school and beyond, imagining what they might be or be doing as adults, working toward aligning themselves with some of these possibilities, deciding they are interested in some and not interested in others, and eventually identifying how they will live their lives and achieve their goals. Some will be scientists or engineers; some will be writers or expressive artists; some will provide services; some will be technicians; but all will be gainfully employed doing something they want to be doing.

Plenty of research on how people learn suggests that engaging learners in achieving engineering challenges that they are personally interested in and capable of solving successfully (with help) can go a long way toward fulfilling my dream, which I hope you share. You can play an essential role in your students' lives by engaging them in design challenges that are relevant to their personal interests and helping them to extract lessons from their work about how to define and solve problems and to imagine themselves as grown-ups who can solve important problems in the real world. A tall order, for sure, but not an impossible one. It won't happen tomorrow, and it won't happen at all if we don't seriously take on the challenge.

There are many reasons to be optimistic about the role design challenges can play in helping our youngsters grow and learn. First, it is not hard to make engineering design challenges fun, and it is not hard to help students see the value of math and science in their everyday lives if they are using disciplinary knowledge to address challenges they recognize as important. Achieving complex design challenges will not be easy fun for students, but if they are interested enough, they will put in the hard work. And if they see the value in what they are doing and learning and experience the success of learning and using science, more might enjoy science; more might see themselves as people who can engage well in thinking scientifically; more might understand the role science plays in our everyday world; more might become scientists, engineers, technicians, or policy makers who use science; and more might engage, during their adult lives, in thinking scientifically at times when that is appropriate.

Second, we know that developing deep understanding and masterful capabilities is hard and requires considerable time, but we also know that when somebody is really interested in what they are learning or in what they are attempting to do, and if the expectations are not so far beyond their capabilities that activities are overly frustrating, then people are willing to put in the time and effort. Learning something well, whether we are gaining understanding or learning how to do something, requires time and patience; it requires that we try our best to understand or achieve a challenge, that we pay attention to results and judge what is successful and not as successful, that we work on explaining when we don't understand something well or when we are not as successful as we want at solving a problem, that we develop new ideas and understandings, and that we have chances to try again (and fail again, and so on).

Achieving engineering design challenges provides opportunities for doing all of these things—trying and not quite getting it right, observing what happens, explaining, developing new understandings, and trying again. When a science class is achieving engineering challenges together, the teacher and class can work as a unit to provide the help everyone in the class needs to engage successfully in all of these processes. Not every student in the class will learn everything in depth or become masterfully adept at all skills and practices, but engaging together as a class in achieving engineering design challenges makes the classroom a place to help all students achieve as well as they can.

Third, engineering design challenges provide opportunities to use science, to engage in carrying out disciplinary practices, to engage in engineering design practices, and to engage in 21st-century skills. When students get excited about achieving a challenge, they will want to develop the necessary skills well enough to be able to achieve the challenge; if they need each other's advice, they will want to learn how to give good advice and take advice well, and if they are working on a challenge that requires several kinds of expertise or perspective, they will want to learn to collaborate well. When a class engages in engineering design together, there are opportunities to reflect on and discuss how to carry out skills and practices well, and when students are eager to achieve the engineering design goal, they will also be eager to know how to do whatever is necessary to achieve that goal; they will take the time to reflect on what they are doing and work on refining the way they carry out processes if time is set aside for that and appropriate help is given.

Fourth, we know that learners become more engaged and interested and willing to work hard when they are able to take on agency, that is, when they are trusted to make choices. There are rarely optimal choices in achieving engineering goals; engineers are constantly involved in making trade-offs, and several engineers working on the same real-world problem might come up with very different designs. The context of achieving engineering design challenges is perfect for allowing learners agency. When different groups suggest different solutions, have a chance to present and justify their solutions for the class, and have a chance to argue with each other using evidence, learning opportunities are enhanced for everybody in the class, as each group gets to experience and think about not only their own ideas but also the ideas of others.

Finally, when learners are allowed to try on the shoes of scientists and engineers, they also can begin to imagine themselves in those shoes. Students who are helped to be successful student scientists and student engineers, as they are asked to do in achieving engineering design challenges, will also begin to develop understandings of the kinds of activities they enjoy and the kinds of work they might want to do later in life. If the set of challenges they attempt is large, encompassing a large variety of disciplines, life situations, and roles they might take on, they will have solid foundations to build on in imagining their futures.

