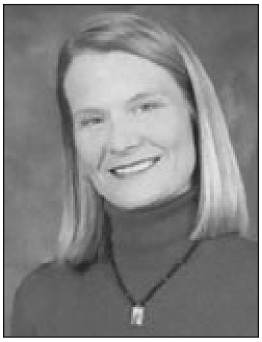
Engineering activities tap into the natural curiosity and creativity of all children.

Engineering Is Elementary

Christine M. Cunningham



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As our society becomes increasingly dependent on engineering and technology, it is more important than ever that everyone be aware of what engineers do and understand the uses and implications of the technologies they create. Yet few American citizens are technologically literate, largely because technology and engineering have not been taught in our schools (Pearson, 2004).

Children (and many adults) know shockingly little about technology and engineering. In fact, the vast majority believe the term "technology" refers only to electronics and computers and that engineering and science are basically the same (Lachapelle and Cunningham, 2007; Pearson and Young, 2002). To understand the human-made world in which we live, it is vital that we increase engineering and technological literacy among all people, even young children!

Children are born engineers—they are fascinated with designing their own creations, with taking things apart, and with figuring out how things work. In 2003, the Engineering is Elementary (EiE, *www.mos.org/eie*) project was initiated to take advantage of the natural curiosity of *all* children to cultivate their understanding and problem-solving in engineering and technology.

The EiE project staff worked closely with teachers and engineers to develop a research-based, standards-driven, classroom-tested curriculum that integrates engineering and technology concepts and skills and elementary science topics and mathematics learning, as well as literacy and social studies. In addition, EiE provides professional development workshops and resources to improve teachers' understanding of engineering concepts and to develop pedagogical methods for teaching engineering material.

EiE has four main goals:

1. Increase children's technological literacy.
2. Improve elementary educators' ability to teach engineering and technology.
3. Increase the number of schools in the United States that include engineering in their curricula.
4. Conduct research and assessments to further the first three goals and to develop a knowledge base on the teaching and learning of engineering at the elementary school level.

To accomplish these goals, EiE has developed curricular materials and resources, professional development workshops and resources for teachers and teacher educators, a system of national partnerships, and a research and assessment program.

Over the past six years, based on experience, observation, research, and collaboration, the EiE team has learned a great deal about teaching and "doing" engineering at the elementary level. This article presents some of the principles of the project and describes what we have learned so far. However, we know we still have much to learn! The EiE team continues to modify and improve existing materials and workshops, to experiment with new offerings, and to expand our knowledge, programs, and resources.

EiE has designed materials to engage students from marginalized and "at-risk" groups.

Design of the Curriculum: Criteria, Constraints, and Commitments

At its core, the purpose of EiE is to help children understand the human-made world around them. Initially the EiE team defined essential concepts and skills that are central to technological literacy at the elementary school level:

Knowledge (Know about/that):

- what engineering and technology are and what engineers do
- various fields of engineering
- nearly everything in the human world has been touched by engineering
- engineering problems have multiple solutions
- how society influences and is influenced by engineering
- how technology affects the world (both positively and negatively)
- engineers are from all races, ethnicities, and sexes and have various abilities/disabilities

Skills/Experience (Be able to do):

- engage in the engineering design process
- apply science and mathematics to engineering problems
- use creativity and careful thinking to solve problems
- envision one's own abilities as an engineer
- troubleshoot and learn from failure
- understand the central role of materials and their properties in engineering solutions

EiE's foundational principle is a deep commitment to engaging and interesting *all* children in engineering and science, particularly children in groups that have traditionally been underrepresented and underserved. From the beginning, EiE has designed materials to engage marginalized and "at risk" populations, such as girls, minorities, youngsters with disabilities, and children from low socioeconomic backgrounds.

In addition to outlining essential skills and concepts, the EiE team set forth a number of core criteria and constraints to guide product development and ensure that the materials and the engineering they portray are accessible and attractive to a wide variety of students. Thus EiE units and activities reflect the following considerations:

- Engineering design challenges must demonstrate how engineers help people, animals, or society.

