9–12

ENGINEERING IN THE LIFE SCIENCES

RODNEY L. CUSTER • JENNY L. DAUGHERTY • JULIA M. ROSS
KATHERYN B. KENNEDY • CORY CULBERTSON

NSTApress
National Science Teachers Association

ENGINEERING IN THE LIFE SCIENCES

9–12

ENGINEERING IN THE LIFE SCIENCES

9–12

RODNEY L. CUSTER

JENNY L. DAUGHERTY

JULIA M. ROSS

KATHERYN B. KENNEDY

CORY CULBERTSON

NSTApress
National Science Teachers Association

Arlington, Virginia

Claire Reinburg, Director
Rachel Ledbetter, Managing Editor
Deborah Siegel, Associate Editor
Andrea Silen, Associate Editor
Donna Yudkin, Book Acquisitions Manager

Art and Design
Will Thomas Jr., Director
Joe Butera, Senior Graphic Designer, cover and interior design

Printing and Production
Catherine Lorrain, Director

National Science Teachers Association
David L. Evans, Executive Director

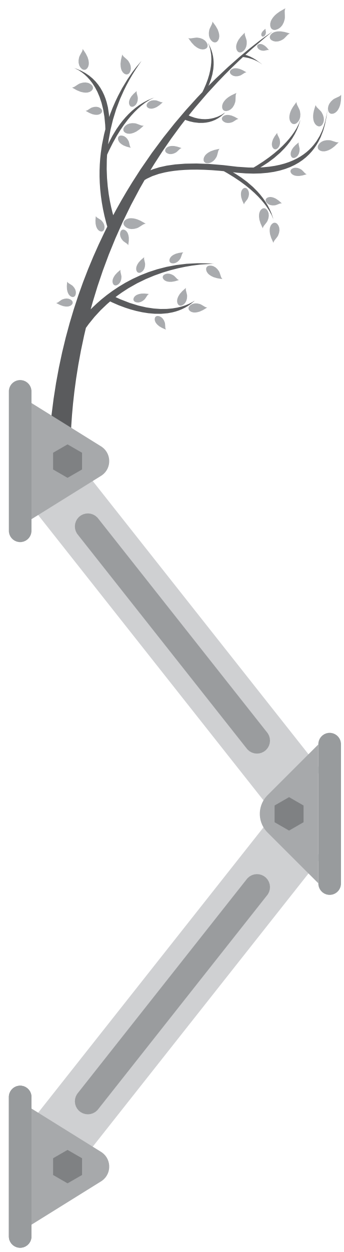
1840 Wilson Blvd., Arlington, VA 22201
www.nsta.org/store
For customer service inquiries, please call 800-277-5300.

21 20 19 18 4 3 2 1

Library of Congress Cataloging-in-Publication Data

Names: Custer, Rodney L., author.
Title: Engineering in the life sciences, 9-12 / by Rodney L. Custer, Jenny L. Daugherty, Julia M. Ross, Katheryn B. Kennedy, and Cory Culbertson.
Description: Arlington, VA : National Science Teachers Association, [2018] | Audience: Grades 9-12. | Includes bibliographical references and index.
Identifiers: LCCN 2018019046 (print) | LCCN 2018021167 (ebook) | ISBN 9781681404783 (e-book) | ISBN 9781681404776 (print)
Subjects: LCSH: Bioengineering--Study and teaching (Secondary)--Juvenile literature.
Classification: LCC TA164 (ebook) | LCC TA164 .C87 2018 (print) | DDC 660.6071/2--dc23
LC record available at *https://lccn.loc.gov/2018019046*

CONTENTS



CONTRIBUTORS

The materials presented in this handbook are based on work supported by the National Science Foundation under grant number 1158615.

The authors wish to express appreciation to Melissa Doellman-Brown for her insights and guidance during the project and, in particular, for her help with creating the lessons. Melissa taught biology for several years at Illinois State University's University High School, before moving to New York where she continues to teach biology at Horace Mann School. She has an MS in Teaching and Learning, and her special interests in science education lie in assessment and instructional design to increase student engagement and learning.

The authors also wish to thank Dr. Philip Leopold, Associate Professor of Research in Genetic Medicine at Weill Cornell Medical College, for his help in developing Chapter 5. Philip's deep knowledge of life science content and his creativity with instructional design supplied the framework for several of the featured lessons. Before taking his current position at Weill Cornell, Philip was the Director and Professor of Chemical Biology and Biomedical Engineering at Stevens Institute of Technology, where he contributed to several K–12 science and engineering programs through his collaboration with the Center for Innovation in Engineering and Science Education.

