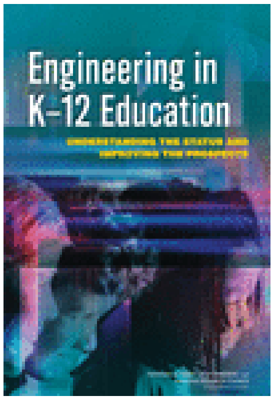
Free Executive Summary



Engineering in K-12 Education: Understanding the Status and Improving the Prospects

Linda Katehi, Greg Pearson, and Michael Feder, Editors; Committee on Kâ€“12 Engineering Education; National Academy of Engineering and National Research Council

ISBN: 978-0-309-13778-2, 234 pages, 6 x 9, paperback (2009)

Engineering in K-12 Education reviews the scope and the impact of engineering education today and makes several recommendations to address curriculum, policy, and funding issues. The book also analyzes a number of K-12 engineering curricula in depth and discusses what is known from the cognitive sciences about how children learn engineering-related concepts and skills.

Summary

Although K–12 engineering education has received little attention from most Americans, including educators and policy makers, it has slowly been making its way into U.S. K–12 classrooms. Today, several dozen different engineering programs and curricula are offered in school districts around the country, and thousands of teachers have attended professional development sessions to teach engineering-related coursework. In the past 15 years, several million K–12 students have experienced some formal engineering education.

The presence of engineering in K–12 classrooms is an important phenomenon, not because of the number of students impacted, which is still small relative to other school subjects, but because of the implications of engineering education for the future of science, technology, engineering, and mathematics (STEM) education more broadly. Specifically, as elaborated in the full report, K–12 engineering education may improve student learning and achievement in science and mathematics; increase awareness of engineering and the work of engineers; boost youth interest in pursuing engineering as a career; and increase the technological literacy of all students. The committee believes engineering education may even act as a catalyst for a more interconnected and effective K–12 STEM education system in the United States. Achieving the latter outcome will require significant rethinking of what STEM education can and should be.

In recent years, educators and policy makers have come to a consensus that the teaching of STEM subjects in U.S. schools must be improved. The focus on STEM topics is closely related to concerns about U.S. competitiveness in the global economy and about the development of a workforce with the knowledge and skills to address technical and technological issues. To date, most efforts to improve STEM education have been concentrated on mathematics and science, but an increasing number of states and school districts have been adding technology education to the mix, and a smaller but significant number have added engineering.

In contrast to science, mathematics, and even technology education, all of which have established learning standards and a long history in the K–12 curriculum, the teaching of engineering in elementary and secondary schools is still very much a work in progress. Not only have no learning standards been developed, little is available in the way of guidance for teacher professional development, and no national or state-level assessments of student accomplishment have been developed. In addition, no single organization or central clearinghouse collects information on K–12 engineering education.

Thus a number of basic questions remain unanswered. How is engineering taught in grades K–12? What types of instructional materials and curricula have been used? How does engineering education "interact" with other STEM subjects? In particular, how has K–12 engineering instruction incorporated science, technology, and mathematics concepts, and how has it used these subjects as a context for exploring engineering concepts? Conversely, how has engineering been used as a context for exploring science, technology, and mathematics concepts? And what impact have various initiatives had? Have they, for instance, improved student achievement in science or mathematics or stimulated interest among students in pursuing careers in engineering?

In 2006 the National Academy of Engineering and National Research Council Center for Education established the Committee on K–12 Engineering Education to begin to address these and other questions. Over a period of two years, the committee held five face-to-face meetings, two of which accompanied information-gathering workshops. The committee also commissioned an analysis of existing K–12 engineering curricula; conducted reviews of the literature on areas of conceptual learning related to engineering, the development of engineering skills, and the impact of K–12 engineering education initiatives; and collected preliminary information about a few pre-college engineering education programs in other countries.

The goal of the project was to provide carefully reasoned guidance to key stakeholders regarding the creation and implementation of K–12 engineering curricula and instructional practices, focusing especially on the connections among science, technology, engineering, and mathematics education. The project had these specific objectives:

- Survey the landscape of current and past efforts to implement engineering-related K–12 instructional materials and curricula in the United States and other nations;
- Review evidence related to the impact of these initiatives, to the extent such information is available;
- Describe the ways in which K–12 engineering content has incorporated science, technology, and mathematics concepts, used these subjects as context to explore engineering concepts, or used engineering as a context to explore science, technology, and mathematics concepts; and
- Report on the intended learning outcomes of K–12 engineering education initiatives, taking into account student age, curriculum focus (e.g., science vs. technology education), program orientation (e.g., general education vs. career/vocational education), and other factors.