Everything we know about how people learn and how to promote learning suggests that engaging our young people in achieving engineering challenges and solving engineering problems has potential to promote deep science learning and mastery of important disciplinary and life skills. The Next Generation Science Standards (NGSS) (NGSS Lead States, 2013), in encouraging curriculum approaches that foster learning STEM skills and practices along with science content, give school systems and teachers permission to move in that direction.

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This book documents 14 sets of curriculum materials for the elementary years that integrate engineering design as a part of science. Although these materials were developed before publication of the NGSS, the authors of these chapters explain ways that they can be used today to support the NGSS at the middle school level. And nearly all will be fine-tuned in the years to come as developers gain further experience with the NGSS.

Each of the chapters illustrates different ways that engineering design can help achieve my dream, starting with Chapter 1, *Engineering Is Elementary: Engineering for Elementary School Students,* which illustrates how to use engineering as a context to combine science, social studies, and reading. Students use storybooks about children from around the world to learn about different engineering projects and professions, and then engage in related hands-on engineering design projects related to the stories.

In Chapter 2, *Physical Science Comes Alive! Integrating Engineering and Science Through Design and Troubleshooting of Cars and Gadgets* students combine art, science, and engineering design as they create their own vehicles and gadgets that move and light up. The tasks are designed to introduce students to mechanical and electrical principles that they apply to building, troubleshooting, and redesigning their creations.

Chapter 3, *Engineering byDesign TEEMS™: Kindergarten Through Second Grade,* describes three modules organized around environmental contexts and real-world design challenges, including designing a birdhouse, planning a sustainable garden, and cleaning up oil spills, that require students to learn and apply targeted technology, engineering, mathematics, and science concepts.

BSCS Science Tracks: Connecting Science and Literacy, featured in Chapter 4, is a complete K–5 curriculum in which students learn and apply basic science concepts through engaging experiences that involve them both physically and mentally in the processes of scientific inquiry and engineering design. Lessons employ the 5E instructional model, developed by educators at BSCS.

Chapter 5, *A World in Motion: From SAE International,* offers design challenges for students in Grades K–3, 4–6, and 7–8. The materials were developed by SAE International, a professional organization of more than 100,000 engineers in various industries, with a strong commitment to volunteering in the nation's schools. The challenges involve designing, creating, and testing various kinds of vehicles.

Chapter 6, *Engineering Opportunities in FOSS (The Full Option Science System): Third Edition for Upper Elementary Science Students,* summarizes the history of this K–8 curriculum series that has long featured engineering alongside science. The third edition, which is featured in this chapter, was a major reinvention of the curriculum that featured fusion of the STEM fields, consistent with the vision of the *Framework for K–12 Science Education* (NRC, 2012). Featured modules in this chapter include Electricity and Electromagnetism and Motion, Force, and Models.

Chapter 7, *Seeds of Science/Roots of Reading,* engages students in firsthand investigations, student-to-student discussion, reading science texts, and writing. The curriculum is designed

to help students develop the specialized skills involved in reading, writing, and talking about science as well as practices of science and engineering.

Computer programming for kindergarteners is the topic of Chapter 8, *Tangible Kindergarten: Learning How to Program Robots in Early Childhood.* The chapter describes how kindergartners work individually, in pairs, and in teams to program a robot's behaviors. In the process they apply knowledge of mathematics, use inquiry and problem-solving skills, and develop their creativity by using the engineering design process.

Educators who teach in afterschool or summer programs will be especially interested in Chapter 9, *Engineering Adventures: Engineering for Out-of-School Time,* which provides several examples to illustrate how setting the context for an engineering challenge by using a realistic scenario helps children connect engineering to the world in which they live and helps them become more invested in the problem.

Chapter 10, *Engineering byDesign TEEMS^{TM} and I³: For Grades 3, 4, 5, and 6,* describes how a fifth-grade teacher helps his students design and build a working wind turbine, develop their ideas into inventions, and solve problems in food safety, structural engineering, transportation, and communication.

Chapter 11, *Design It! Design Engineering Projects for Afterschool,* is about a curriculum that was created for children from traditionally underserved communities who regularly attend afterschool and other nonacademic out-of-school programs. Each *Design It!* project consists of a series of *challenges* that lead toward an engaging endpoint—a rollercoaster, go-cart, bridge, crane, glider, string telephone, pinball machine, trebuchet, top or yo-yo— made out of commonly available, expendable, and inexpensive materials.

Chapter 12, *Engineering for Everyone: 4-H's Junk Drawer Robotics Curriculum,* describes a series of three modules that use common household items such as paperclips, brass brads, toy motors, craft sticks, batteries, aluminum foil, and binder clips in a sequence of activities that enable students to design their own creative electro-mechanical robots. The program is designed for use by 4-H volunteers or other youth program leaders.