Additionally, the authors want to express their appreciation to the following individuals who helped develop and test the lessons included in this book.

LESSON DEVELOPMENT TEAM

Ciara Agresti
Stevens Institute of Technology
Hoboken, New Jersey

Francisco Barquin
Memorial High School
West New York, New Jersey

Debra Brockway
Educational Testing Service
Princeton, New Jersey

Raina Parvanov Dawson
Midland Park High School
Midland Park, New Jersey

Kristin Germinario
Randolph High School
Randolph, New Jersey

Amanda Gregorek
Toms River High School East
Toms River, New Jersey

Samantha Haughwout
Lacey Township High School
Lanoka Harbor, New Jersey

Philip L. Leopold, PhD
Department of Genetic Medicine, Weill Cornell Medicine
New York, New York

Robin Marsiglia
Waldwick High School
Waldwick, New Jersey

Carolyn McCarthy
Madison High School
Madison, New Jersey

James Nonas
Teaneck High School
Teaneck, New Jersey

Joseph Simko
Nutley High School
Nutley, New Jersey

Continued

FIELD TEST TEACHERS

Alicia Daniels
Crocker High School
Crocker, Missouri

Cynthia Duncan
Father Gabriel Richard High School
Ann Arbor, Michigan

Jessica Falk
Paris High School
Paris, Kentucky

Catherine Glofelter
Dauphin County Technical School
Harrisburg, Pennsylvania

Suzy Goedeken
Madison Public Schools
Madison, Connecticut

Susan Jones
Ottoville High School
Ottoville, Ohio

Laura Julien
Lancaster High School
Lancaster, Ohio

Suzanne McDonald
Clay Batelle High School
Blacksville, West Virginia

Denise McKenna
Secaucus High School
Secaucus, New Jersey

Elizabeth Mitchell
Santa Paula High School
Santa Paula, California

Kerry O'Brien
St. Albans School
Washington, DC

Korrin Schriver
Wahlert Catholic High School
Dubuque, Iowa

Wendy Simpson
Cosumnes Oaks High School
Elk Grove, California

Catherine Yuhas
High Tech High School
North Bergen, New Jersey

LESSON ABSTRACT IDEA DEVELOPERS

Laura DeCherico
Yorkshire Academy
Houston, Texas

Wendy Green
Marine Academy of Science and Technology
Highlands, New Jersey

Casey Harris
Verona High School
Verona, New Jersey

Kathy Malone
The Ohio State University
Columbus, Ohio

Tricia Neugebauer
Mitchell Career and Technical Education Academy
Mitchell, South Dakota

Julie Olson
Mitchell Public Schools
Mitchell, South Dakota

Maggy Proctor
University High School
Normal, Illinois

Julie Shuler-Misra
Menaul School
Albuquerque, New Mexico

Amanda Smith-Dougherty
Union City Public Schools
Union City, New Jersey

PROJECT INFUSE PRINCIPAL INVESTIGATORS

Rodney L. Custer
Black Hills State University
Spearfish, South Dakota

Jenny L. Daugherty
Louisiana State University
Baton Rouge, Louisiana

Julia Ross
Virginia Polytechnic Institute and State University
Blacksburg, Virginia

ABOUT THE AUTHORS

Rodney L. Custer is professor and chair of education at Black Hills State University in Spearfish, South Dakota. He earned a BA in psychology from McPherson College, a BS and MS in industrial education from Fort Hays State University, and a PhD from the University of Missouri–Columbia in technology education with an emphasis in industrial engineering. Rodney previously served as provost and vice president of academic affairs at Black Hills State University. His work includes teacher professional development, curriculum development, and assessment in engineering and technology education. Rodney is a principal investigator of Project Infuse, a National Science Foundation (NSF)–funded project focused on an engineering concept–based approach to professional development for physics and life science teachers.

Jenny L. Daugherty is the Jones S. Davis Distinguished Associate Professor of Leadership and Human Resource at Louisiana State University in Baton Rouge, Louisiana. She is also the director of the Leadership Development Institute (LDI), which serves as the umbrella organization promoting interdisciplinary research and collaboration related to leadership development. Jenny earned a BA in sociology and history from Indiana University, an MA in American history from Purdue University, and a PhD in human resource education from the University of Illinois at Urbana-Champaign, where she was awarded a doctoral fellowship with the National Center for Engineering and Technology Education. Her research is focused on science, technology, engineering, and mathematics (STEM) teacher professional development and leadership development. Jenny is a principal investigator of Project Infuse.

