E+S

INTEGRATING ENGINEERING + SCIENCE IN YOUR CLASSROOM

Edited by
Eric Brunsell

NSTApress
National Science Teachers Association

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15 14 13 12 4 3 2 1

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Library of Congress Cataloging-in-Publication Data
Integrating engineering and science in your classroom / Eric Brunsell, editor.
pages cm
ISBN 978-1-936959-41-9
1. Science--Study and teaching (Elementary) 2. Engineering--Study and teaching (Elementary) 3. Science--Study and teaching (Secondary) 4. Engineering--Study and teaching (Secondary) I. Brunsell, Eric.
LB1585.I495 2012
372.35'044--dc23
2012026196
ISBN 978-1-936959-63-1 (ebook)

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Contents

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Contents

Part Two

Content Area Activities

LIFE AND ENVIRONMENTAL SCIENCE

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EARTH SCIENCE

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Contents

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Introduction

I still remember my very first day as a teacher. A few days earlier, my principal had given me this advice: "Whatever you do, do not start with an overview of your course. Do something active and set the tone. The overview can wait for day two or three." Of course, I had planned on introducing the course, so I had to quickly make some changes. I decided to have students do a simple tower building challenge. As I nervously awaited the arrival of my first period physical science students, I wondered how they would react. To my relief, they jumped right in and remained engaged throughout the entire class—building, testing, and revising prototypes of paper towers. Since that day, I have continued to use design challenges as a way to engage students and teachers in classes and professional development. I have also been involved in other after-school engineering clubs and competitions. Almost universally, these activities engage and excite students of any age. More importantly, when done well, these activities reinforce important skills and science content. The recent surge in interest for engineering education, including engineering's inclusion in the *Framework for K–12 Science Education* and *Next Generation Science Standards*, presents an exciting opportunity for teachers of science. This book includes a variety of excellent articles from NSTA's *Science and Children*, *Science Scope*, and *The Science Teacher* to help you integrate authentic and meaningful engineering activities into your teaching.

Engineering in the NAS Framework for K–12 Science Education

The National Research Council's Framework for K–12 Education states, "any science education that focuses predominately on the detailed products of scientific labor—the facts of science—without developing an understanding of how those facts were established or that ignores the many important applications of science in the world misrepresents science and marginalizes the importance of engineering" (2012). The Framework continues by identifying two implications that this statement has for science education standards:

- Students should learn how scientific knowledge is acquired and how scientific explanations are developed.
- Students should learn how science is used, in particular through the engineering design process, and they should come to appreciate the distinctions and relationships between engineering, technology, and applications of science.

The Framework includes two engineering "core ideas" for K–12 science education. ETS 1: How do engineers solve problems? and ETS 2: How are engineering, technology, science, and society

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interconnected? The first core idea focuses on students understanding an engineering design process that includes defining an engineering problem, developing potential solutions, and optimizing the design solution. The second core idea focuses on helping students understand the interdependence of science, engineering, and technology, and their influence on society and the natural world. The Framework also describes a series of eight science and engineering practices, summarized in Table 1.

The inclusion of engineering concepts and practices in the Framework is not intended to add more to the plate of teachers with an already overburdened science curriculum. Additionally, it is not intended to replace state or district engineering standards nor co-opt stand-alone engineering courses and programs. Instead, these core ideas and practices are meant to help teachers introduce the interdependence of science, technology, and engineering and to harness the power of design activities to support authentic learning of science concepts.

Including engineering activities in your science curriculum can reinforce science concepts while providing experiences for your students that illustrate a wide range of STEM skills, issues, and opportunities. For example, in Yocom De Romero, Slater and DeCristofano's, "Design Challenges Are ELL-ementary," students learn about properties of Earth materials as they design a wall. High school students explore gene therapy technology and issues in Lockhart and Le Doux's article, "A Partnership for Problem-Based Learning." In Thompson's "The Science of Star Wars: Integrating technology and the Benchmarks for Science Literacy," middle school students apply their understanding of electric circuits as they design and construct model light sabers.