Chapter 13*, PictureSTEM,* concerns a series of modules that use high-quality trade books with compelling stories that engage student interest and pose a problem that can be solved by the engineering design process. In the next part of the module, students solve the problem by brainstorming, proposing multiple potential solutions, and evaluating the pros and cons of competing solutions. The students then implement their design by creating and testing a prototype, model, or other product.

Chapter 14, *STEM in Action: Solar House Design,* describes a series of modules for preK through Grade 5 that integrate science and mathematics through engineering design challenges. The developers emphasize the importance of beginning with integrated STEM programs as early as possible. The chapter features a unit for fourth grade on designing and building a model house warmed by the power of sunlight.

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It will not be easy to make traditional classrooms into engineering design classrooms. Some students who are used to reading and answering questions will balk at having to work hard; other students for whom learning comes easy will balk at having to work collaboratively with their classmates. If you are new to engineering education, you will have to learn new ways of interacting with students and facilitating learning. It does not take long to draw students in if challenges are meaningful to them and if they are trusted with agency, but it will take a special effort to develop new ways of interacting with your students.

If this is your first time teaching engineering, you may not be as successful as you want immediately, but don't worry. As you learn to be a better facilitator of the engineering design process, your students will learn more deeply. If possible, work together with other teachers who are also learning to implement engineering or other project-based activities in their classrooms. And just as your students will be learning a new approach by attempting to solve a problem but not quite succeeding, getting help in understanding why their first approach didn't work, then redesigning, and trying again, it is very likely that you will go through a similar sequence of stages in your teaching. It will take time and willingness to work through possibly frustrating attempts to enact very different kinds of activities than you are used to, but it will be worthy and worthwhile work.

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The many chapters in this collection provide advice and resources for using design challenges and problems to promote science learning. I hope that the chapters help readers develop imagination about integrating engineering design and problem-solving experiences into science classes, passion for moving forward to implement engineering design activities in their classrooms, and understanding of the conditions under which integrating such activities into our classrooms will lead to deep learning.

Choosing which of these instructional materials are right for you and your students is, of course, a huge part of the challenge. But it should be possible to identify likely candidates by reading the first three or four pages of each chapter, then reading the complete chapter for those that are most likely to meet your needs. As you do that, you might keep in mind several thoughts:

- Good education is not about "covering the material." Developing deep understanding and masterful capabilities is hard and requires considerable time. It is more important that students spend significant time on a few projects than that they do a lot of brief activities that cover a wide variety of topics.
- In order to sustain your students' interests over time, it is essential for projects to be sufficiently interesting and diverse to maintain your students' attention. Resources will provide some advice about how to do that, but you know your students better than curriculum developers; use your judgment to help problems come alive for your students, and if you see interest waning, figure out how to bring interest back. It's not hard to keep youngsters excited about things that impact their world and that help them experience worlds they've become familiar with, from TV or the movies, but sometimes they need to be reminded why they are doing what they are doing.
- Judging the difficulty of a task will require your best judgment as a teacher. The requirements of a task should not be so difficult that it becomes frustrating so that students give up. Conversely, if what they are asked to do is too easy, students will not have opportunities to develop new skills or gain confidence in their abilities to tackle and solve really challenging problems. Some materials allow you to modify the level of the challenge to meet your students' needs.
- Opportunities for teamwork are evident in every one of these sets of materials. However, some are more explicit than others about how to manage teams and help students learn to work together effectively. What is important to remember is that working in teams should not just be seen as a way of managing the classroom, but rather, it is important for students to come to appreciate the benefits of collaboration and learn how to collaborate well. Help your students identify the understanding

and capabilities they are gaining from teamwork and help them develop collaboration habits that they use and further develop across curriculum units and projects.

- Many of the materials described in this book expose students to the world of technology and a wide variety of career possibilities. Helping students recognize those possibilities provides a way of keeping them engaged and will aim students toward goals that are part of my dream (and I hope yours).
- In choosing materials to use in your classroom, remember that in addition to choosing particular curriculum units for the targeted content they address and the interests of your students, it is important that your students experience and appreciate the big ideas of science and technology. Curriculum materials used over a year or several years of school should build on each other in ways that allow learners to see the connections between topical areas and to exercise and develop their capabilities. Help your students see across curriculum units as well as digging deep into the content and skills targeted in each one.

I offer my best wishes and congratulations to all of your efforts! I will be cheering for all of you and looking forward to meeting your many learned and mature-thinking students and experiencing the success of your endeavors in the decades to come.

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