- Projects must be set in a large, real-world context to show where and how engineering information and tasks might be relevant.
- Engineering role models must be of both sexes, from a variety of races and ethnicities, and have different abilities/disabilities and a wide range of hobbies and interests.
- Design challenges must be truly open-ended with more than one correct answer.
- Challenges must be amenable to evaluation by both qualitative and quantitative measures.
- Failure must be treated as a necessary and inherent part of engineering that invites subsequent improvements in designs.
- Steps in the process should be explicitly organized to build student skills progressively, without making the process formulaic.
- No previous familiarity with materials or terminology should be assumed.
- Addressing design challenges must require very low-cost, readily available materials.
- Activities must encourage a culture of collaboration and teamwork.
- Situations must create an atmosphere in which all students' ideas can be heard and considered.
- Activities must require that students engage in active, hands-on engineering.
- Materials must be easily scalable, up or down, to meet the needs of different kinds of learners.
- The overall focus must be on developing problem-solving skills.

The EiE team attempted to design materials that would mentor students as they "engineer." Our goal is to develop problems and contexts that are interesting and then invite students to have fun and envision themselves as engineers as they use their knowledge of science and engineering to design, create, and improve solutions.

Structure of the Curriculum

Engineering is a new subject for most elementary school teachers, and so far, only a few states (e.g., Massachusetts and Minnesota) have developed educational learning standards that include engineering at the elementary level. To facilitate the introduction of this new discipline in elementary classes, the EiE team adopted an integrated approach and selected science as the subject most closely connected to engineering. Based on a review of curricula and standards from across the nation, EiE staff identified 20 of the most commonly taught elementary school science topics. We then designed EiE units that build upon and reinforce these concepts through application. Each unit also connects to language arts, mathematics, and social studies skills and topics.

Each EiE engineering unit is based on a science topic (e.g., astronomy), revolves around a field of engineering (e.g., aerospace engineering), and highlights a technology from that field (e.g., parachutes). Projects are also set in different countries.[1] EiE projects are designed so teachers only use the units connected to the science topics they teach (Table 1).

EiE units reinforce science concepts through application.

Structure of Each Unit

All EiE units have a common structure consisting of a preparatory lesson designed to prompt students to think about engineering, technology, and the engineering design process and four unit lessons. The EiE unit guide provides teacher lesson plans, student duplication masters (worksheets), background resources for teachers, and assessment items. By design, the program requires that children DO engineering; there is no student textbook.

Lesson 1. Engineering Story. To provide a context for the unit, to introduce engineering to teachers through a comfortable medium (language arts), and to piggyback on the abundant time available for reading in elementary school classes, EiE units begin with an illustrated storybook. The stories, which are set in cultures and countries around the world, feature a child protagonist who confronts a real-world problem. An adult engineer in the child's life introduces the engineering design process and invites the child character

[1] For a table with information about all 20 units, see *http://www.mos.org/eie/20_unit.php.*

TABLE 1 A Sampling of EiE Units

EiE Unit Title	Science Topic	Engineering Field	Storybook (Setting)
Catching the Wind: Designing Windmills	Wind and Weather	Mechanical	Leif Catches the Wind (Denmark)
Water, Water Everywhere: Designing Water Filters	Water	Environmental	Saving Salila's Turtle (India)
Sounds Like Fun: Seeing Animal Sounds	Sound	Acoustical	Kwame's Sound (Ghana)
The Best of Bugs: Designing Hand Pollinators	Insects/Plants	Agricultural	Mariana Becomes a Butterfly (Dominican Republic)
An Alarming Idea: Designing Alarm Circuits	Electricity	Electrical	A Reminder for Emily (Australia)
Marvelous Machines: Making Work Easier	Simple Machines	Industrial	Aisha Makes Work Easier (USA)

to apply it to develop a solution to the problem. In the classroom, students are then challenged to solve a similar problem.

Lesson 2. A Broad View of an Engineering Field. The second lesson helps students develop a broad perspective on the engineering field of focus. Through hands-on activities, students learn about the kind of work done by engineers in that field and the technologies they produce.

Lesson 3. Scientific Data to Inform Engineering Design. The third lesson is designed to help students improve their understanding of underlying science concepts, explore available materials, and determine which properties of these materials are relevant to the challenge at hand. These lessons also help children recognize linkages between science, mathematics, and engineering. In this lesson, children collect and analyze scientific data they can refer to in Lesson 4 to inform their designs.