Julia M. Ross is dean of the College of Engineering and a tenured professor of chemical engineering and engineering education at the Virginia Polytechnic Institute and State University in Blacksburg, Virginia. She leads a multidisciplinary research team in the development and implementation of the NSF-funded INSPIRES Curriculum (INcreasing Student Participation, Interest, and Recruitment in Engineering and Science), which integrates engineering, science, and mathematics learning and provides professional development to high school teachers. Julia earned a BS in chemical engineering from Purdue University and a PhD in chemical engineering from Rice University. She is a Fellow of the American Institute for Medical and

Biological Engineering and is the recipient of the American Society for Engineering Education Sharon Keillor Award for Women in Engineering Education and an NSF CAREER (Faculty Early Career Development Program) Award. Julia is a principal investigator of Project Infuse.

Katheryn B. Kennedy is the manager of professional development services for the Center of Innovation in Engineering and Science Education (CIESE) at Stevens Institute of Technology in Hoboken, New Jersey. She earned a BS in biology from Siena College, an MS in biomedical sciences from Baylor University, and a PhD in education from Walden University. Katheryn's classroom teaching experience includes life science at the high school and college level. Her work at CIESE has a focus on teacher professional development and curriculum development for science and engineering education.

Cory Culbertson teaches engineering technology and computer science at University High School, part of the Laboratory Schools of Illinois State University in Normal, Illinois. Besides full-time classroom teaching, he guides preservice teacher candidates in curriculum planning and instructional practices. Cory is a recipient of the Council on Technology Teacher Education's Outstanding Research Award, and his work has also included curriculum writing, editing, and presenting professional development for Project Infuse, the National Center for Engineering and Technology Education, and Project ProBase. He earned a BSE in mechanical engineering from the University of Michigan at Ann Arbor and an MS in technology education from Illinois State University. Cory remains active in the product design field.

CHAPTER

1

ENGINEERING IN THE SCIENCES

Science and engineering intersect in a number of ways in both education and real-world applications. Engineers need to understand how the world works from a variety of perspectives, including from those of the life, physical, and environmental sciences. Engineers need the knowledge of scientists and mathematicians to design and make the many devices and systems on which we depend on a daily basis. At the same time, science benefits from advances in engineering to develop the devices, instruments, and processes needed to test and understand the natural world. Science, technology, engineering, and mathematics (STEM) are intertwined, and each field contributes to the understanding of the natural world and the development of a wide variety of goods and services designed to enhance the quality of life.

This intermingling is reflected in the *Next Generation Science Standards* (*NGSS*; NGSS Lead States 2013). The engineering dimension provides a stimulating and real-world context within which we can understand science and its many applications, and students are able to develop some sense of where "this stuff is used in the real world."

This complex and interdependent interaction between science and engineering has been at the core of a National Science Foundation–funded project called Project Infuse, which was designed to help life and physical science teachers enhance their teaching of science through the infusion of engineering. Throughout Project Infuse, we learned a number of important lessons. The teachers were intrigued with engineering, not only conceptually but also with the many opportunities to enrich the teaching and learning of science with engineering design projects and other real-world applications. But there were also logistical challenges involving such things as selecting and designing appropriate classroom activities, managing projects requiring group work and multiple solutions to problems, and the need for new forms of assessment and pedagogy. So we rolled up our sleeves and worked with a team of outstanding teachers, curriculum developers, professional development providers, and researchers to address these issues. We developed and tested teacher resources, engineering-infused life science lessons, and assessment tools, and we pilot tested them with real students in real classrooms. The results yielded the materials found in this book.

This book was designed to share some of the important lessons learned and materials developed through this valuable set of interactions. Through our experience working with an amazing group of life science teachers, we learned which ideas worked and which did not work. In some cases, we recrafted. At other times, we discarded and started over. These teachers were instrumental in helping to formulate the book's structure and identify information that they thought would be most useful to other teachers who are working to align their classes with contemporary directions in the life sciences.

Engineering and the *Next Generation Science Standards*

Let's take a closer look at how engineering has been framed in the *NGSS*. First, it is very important to remember that engineering is situated within three distinct but equally important dimensions to science learning: disciplinary core ideas (DCIs), crosscutting concepts (CCCs), and science and engineering practices (SEPs) (NGSS Lead States 2013). Collectively, the three dimensions "unpack" and clarify the performance expectations that describe specific areas of student understanding across the science and engineering disciplines. Throughout the *NGSS,* the performance expectations are designed to move learning beyond memorization of factual information to a deeper and more comprehensive understanding. Although you may already be familiar with these three dimensions, it will be helpful to provide a brief summary as background to our larger discussion of engineering in the life sciences.