In their article, "Engineering for All," Lottero-Perdue, Lovelidge, and Bowling describe the implementation of an engineering design challenge in an inclusive environment. They end with two warnings, "(1) brace yourself for the excitement that students have as they engage in the engineering design process; and (2) be prepared for all students to succeed and for some who normally struggle to shine." The hands-on nature of engineering design activities will engage your students, foster higher-order thinking, and deepen their understanding of how science, technology, engineering, and mathematics (STEM) influences the world around them. By exposing students to authentic engineering activities, you can help students uncover the profession that makes the world work.

Engineering Core Ideas in *A Framework for K–12 Science Education*

ETS 1: How do engineers solve problems?

- Defining and delimiting an engineering problem
- Developing possible solutions
- Optimizing the design solution

ETS 2: How are engineering, technology, science, and society interconnected?

- Interdependence of science engineering, and technology
- Influence of engineering, technology, and science on society and the natural world

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TABLE 1.

The Framework's eight science and engineering practices

Practice	Description
Asking Questions and Defining Problems	Engineering challenges usually start with a need, want, or problem. Engineers ask questions to help define the problem by identifying constraints and identifying criteria for success.
Developing and Using Models	Models can be physical, conceptual, or mathematical. Engineers use models to identify and test solutions.
Planning and Carrying Out Investigations	Engineers use investigations to test and refine their solutions. Engineers need to be able to identify variables and develop investigations to test the reliability or capability of their solutions.
Analyzing and Interpreting Data	Engineers need to be able to analyze and interpret data by using graphs and other representations of data to determine the suitability of their solutions.
Using Mathematics and Computational Thinking	Engineers use mathematics to develop models and test solutions. Engineers also use computers to assist with data analysis and simulations.
Constructing Explanations and Designing Solutions	Engineers use the engineering design process to develop solutions for problems. Engineers must balance many different factors (e.g., cost, esthetics, materials, safety) as they develop solutions. Additionally, engineers must make judgments about which solution might be the most fruitful depending on specific criteria.
Engaging in Argument From Evidence	Argumentation is the use of reasoning to create a claim supported by evidence. Engineers must be able to craft an argument to explain and defend their design decisions. Engineers should also be able to critique arguments created by others.
Obtaining, Evaluating, and Communicating Information	Engineers must be able to read and comprehend technical information from a variety of sources, including text. Additionally, engineers must be able to effectively communicate ideas and collaborate with others.

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Organization

This book begins with an initial essay on engineering design as a problem-solving approach. Next, the book is divided into three major parts. Part one, Engineering Design, illustrates the engineering design process in elementary, middle, and high school courses. Part two, Content Area Activities, provides ideas for supporting disciplinary content in life and environmental science, Earth science, and physical science by using engineering concepts and processes. Each subsection includes a diversity of articles at each grade level. Part three, After-School Programs, examines model after-school programs that can engage students in science and engineering activities.

National Research Council (NRC). 2012. *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: The National Academies Press. Available online at *www.nap.edu/catalog.php?record_id=13165*

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CHAPTER 9

Get a Grip!

A Middle School Engineering Challenge

By Suzanne A. Olds, Deborah A. Harrell, and Michael E. Valente

Investigating the field of engineering offers the opportunity for interdisciplinary, hands-on, inquiry-based units that integrate real-world applications; yet, many K–12 students are not exposed to engineering until they enter college. Get a Grip! is a problem-based unit that places middle school students in the role of engineers who are challenged to design and construct prosthetic arms for amputees in a war-torn country. The students use common materials to build arms that accomplish tasks requiring fine motor control and strength. A critical component of the unit is its ability to demonstrate to middle school students that strong, interdisciplinary knowledge is required to solve engineering problems. As such, it is a practical and efficient mode of interdisciplinary instruction meeting state and national standards in science, math, reading, and social studies.

This activity, the result of a partnership among university faculty, K–12 teachers, the Center for International Rehabilitation, and university engineering students, seeks to:

- inform middle school students about engineering as a career—what engineers do and the impact they have on society,
- engage middle school students in the engineering design process, and

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- encourage middle school students to draw on previously learned science concepts to accomplish a real-world engineering task.

Get a Grip! is a variable-length unit that challenges middle school student teams (groups of four or five) to design and construct a prosthetic arm from common materials for a 12-year-old Afghan girl who needs to eat and carry water from a nearby river to her home. Limiting the supplies to those that are readily available in that country constrains the students and reduces the materials cost of the unit.