Lesson 4. Engineering Design Challenge. The unit culminates with an engineering design challenge. Following the five steps of the EiE engineering design process, students ask, imagine, plan, create, and improve solutions to an engineering problem (Figure 1).

The Unit Development Process

The design of the EiE curriculum is based on Wiggins and McTighe's (1998) "backward design" process, and the essential concepts and skills are closely linked with curricular development. The final curriculum design is shaped by the interplay of the EiE team's commitments, copious feedback from classroom teachers, and results from quantitative and qualitative assessments collected from students and teachers (Figure 2).

The curriculum development process for an EiE unit is intensive, cyclical, and structured to make use of qualitative and quantitative data from students and teachers to inform numerous revisions. Classroom testing is a hallmark of the EiE program; all lessons undergo at least two types of classroom testing—pilot testing and field testing—before they are finalized. Teachers for pilot and field tests are chosen to represent a wide range of schools with many different types of students.

The development process begins with a science topic. EiE staff review science curricula and standards to determine what elementary children will learn about this topic. Then, keeping in mind the science concepts, the field of engineering, and the cultural setting, curriculum developers experiment to generate a design challenge that meets project criteria. Once a viable option has been found, 15 regional pilot teachers review the initial

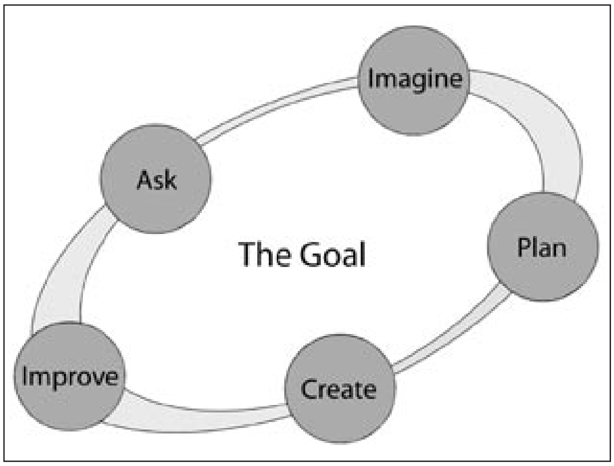

FIGURE 1 The EiE engineering design process.

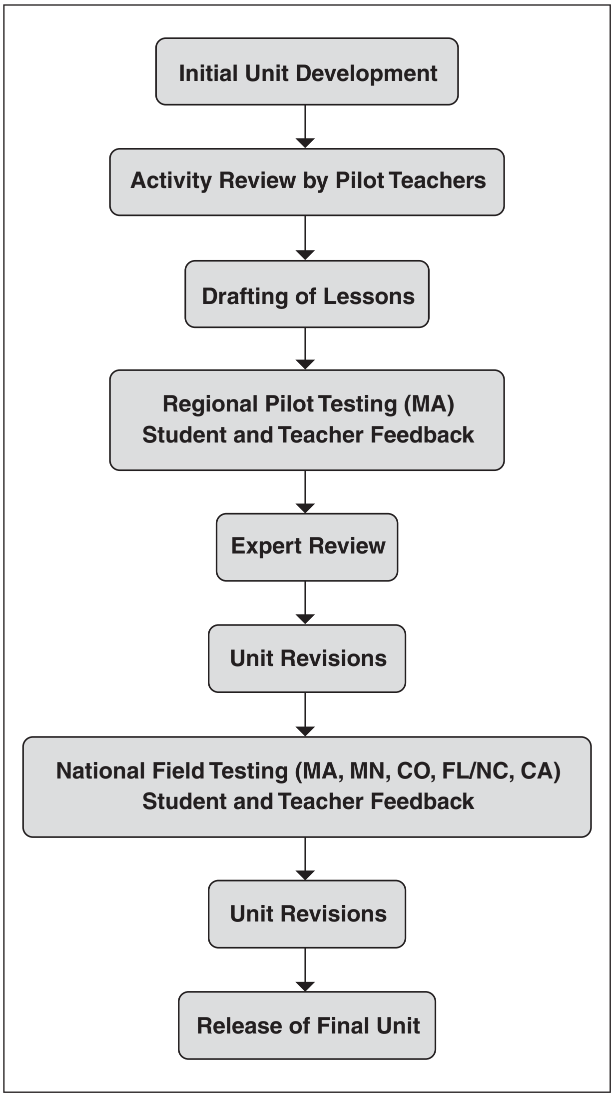

FIGURE 2 The EiE curriculum development process.

ideas and drafts of materials and provide feedback. The lessons are then rewritten based on their comments.