Disciplinary Core Ideas

The DCIs outline key areas of knowledge across four main domains: (1) physical sciences, (2) life sciences, (3) Earth and space sciences, and (4) engineering, technology, and applications of science. The *NGSS* represent the first time that engineering has been included as a distinct area within K–12 science learning. The DCIs are designed to establish a carefully selected and manageable set of performance expectations in each area as students progress through the educational system. Although the focus of this book is at the secondary level, it is important to note that the *NGSS* present the DCIs as a series of grade-level learning progressions, with engineering design as the central theme of the engineering DCI. At the high school level, the DCI is captured by standard HS-ETS1 Engineering Design.

Crosscutting Concepts

The CCCs represent "threads" that are "woven" throughout the standards. Collectively, the CCCs help students make connections between and deepen their understanding of the DCIs. The CCCs are as follows[1]:

- Patterns
- Cause and Effect
- Scale, Proportion, and Quantity
- Systems and System Models
- Energy and Matter
- Structure and Function
- Stability and Change
- Interdependence of Science, Engineering, and Technology
- Influence of Engineering, Technology, and Science on Society and the Natural World

Science and Engineering Practices

The SEPs describe the habits and skills that scientists and engineers use every day in investigating the natural world and designing and building systems. The SEPs are as follows:

- Asking Questions and Defining Problems
- Developing and Using Models
- Planning and Carrying Out Investigations
- Analyzing and Interpreting Data
- Using Mathematics and Computational Thinking
- Constructing Explanations and Designing Solutions
- Engaging in Argument From Evidence
- Obtaining, Evaluating, and Communicating Information

The developers of the *NGSS* captured the unique interrelationship between science and engineering in the SEPs. Although the actions of scientists and engineers

1 Note that "Interdependence of Science, Engineering, and Technology" and "Influence of Engineering, Technology, and Science on Society and the Natural World" are not official *NGSS* crosscutting concepts. They are actually *NGSS* disciplinary core ideas that can also be considered crosscutting concepts. Thus, the term *crosscutting concepts* in this book includes "Interdependence of Science, Engineering, and Technology" and "Influence of Engineering, Technology, and Science on Society and the Natural World."

may look very similar, they are fundamentally different from each other in the basic goals or purpose of their work. The primary goal of science is to understand the natural world and how it works, whereas engineers strive to produce and refine products and services designed to meet human wants and needs. These similarities and differences are captured in the SEPs in a way that can help students understand how the two fields are different.

The *NGSS* are designed to place the entire educational process (including lesson planning, student learning, *and* assessment) *at the intersection* of these three dimensions. That's a very tall order! But it's also a tremendous opportunity to engage students with important science concepts at a deeper level in ways that help them connect science to other learning. The "intersection" also helps to contextualize their learning within the real world of industry, business, research, and careers. This three-dimensional structure and approach raises the stakes for the teaching, learning, and assessment of science. It will challenge teachers and curriculum developers to think of new ways to engage students at a deeper level. For many, it will also require a rethinking of how the science concepts and ideas are assessed.

Questions About Engineering in the Sciences

Why Is the Inclusion of Engineering in the *NGSS* a Good Thing?