Structure of the Unit

The Get a Grip! unit is composed of eight lessons that support the Grand Challenge (see Figure 9.1). This curriculum is available online at *www.middleschoolengineers.com*. The cost to participate is $50, which includes training and support to use the curricular materials, access to the teacher's manual (lesson plans, student handouts, teacher notes, answer keys, extension activities), plus the videos referenced in this article. This access charge will be used to sustain the support, training, and development of the module—and not for any profit. For the 2006–2007 academic year only, the NSF grant will cover the access charge for all participants. The training is online and can be taken at the user's convenience. Tools that can also be accessed from the site including a document repository, a discussion forum, and an e-mail list. The cost does not include the materials used to build the arms or the Pinto's Hope books. The materials to build the arms can be purchased and gathered for about $10–15 per box, with a much smaller replenishment cost. The *Pinto's Hope* books can be purchased from *www.iuniverse.com* for about $8 each, depending on the quantity ordered. Each lesson may be adjusted in length based on the content goals of the teacher. All lessons follow the Legacy Cycle framework, a format that incorporates findings from educational research on how people best learn (see Figure 9.2, p. 62). Research and theory behind this method of learning may be found in *How People Learn* (Bransford, Brown, and Cocking 1999). All lessons also include extension activities that enable the teacher and students to further explore some of the topics addressed. If all lessons are completed in full, the unit will take about 30 hours of classroom time (about seven weeks if done entirely within a science classroom). However, some teachers have trimmed this unit down to three or four weeks, depending on their needs. The unit can be reduced in length by offering some activities concurrently in other subjects. This project has been implemented by middle school teachers who are teaching over 140 students at any given time. They have found it helpful to keep the materials for the arms in one clear plastic box for each team. Each team can store their materials, sketches, and notes in the container. Teachers have also found it helpful to assign a role to each group member (facilitator, time keeper, recorder, spokesperson, and so on) and to distribute team evaluation sheets periodically to keep each group focused.

Before beginning the unit, students may gain an appreciation for the culture and plight of the amputee by reading the award-winning novel *Pinto's Hope* by module co-developer Deborah A. Harrell. While helpful, the book is not an essential part of the unit. The book is 64 pages and has questions within it for discussion. Many teachers have assigned this as outside reading or through the language arts class. *Pinto's Hope* is a story of a young boy's recovery from a land mine accident and his adaptation to his new prosthetic leg. The literature component to the unit offers cross-curricular enhancement lessons that sup-