Next the pilot teachers who teach that science topic try teaching the fledgling unit to a class. EiE developers observe every new lesson in at least two different classes with students of different ages and take copious notes about what works and what doesn't. Students then complete pre- and post-class assessments, and pilot teachers complete a detailed feedback form about the lessons in the unit. Reviews of the materials are also solicited from experts in the particular field of engineering and cultural consultants.

The unit is then revised based on observations of pilot tests, feedback, reviews, and assessments. Next the unit is field tested nationally in five states (Massachusetts, California, Colorado, Florida/North Carolina, and Minnesota) by about 60 teachers. Again students and teachers provide feedback, and lessons are observed in Massachusetts classes. These data inform the final revision of the unit.

This development process is extremely time and labor intensive! It takes more than 3,000 hours of EiE staff time and more than two-and-a-half years to develop each unit (a unit generally takes about 6 to 8 hours of classroom time to implement). But, as the final curricular materials and evaluations have shown, those efforts pay off. When EiE materials are finally released, they can help almost any elementary educator teach engineering in a way that generates a contagious excitement among students.

Lessons Learned

In the years we have spent developing materials and observing activities, EiE has learned a number of lessons, some of which are listed below:

- Testing EiE units and specific lessons in classrooms is critical to their success. Even after five years of development experience, EiE lessons are significantly improved by repeated classroom testing. Nothing can replace real-world trials of a lesson and unit in diverse classrooms.
- Children, even young children, are capable of much more complex engineering thinking than we originally anticipated. They can balance multiple constraints and criteria, compare the merits of designs, and represent their designs from different points of view.
- Contextualized design challenges appeal to children. Many students, particularly children who may not show an initial interest or talent for science and mathematics, have been drawn into an EiE engineering challenge through the language arts or social studies hook. They may relate to or be fascinated by the country in which the unit is set, a storybook character, or the story line.
- Engineering has the potential to reach ALL students. Teachers regularly report that struggling, unremarkable, or withdrawn students blossom during EiE lessons. These students contribute, stay on task, and often voluntarily continue the engineering challenges in their out-of-school time.
- National, controlled evaluation studies have shown that student perceptions of engineering and technology, their understanding of engineering, and their

understanding of relevant science are greatly improved by participation in EiE activities. Early results also suggest that using EiE materials can narrow, or even close, the achievement gap between children from high and low socioeconomic backgrounds.

Teacher Professional Development

Helping children develop knowledge and skills requires that teachers understand, feel comfortable with, and can teach the relevant subject matter. Because engineering has barely been taught at all at the elementary level, the vast majority of elementary teachers have had very little education about or experience with this subject. Therefore, the EiE project also focuses on helping elementary educators learn to teach engineering by providing resources and professional development workshops for teachers. Professional development workshops vary in length from two hours to several weeks.

Workshops give teachers an opportunity to model engineering education based on engaged, open-ended problem solving.

Through EiE workshops, we can demystify engineering and defuse elementary teachers' feelings of ineptitude, at the same time reinforcing their comfort level and confidence in their grasp of engineering materials. During workshop sessions, participants engage with EiE materials, engage in design challenges, and think about how this new subject matter can be integrated into the other subjects they teach.

After running more than 300 workshops, the EiE team has developed a common structure that encompasses many elements essential to high-quality professional development. During an EiE workshop, teachers working in small groups engage in a series of activities. The first one leads them to develop a definition of technology aligned with the definition adopted by EiE. Next they are presented with a challenge to solve; in discussions afterward they discover that they naturally used an engineering design process to do so. At this point, EiE's five-step Engineering Design Process is introduced.

Once teachers understand the philosophy and structure of the EiE project, they work through all four lessons of a unit. As they become more familiar with the program and with what elementary school level engineering involves, they become more confident in their own abilities.

Mentor-teachers (who often co-lead the sessions) answer participants' questions and offer advice and perspectives about the program. During small group breakout sessions, participants discuss next steps for classroom implementation. Web-based EiE Educator Resources provide continuing support for teachers when they return to their schools.