In meeting the goal and objectives, the project focused on three key issues and three related guiding questions:

- There are multiple perspectives about the purpose and place of engineering in the K–12 classroom. These points of view lead to emphases on very different outcomes. QUESTION: What are realistic and appropriate learning outcomes for engineering education in K–12?
- There has not been a careful analysis of engineering education within a K–12 environment that looks at possible subject intersections. QUESTION: How might engineering education complement the learning objectives of other content areas, particularly science, technology, and mathematics, and how might these other content areas complement learning objectives in engineering education?
- There has been little if any serious consideration of the systemic changes in the U.S. education system that might be required to enhance K–12 engineering education. QUESTION: What educa-

tional policies, programs, and practice at the local, state, and federal levels might permit meaningful inclusion of engineering at the K–12 level in the United States?

The committee believes this report will be of special interest to individuals and groups interested in improving the quality of K–12 STEM education in this country. But engineering educators, policy makers, employers, and others concerned about the development of the country's technical workforce will also find much to ponder. The report should prove useful to advocates for greater public understanding of engineering, as well as to those working to boost citizens' technological and scientific literacy. Finally, for educational researchers and cognitive scientists, the document exposes a rich set of questions related to how and under what conditions students come to understand engineering.

GENERAL PRINCIPLES FOR K–12 ENGINEERING EDUCATION

The specifics of how engineering is taught vary from school district to school district, and what takes place in classrooms in the name of engineering education does not always align with generally accepted ideas about the discipline and practice of engineering. This is not to suggest that K–12 students should be treated like little engineers, but when a school subject is taught for which there is a professional counterpart, there should be a conceptual connection to post-secondary studies and to the practice of that subject in the real world.

The committee set forth three general principles for K–12 engineering education.

Principle 1. K–12 engineering education should emphasize engineering design.

The design process, the engineering approach to identifying and solving problems, is (1) highly iterative; (2) open to the idea that a problem may have many possible solutions; (3) a meaningful context for learning scientific, mathematical, and technological concepts; and (4) a stimulus to systems thinking, modeling, and analysis. In all of these ways, engineering design is a potentially useful pedagogical strategy.

Principle 2. K–12 engineering education should incorporate important and developmentally appropriate mathematics, science, and technology knowledge and skills.

Certain science concepts as well as the use of scientific inquiry methods can support engineering design activities. Similarly, certain mathematical concepts and computational methods can support engineering design, especially in service of analysis and modeling. Technology and technology concepts can illustrate the outcomes of engineering design, provide opportunities for "reverse engineering" activities, and encourage the consideration of social, environmental, and other impacts of engineering design decisions. Testing and measurement technologies, such as thermometers and oscilloscopes; software for data acquisition and management; computational and visualization tools, such as graphing calculators and CAD/CAM (i.e., computer design) programs; and the Internet should be used, as appropriate, to support engineering design, particularly at the high school level.

Principle 3. K–12 engineering education should promote engineering habits of mind.

Engineering "habits of mind"[1] align with what many believe are essential skills for citizens in the 21st century.[2] These include (1) systems thinking, (2) creativity, (3) optimism, (4) collaboration, (5) communication, and (6) attention to ethical considerations. Systems thinking equips students to recognize essential interconnections in the technological world and to appreciate that systems may have unexpected effects that cannot be predicted from the behavior of individual subsystems. Creativity is inherent in the engineering design process. Optimism reflects a world view in which possibilities and opportunities can be found in every challenge and an understanding that every technology can be improved. Engineering is a "team sport"; collaboration leverages the perspectives, knowledge, and capabilities of team members to address a design challenge. Communication is essential to effective collaboration, to understanding the particular wants and needs of a "customer," and to explaining and justifying the final design solution. Ethical considerations draw attention to the impacts of engineering on people and the environment; ethical considerations include possible unintended consequences

[1]The committee has adopted the term "habits of mind," as used by the American Association for the Advancement of Science in *Science for All Americans* (1990), to refer to the values, attitudes, and thinking skills associated with engineering.

[2]See, for example, The Partnership for 21st Century Skills, *www.21stcenturyskills.org*.

of a technology, the potential disproportionate advantages or disadvantages of a technology for certain groups or individuals, and other issues.

These principles, particularly Principle 3, should be considered aspirational rather than a reflection of what is present in current K–12 engineering education efforts or, indeed, in post-secondary engineering education.