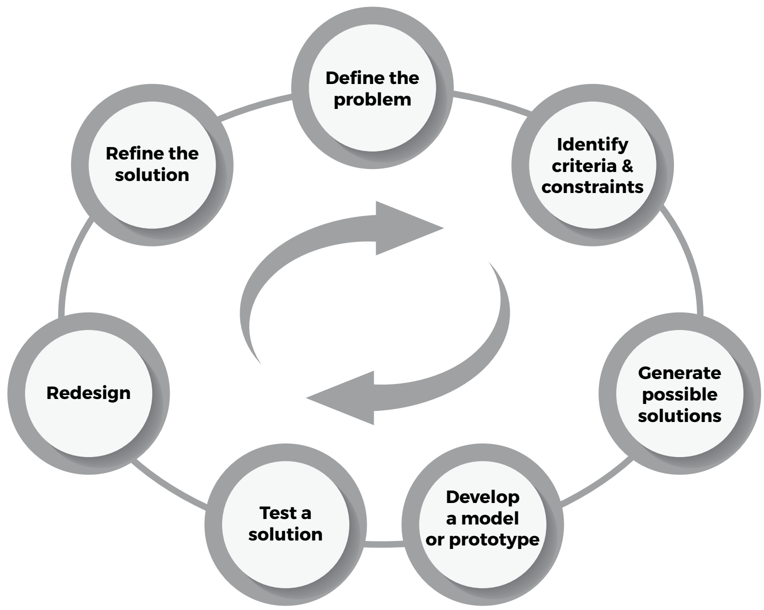
What impact do science and engineering have on society and our environment? If you incorporate engineering into your science classroom, your students will be better able to answer that question! Engineering naturally integrates science and math learning to solve real-world problems. Using a problem-based learning approach that embeds science content into meaningful contexts is highly motivating for students. It can deepen science and math learning, target multiple learning styles, and spark creativity in the classroom. It can also broaden interest and participation of students in STEM-related careers. But regardless of career choice, exposure to engineering helps all students gain a better understanding of the technological world in which we live.

What Is Engineering Design?

Engineering design is an iterative process that involves defining problems, establishing design criteria and constraints, generating solution ideas, developing models, testing solutions, redesigning, and refining solutions (see Figure 1.1). It is important to note that this is somewhat of an oversimplification of how engineering really works. Engineering design is much more complex than simply moving from one stage to the next in some kind of prescribed order.

FIGURE 1.1

Engineering Design Loop Model



It is also important to note that other models exist; some of them are less complex, whereas others contain substantially more detail. For example, *NGSS* Appendix I presents engineering design in less detail, condensing the loop shown in Figure 1.1 into three broad components: Define, Develop Solutions, and Optimize. Regardless of the level of detail given in an engineering design loop, the process tends to be complex and iterative and depends on many factors, including the nature of the problem, its scope, and even the thinking style of an engineer or the culture of an engineering firm. As engineers do their work, they often move back and forth between stages depending on the nature of the design problem. But the model depicted in Figure 1.1 captures the main components of the engineering design process.

Engineers tend to draw from a wide range of knowledge, including science, mathematics, psychology, sociology, economics, and many other fields. They also use knowledge that is unique to engineering as well as the "know-how" of technicians and craftspeople. As they navigate through the design process, engineers use optimization, trade-offs, prototyping, economic analysis, and a variety of other techniques to address the constraints and criteria of their designs.

Engineering design is most often introduced in the classroom through the use of a "design challenge" that describes a problem students need to solve. In contrast with many science lessons, design challenges are deliberately open-ended and configured to allow for multiple solutions. At their best, they require an understanding of science and math concepts for solution. As in the real world, the most creative solutions come when students work together in groups to solve a challenge. To use this strategy effectively, teachers must assume a facilitative and supportive role, helping teams of students make connections to the science, interpret results, refine their designs, examine misconceptions, and, often, extend their learning to broader social impacts. Design-based instruction and assessment are quite different from a direct instruction approach and pose challenges for time and classroom management. Engineering design challenges are a lot of fun, but implementing them well will require many teachers to expand their approach to teaching and learning. Chapter 3 of this book is specifically designed to address these kinds of issues.

Can You Do Engineering in the Life Sciences?

Yes! Bioengineering is a large and growing discipline within the engineering field. A few of the many applications include the development of artificial implants, limbs, and organs; new-generation medical imaging techniques; improved processes for genomic testing; and the manufacturing and administering of drugs. Biological systems engineering focuses on the development of environmentally sound and sustainable systems to improve animal, human, and environmental health. Examples include the conversion of biological resources such as plant materials and animal waste into value-added products such a biomaterials and biofuels in a sustainable manner.

Unfortunately, curriculum materials that integrate engineering into high school life science are not yet widely available. Teachers who want to include engineering in life science classrooms often need to develop or revise lessons to meet their students' needs. This book was written to help you do just that! In addition to basic information on instructional strategies and assessment (see Chapters 3 and 4), design challenge ideas for high school–level life sciences are presented in Chapter 5. Clearly, this approach will not be appropriate for all life science lessons, but it can be a powerful way of placing science within a rich and authentic problem-solving context.