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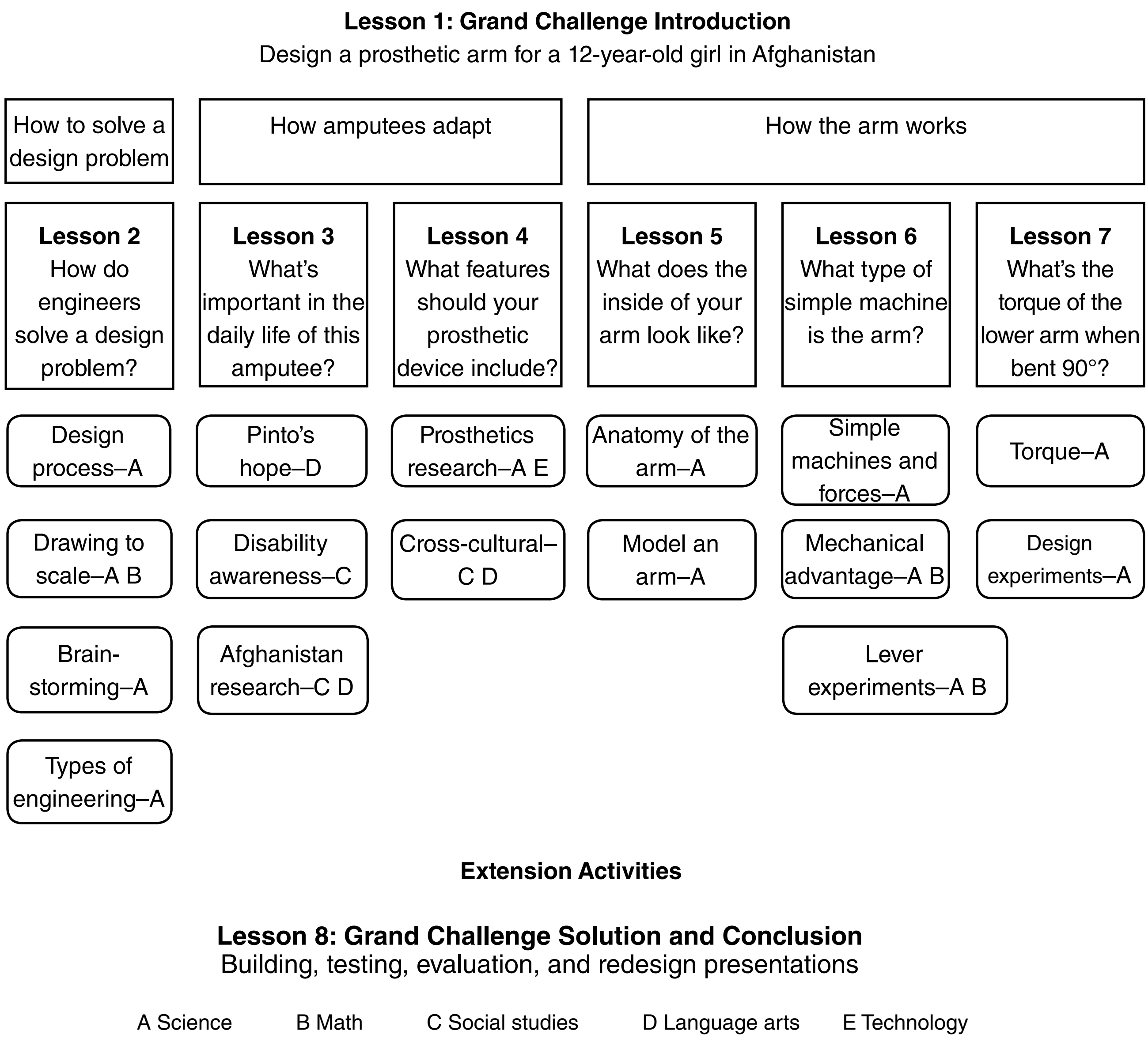
FIGURE 9.1.

Lesson structure



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port many of the Standards for English Language Arts (SELA).

On the first day of the unit, students are introduced to the Grand Challenge. The Grand Challenge, like the other challenges that initiate each lesson, is a question that engages students, and piques their curiosity. The Grand Challenge frames the unit and requires students to bring to bear their current knowledge and preconceptions about the topic. After viewing a downloadable five-minute video of the Grand Challenge, students generate ideas by writing responses to the following questions in their journals:

- What do you know about this problem?
- What ideas do you have for the prosthetic arm?
- What information do you need to solve this problem?

FIGURE 9.2.

Legacy Cycle framework

Challenge	A question that causes students to wonder about the topic and become engaged with it. The question frames the unit or lesson and requires students to bring to bear their current knowledge and preconceptions about the topic.
Generate ideas	A whole-class activity that causes students to display and compile their current knowledge/ideas/perceptions. Implementation of this step is often done in the form of questions: What things would you need to know to answer this question? What additional information would you like to have to help you answer this question?
Multiple perspectives	Outside resources that provide information related to the topic of the challenge. These tend to "point students in the right direction" for further inquiry.
Research and revise	Additional information that students receive/seek. This may be in the form of inquiry-based experiments, lectures, readings, websites, and so on. Students revise their original ideas based on new information.
Test your mettle	A set of activities in which students engage to help them explore their depth of knowledge. The goal is to create formative assessment situations that help them evaluate what they do not know so that they may return to the research-and-revise step again to learn more.
Go public	Final conclusion(s) that students display.

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The technique is similar to the KWHL technique for helping students activate prior knowledge, gather information, and think through a problem. (Students write what they **K**now about the problem, what they **W**ant to know about the problem, **H**ow they will find information to solve the problem, and what they have **L**earned.)

The students then obtain multiple perspectives by sharing their ideas with the class. We then categorize their responses, grouping them as much as possible into the subsequent challenges that will be addressed in the lesson:

- How do engineers solve a design problem?
- What is important in the daily life of this amputee?
- What design features are important to include in your prosthesis?
- What does the inside of your arm look like?
- What type of simple machine is the arm?
- What is the torque of your lower arm when it is bent 90°?