Lessons Learned

- Perhaps the biggest hurdle to getting engineering into classrooms is teachers' initial fears of the word "engineering," which they perceive as a discipline that can be done, and taught, only by "super-smart" students and teachers.
- Workshops provide an opportunity for them to model engineering instruction. Because of teachers' lack of exposure, experience, and education about engineering, we are presented with a unique situation—teachers do not have ingrained habits of teaching or competing instructional philosophies or paradigms that have to be modified. Therefore, we can model from scratch what we think engineering instruction should be—models that are consistent with engaged, open-ended problem solving.
- In workshop sessions, teachers do what they will do in their classrooms. We have learned that an activity, innovation, or pedagogical strategy is much more likely to be implemented in the classroom if teachers have engaged with it themselves first. In EiE workshops, teachers always work through a unit by doing the lessons. Becoming familiar with the materials and the student handouts helps them visualize how they will use them in their classes. It also helps them understand which aspects of the lessons are most likely to cause students difficulty or to require overcoming misconceptions.
- Follow-up workshops are valuable. Because of teachers' lack of classroom experience with engineering (either as teachers or students), metacognitive or experience-based discussions that enrich professional development programs may be limited in the initial workshop. We encourage teachers to return for a

follow-up workshop after they have begun teaching engineering. The follow-up session usually results in a much richer discussion based on classroom experience and the challenges that arose.

- Engineering can change the way teachers teach. Teachers report that their engineering professional development experiences, the first time many encountered a truly open-ended problem with no single "correct" answer, have fundamentally changed the way they teach science and other subjects. They report introducing open-ended inquiry in their lessons. In fact, this change has been one of the most unexpected and most powerful results of our engineering professional development program.

National Dissemination through Hub Sites

In response to early interest in EiE from schools and organizations across the country engaged in engineering outreach, EiE developed models for national dissemination. To reach teachers and students on a national scale, the project involves partnering with complementary organizations interested or engaged in teacher or student science or engineering education to leverage their talent, resources, and professional networks as an EiE Hub Site—an organization or institution that already offers professional development and is interested in leading EiE efforts in its area.

Initially, potential partners attend an EiE Teacher Educator Institute, a two-and-a-half-day workshop that introduces teacher educators to EiE, engages them in engineering challenges, and exposes them to various structures, models, and resources for offering professional development programs. Based on teacher educators' requests, the EiE team has produced unit-specific EiE Professional Development Guides to support workshops offered by other providers of professional development.

Participants then return to their home state or region, where they are familiar with the educational standards, have established networks of local teachers to work with, and are aware of possible funding opportunities. The EiE goal is to provide a solid structure and set of materials for teaching elementary engineering and then encourage, promote, and celebrate creative ideas in sites around the country that pass on this vision. Teacher educators in at least 17 states now offer EiE workshops. With their help, the EiE program has reached more than 15,000 teachers and one million children in all 50 states—so far!

Contributions from Practicing Engineers

From the beginning, engineers have been closely involved in the creation of the EiE curriculum; in bringing EiE to teachers, schools, and districts; and in advocating for including engineering in the elementary school curriculum. Developers of each EiE unit are advised by engineers in the field of focus (e.g., acoustical engineers), who answer questions as they arise and review drafts of the unit binder and storybook to ensure that the content, although simplified, is still accurate.

Engineers have helped raise awareness in schools by introducing EiE curricular materials and have advocated with teachers and administrators that engineering be included in grade school education. Engineers have also volunteered to help teachers in classrooms implement EiE lessons. They provide an extra set of hands to assist in preparing and managing materials and guidance on open-ended projects. In some classes, teachers ask engineers to answer students' questions or talk about their work.

Engineering companies have "adopted" classrooms, schools, and districts to encourage them to adopt and use EiE. Some provide funding for the purchase of EiE materials and/or opt to provide volunteers to support teachers in implementing the materials.

Conclusion

Educating a generation that understands what engineering and technology are and their importance to our society and our world will require the energies, creativity, and talents of teacher educators, teachers, engineers, parents, and children. By developing high-quality, accessible, heavily tested curricular materials, professional development programs, and partnerships, the EiE project is developing resources that can guide and promote elementary engineering education nationwide.

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