THE SCOPE OF K–12 ENGINEERING EDUCATION

No reliable data are available on the precise number of U.S. K–12 students who have been exposed to engineering-related coursework. With a few notable exceptions, the first formal K–12 engineering programs in the United States emerged in the early 1990s. Since that time, fewer than 6 million students have had some kind of formal engineering education. By comparison, the estimated enrollment for grades pre-K–12 for U.S. public and private schools in 2008 was nearly 56 million.

No reliable data are available on the number of teachers involved in K–12 engineering education. The committee estimates that only about 18,000 teachers have received pre- or in-service professional development training to teach engineering-related coursework. The relatively small number of curricular and teacher professional development initiatives for K–12 engineering education were developed independently, often have different goals, and vary in how they treat engineering concepts, engineering design, and relationships among engineering and the other STEM subjects.

Although engineering education represents a relatively small slice of the K–12 educational pie, activity in this arena has increased significantly, from almost no curricula or programs 15 years ago to several dozen today. The future of K–12 engineering education will depend, at least in part, on whether it continues to be taught as a separate subject or whether engineering becomes a catalyst for more interconnected STEM education.

IMPACTS OF K–12 ENGINEERING EDUCATION

A variety of claims have been made for the benefits of teaching engineering to K–12 students, ranging from improved performance in related subjects, such as science and mathematics, and increased technological literacy to improvements in school attendance and retention, a better understanding of what engineers do, and an increase in the number of students who pursue careers in engineering. Only limited reliable data are available to support these claims. The most intriguing possible benefit of K–12 engineering education relates to improved student learning and achievement in mathematics and science, but even here, the paucity and small size of studies and their uneven quality cannot support unqualified claims of impact. For engineering education to become a mainstream component of K–12 education, there will have to be much more, and much higher quality, outcomes-based data.

RECOMMENDATION 1. Foundations and federal agencies with an interest in K–12 engineering education should support long-term research to confirm and refine the findings of earlier studies of the impacts of engineering education on student learning in STEM subjects, student engagement and retention, understanding of engineering, career aspirations, and technological literacy.

RECOMMENDATION 2. Funders of new efforts to develop and implement curricula for K–12 engineering education should include a research component that will provide a basis for analyzing how design ideas and practices develop in students over time and determining the classroom conditions necessary to support this development. After a solid analytic foundation has been established, a rigorous evaluation should be undertaken to determine what works and why.

THE NATURE OF K–12 ENGINEERING EDUCATION

Based on extensive reviews of the research literature and curricular materials, the committee concluded that there is no widely accepted vision of what K–12 engineering education should include or accomplish. This lack of consensus reflects the ad hoc development of educational materials in engineering and that no major effort has been made to define the content of K–12 engineering in a rigorous way.

Curriculum Content

The committee's review of curricula revealed that engineering design, the central activity of engineering, is predominant in most K–12 curricular and professional development programs. The treatment of key ideas in engineering, many closely related to engineering design, is much more uneven and, in some cases, suggests a lack of understanding on the part of curriculum developers. These shortcomings may be the result, at least in part, of the absence of a clear description of which engineering knowledge, skills, and habits of mind are most important, how they relate to and build on one another, and how and when (i.e., at what age) they should be introduced to students. In fact, it seems that no one has attempted to specify age-appropriate learning progressions in a rigorous or systematic way; this lack of specificity or consensus on learning outcomes and progressions goes a long way toward explaining the variability and unevenness in the curricula.

Curriculum Connections

Although there are a number of natural connections between engineering and the three other STEM subjects, existing curricula in K–12 engineering education do not fully explore them. For example, scientific investigation and engineering design are closely related activities that can be mutually reinforcing. Most curricula include some instances in which this connection is exploited (e.g., using scientific inquiry to generate data that can inform engineering design decisions or using engineering design to provide contextualized opportunities for science learning), but the connection is not systematically emphasized to improve learning in both domains. One option, which was evident in several of the curricula we reviewed, is to use engineering as a pedagogical strategy for science laboratory activities.

Similarly, mathematical analysis and modeling are essential to engineering design, but very few curricula or professional development initiatives reviewed by the committee used mathematics in ways that support modeling and analysis. The committee believes that K–12 engineering can contribute to improvements in students' performance and understanding of certain mathematical concepts and skills.