The second lesson has the class investigating how engineers solve design problems. To help generate ideas, the class considers how they will approach the problem of designing a prosthetic arm for a 12-year old girl, Laila, from Afghanistan. In this lesson, multiple perspectives take two forms—students hear their classmates' ideas and they watch a short video of engineers at work. The teacher plays the video one or two times, after which students revise their initial ideas about how an engineer solves a problem. Students gain additional insight into how engineers solve a problem in the research-and-revise activities of this lesson. In this second lesson, research-and-revise takes the form of team-based activities (brainstorming, drawing to scale and from multiple perspectives) that mirror the work of real-world engineers in search of a solution to a design challenge. In other lessons, research-and-revise takes the form of inquiry-based experiments, minilectures, readings, and internet research. This lesson, like all others, concludes with a formative assessment activity (usually a quiz or journal activity). Finally, students are asked to go public with the knowledge they have gained. This can be done in various ways—journal writing, drawing a cartoon, producing a brochure, creating a model, or giving a presentation. In this particular lesson, it is done through a journal activity titled "How do the activities in this lesson relate to the Grand Challenge?"

In lessons 3 and 4, students generate ideas about features their prostheses should include. To advance their initial ideas, students engage in a disability awareness activity and investigate cultural issues and prosthetic design. In the disability awareness activity, students discover some challenges amputees face. They try to tie their shoes, carry water, and make a jelly sandwich with one arm in a fist and the other arm functioning as usual. Another research and revise activity is researching the culture, geography, and demographics of Afghanistan via a guided internet search. Students then engage in a cross-cultural comparison, where they compare the needs of an amputee in Borneo to those of Jessie Sullivan, the world's first "Bionic Man." The final research and revise activity is an investigation of different types of prostheses and their uses.

All activities together prompt students to think about the user of their prosthesis and any special needs she may have due to culture, geography, or demographics. Assessments in the "test your mettle" section include a quiz and journal responses to: "How is life in your country different than life in Afghanistan? What

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do you think are the most important differences between an artificial limb you might use and one the amputee would use? In the "Go Public" section, students respond in their journal to the following questions: Besides eating and carrying water, what other daily tasks might the Afghan girl need to accomplish? What qualities or features might you include in your prosthesis to make these tasks easier for her? There are five extension activities related to these lessons. One example is to have students write their senator, urging the United States to sign the Ottawa Mine Ban Treaty. Another extension activity is to have students carry out their daily school activities for one entire school day using only one arm.

Lesson 5 transitions students to examining how a human arm operates. After students attempt to draw all the components in their arms (generate ideas), they are asked to bend their arm and discuss what makes the arm bend (multiple perspectives). In the research-and-revise section, they explore the anatomy of the arm via PowerPoint slides and an activity where they model a functional arm with cardboard and balloons. In the test-your-mettle section, students take an anatomy quiz and either journal or discuss the following questions: "Why is it necessary for doctors and biomedical engineers to learn about the anatomy of the human body before they can treat patients or create prosthetic devices for patients? What arm components is Laila missing (completely or partially) due to her amputation? What are some features you might include in your arm to compensate for the missing parts? If Laila's arm was amputated across the humerus instead, would you design your arm differently? If so, how?" In the go-public section, students revise their initial arm sketches and also create a model of a functioning body part.

Lessons 6 and 7 bring the students' attention to the biomechanics of the arm, as they engage in inquiry-based simple machines activities. Students are challenged to determine what type of simple machine the arm is, what mechanical advantage that offers, and how much effort it takes to keep their arm bent at a 90° angle. To address these questions, they engage in a Rube Goldberg activity and design their own experiments to determine the relationship between:

1. load position and effort;
2. load position and mechanical advantage; and
3. force, distance, and torque.

Students then relate the knowledge they gained in these lessons to the Grand Challenge by addressing questions such as: "Should the torque of your prosthetic arm be minimized or maximized? How could you achieve that?"

Students conclude the unit (Lesson 8) by addressing the Grand Challenge, which requires them to synthesize and apply the information they gained in the previous lessons. In this final lesson, the students design and build a prosthetic arm that meets the requirements of the Afghan girl. There is a suggested materials list included in the online packet; however, it does not need to be followed exactly and many items can be found in the classroom or by having students bring them in. Common items used by students in their final designs include cotton rags, pantyhose, plastic bottles, kindling wood, metal hooks, PVC pipe, and a lot of duct tape. Supplies can be purchased for about $10–15 per student team, and restocking is on the order of $5 per box.