Organization of the Book

The book is divided into six chapters, beginning with this general overview of the role of engineering in life science education. Chapter 2 contains a set of six engineering-infused life science lessons. Our Project Infuse teachers considered these lessons to be one of the most important components of the book. It is one thing to discuss how existing lessons might be modified to include an engineering component or what engineering-infused lessons might look like. But it is much more helpful if some good working examples can be presented. One of the most significant challenges throughout the project was identifying life science lessons that are appropriate and "doable" for secondary-level students. The pilot test teachers worked very hard to identify a set of lessons that not only are practical and appropriate but also cover a representative sampling of life science content. Some lessons can be easily integrated in the form presented. Others may need to be adapted. In any case, one of the most important lessons learned throughout the project was the "power of working examples" and the value of engaging teachers with curriculum. Our hope is that the lessons will be used, adapted, and refined so they can serve as the foundation for developing new lessons.

Chapter 3 contains a discussion of practical matters associated with delivering engineering design challenges and projects in science classrooms. In some respects, the pedagogy and techniques will be similar to inquiry-based science. In other ways, the techniques differ significantly. Design challenges are frequently done in groups with multiple solution possibilities. It is also important to think about how to strike a balance between science and engineering content. Some challenges will involve making relatively minor modifications to how science has been taught and learned. In other cases, the changes will be more demanding and difficult to do. This chapter evolved from a set of honest, practical, and engaging discussions conducted between an experienced engineering technology high school teacher and a group of experienced life science teachers.

Chapter 4 focuses on assessment, which is a "must" in the high-stakes, standards-based world of education. The goal of the curriculum design and delivery process is to achieve a close alignment across standards, content, learning experiences, and assessment. The inclusion of engineering raises some additional issues. What changes will be needed to assess new engineering-oriented lessons, which often involve open-ended projects and group activities? Additionally, engineering challenges tend to focus on process, which shifts the focus of assessment to formative procedures where process is, in some cases, as important as content.

Chapter 5 is designed to stimulate additional lesson ideas. For many, the inclusion of engineering might be new and seemingly foreign when considering how to expand the curriculum to include more engineering lessons. Yet with a spark of an idea, teachers can develop lessons that can be integrated into their classrooms. This chapter contains a variety of lesson ideas that have the potential to be developed. For each idea, we have attempted to provide a brief description of what the lesson might contain and, in some cases, an idea or two about how the lesson might be configured.

The final chapter contains five engineering case studies developed and used by Project Infuse. These case studies are designed to ignite classroom discussions on the nature of engineering in the modern world. Teachers have used case studies in various ways: to introduce the field of engineering and discuss engineering careers, to engage students in a discussion of an engineering concept and then explore the topic more fully in an activity, and to connect the science content to the engineering content by discussing the real-world examples provided in the cases.

We hope that the materials and the rich base of experience that they represent will be helpful as life science teachers seek to engage their students through engineering-enriched science. The materials are designed to be organic, adaptable, and, most important, usable.

Reference

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

INDEX

Page numbers printed in **boldface type** indicate tables or figures.

ENGINEERING IN THE LIFE SCIENCES

9–12

When the authors of this book took part in Project INFUSE, the National Science Foundation–funded teacher development program, they noticed something. Life science teachers were highly receptive to engineering ideas related to everything from genomic testing to biofuels. But they also saw that teachers struggled to develop age-appropriate, standards-based lessons. The teachers asked for help facilitating the kind of open-ended design challenges that are useful to presenting engineering concepts in quick, engaging ways.

Out of that intensive interaction came *Engineering in the Life Sciences, 9–12*. It is designed to help you understand both what to teach and how to teach it. The authors created it specifically to be

- **Content-rich.** Six fully developed lessons show how to use engineering concepts to enhance life science courses. The lessons draw on each of the major content areas in biological sciences, including structures and processes, ecosystems, heredity, and biological evolution.
- **Standards-based.** This book will help you see how to weave the engineering thread from the *Next Generation Science Standards* into and throughout your content.
- **Engaging.** Lesson titles include "Designer DNA," "Ecosystem Board Game," and "B-pocalypse," which is about battling the decline of bees needed to pollinate crops.
- **Practical.** Inspired by extensive field testing, the authors made the lessons easy to use in diverse settings. The book is packed with detailed advice on managing engineering-oriented activities and conducting assessments. You also get idea-starters, teaching tips, and case studies to inform your own lessons.

Full of both sound science and innovative approaches, *Engineering in the Life Sciences, 9–12* brings fresh meaning to the terms "teacher-tested" and "classroom-ready." It is specifically designed to address the curriculum and pedagogical needs of life science educators.

Grades 9–12

NSTApress
National Science Teachers Association

PB433X
ISBN: 978-1-68140-477-6
9 781681 404776