Students should be given at least four class sessions to complete this phase of the design, although giving them six or seven sessions is better. Students work in teams of four or five. Once

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they build a prototype, they test it performing specific tasks (carrying water a distance of 10 m and setting it on a table 1 m high; and, in less than a minute, lifting three olives to their mouths one at a time without piercing their skin). Then they evaluate the arm on a testing rubric that is provided (or can be designed by them). The testing rubric includes the design requirements the students came up with (such as comfort, cost, adjustability, and ability to do the tasks). Eight design requirements are provided and the teacher can select those appropriate to each class. When their final design is complete (usually determined by time constraints rather than feeling they are "done"), their arms are tested and evaluated by a different group. The other group will also disassemble the arm, check the cost of the arm, and inventory the supply box.

Students "go public" with their final designs by making an oral presentation to the class. In this presentation, they cite the strengths and weaknesses of the arm and discuss what one additional material they would have liked to have used and how they would have used it. They also produce a brochure that advertises their artificial limb to a specific target audience (potential users of the limb or organizations that are interested in purchasing the limb). Extension activities include commercials, skits, and government proposals.

Meeting Standards

Get a Grip! A Middle School Engineering Challenge was developed in alignment with both the National Science Education Standards (NRC 1996) and the *Benchmarks for Science Literacy* (AAAS 1993). Each of the eight core lessons correlates with one or more of the standards. Since most states base their standards on these national guidelines, all of the lessons meet, and in some cases exceed, state and other local standards. Additionally, most lessons address objectives for language arts, reading, mathematics and social studies, supporting National Science Education Standards Program Standard B, which states, "The program of study in science for all students should be developmentally appropriate, interesting, relevant to students' lives; emphasize understanding through inquiry; and be connected with other school subjects." The guiding principal of Get a Grip! is summed up in the AAAS (1993) Benchmark 3a (The Nature of Technology—Design and Systems): "Perhaps the best way to become familiar with the nature of engineering and design is to do some" (p. 48).

Assessments and Conclusions

It is only appropriate to ask if students "got a grip" because of this project—that is, were the students able to demonstrate increased understanding of the engineering design process and an improved ability to apply it? Did they know more about engineering as a career? Did their understanding of basic science concepts improve? Did students gain awareness that technological design involves many other factors in addition to scientific issues? Yes, to all of the above! Several assessment tools were used to measure the effectiveness of each lesson. Pre- and postproject homework assignments and surveys helped us assess students' science, math, and engineering content knowledge as well as their views on these topics. The results indicate that participation in the project increased their understanding and interest in engineering, their enjoyment of science, and their simple machines content knowledge.

Because Get a Grip! explores the unusual topic of amputees, it engages the students like no other. The 1,000+ students who have tested the unit all report a high "fun" factor and a high "learn" factor. Most of the students can remember

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the design steps well after the unit's completion. Teachers as well are excited by its interdisciplinary nature, incredible efficiency, and links to current real-world problems.

Acknowledgment

Get a Grip! was initiated in September 2001 with funding from the National Science Foundation. This work was supported primarily by the Engineering Research Centers Program of the National Science Foundation under Award Number EEC-9876363.

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Internet Resource

Center for International Rehabilitation
www.cirnetwork.org

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Index

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—From the Introduction by editor Eric Brunsell

From the very first day you use them, the design challenges in this compendium will spur your students to jump right in and engage throughout the entire class. The activities reinforce important science content while illustrating a range of STEM skills. The 30 articles have been compiled from *Science and Children*, *Science Scope*, and *The Science Teacher*, NSTA's award-winning journals for elementary through high school.

***Integrating Engineering and Science in Your Classroom* will**

- excite students of all ages with activities involving everything from light sabers and egg racers to prosthetic arms and potatoes;
- apply to lessons in life and environmental science, Earth science, and physical science; and
- work well in traditional classrooms as well as after-school programs.

Next time you need an engaging STEM activity, you'll be glad you have this collection to help you blend meaningful and memorable experiences into your lessons. As editor Eric Brunsell promises, "By exposing students to authentic engineering activities, you can help students uncover the profession that makes the world work."

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ISBN: 978-1-936959-41-9

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