RECOMMENDATION 3. The National Science Foundation and/or U.S. Department of Education should fund research to determine how science inquiry and mathematical reasoning can be connected to engineering design in K–12 curricula and teacher professional development. The research should cover the following specific areas:

- the most important concepts, skills, and habits of mind in science and mathematics that can be taught effectively using an engineering design approach;
- the circumstances under which students learn important science and mathematics concepts, skills, and habits of mind through an

engineering-design approach as well or better than through science or mathematics instruction;
- how engineering design can be used as a pedagogical strategy in science and mathematics instruction; and
- the implications for professional development of using engineering design as a pedagogical tool for supporting science and mathematics learning.

Finally, our review of curricula showed that technology in K–12 engineering education has primarily been used to illustrate the products of engineering and to provide a context for thinking about engineering design. There were few examples of engineering being used to elucidate ideas related to other aspects of technological literacy, such as the nature and history of technology and the cultural, social, economic, and political dimensions of technology development.

Professional Development Programs

Compared with professional development opportunities for teaching other STEM subjects, the opportunities for engineering are few and far between. Nearly all in-service initiatives are associated with a few existing curricula, and many do not have one or more of the characteristics (e.g., activities that last for at least one week, ongoing in-classroom or online support following formal training, and opportunities for continuing education) that have been proven to promote teacher learning.

The committee found no pre-service initiatives that are likely to contribute significantly to the supply of qualified engineering teachers in the near future. Indeed, the "qualifications" for engineering educators at the K–12 level have not even been described. Graduates from a handful of teacher preparation programs have strong backgrounds in STEM subjects, including engineering, but few if any of them teach engineering classes in K–12 schools.

RECOMMENDATION 4. The American Society for Engineering Education (ASEE), through its Division of K–12 and Pre-College Education, should begin a national dialogue on preparing K–12 engineering teachers to address the very different needs and circumstances of elementary and secondary teachers and the pros and cons of establishing a formal credentialing process. Participants in the dialogue should include leaders in K–12 teacher education in mathematics, science, and technology; schools of education and engineering; state departments of education; teacher licensing and certification groups; and STEM program accreditors. ASEE should consult with the National Center for Engineering and Technology Education, which has conducted research on this topic.

Diversity

The lack of diversity in post-secondary engineering education and the engineering workforce in the United States is well documented. Based on evaluation data, analysis of curriculum materials, anecdotal reports, and personal observation, the committee concluded that lack of diversity is probably an issue for K–12 engineering education as well. This problem is manifested in two ways. First, the number of girls and underrepresented minorities who participate in K–12 engineering education initiatives is well below their numbers in the general population. Second, with a few exceptions, curricular materials do not portray engineering in ways that seem likely to excite the interest of students from a variety of ethnic and cultural backgrounds. For K–12 engineering education to yield the many benefits its supporters claim, access and participation will have to be expanded considerably.

RECOMMENDATION 5. Given the demographic trends in the United States and the challenges of attracting girls, African Americans, Hispanics, and some Asian subpopulations to engineering studies, K–12 engineering curricula should be developed with special attention to features which appeal to students from these underrepresented groups, and programs that promote K–12 engineering education should be strategic in their outreach to these populations. Both curriculum developers and outreach organizations should take advantage of recent market research that suggests effective ways of communicating about engineering to the public.

POLICY AND PROGRAM ISSUES

Although many unanswered questions about K–12 engineering education remain, engineering is being taught in K–12 schools around the country, and it appears that the trend is upward. Thus it is imperative that we begin to think about ways to guide and support engineering education in the future. An underlying question for policy makers is how engineering concepts, skills, and habits of mind should be introduced into the school curriculum. There are at least three options—ad hoc infusion, stand-alone courses, and interconnected STEM education. These options vary in terms of ease of implementation:

- Ad hoc infusion, or introduction, of engineering ideas and activities (i.e., design projects) into existing science, mathematics, and technology curricula is the most direct and least complicated option, because implementation requires no significant changes in school structure. The main requirements would be (1) willingness on the part of teachers and (2) access to instructional materials. Ideally, teachers would also have a modicum of engineering pedagogical content knowledge to deliver the new material effectively. The ad hoc option is probably most useful for providing an introductory exposure to engineering ideas rather than a deep understanding of engineering principles and skills.
- Stand-alone courses for engineering, an option required for implementing many of the curricula reviewed for this project, presents considerably more challenges for teachers and schools. In high schools, the new material could be offered as an elective. If that is not possible, it would either have to replace existing classes or content, perhaps a science or technology course, or the school day would have to be reconfigured, perhaps lengthened, to accommodate a new course(s) without eliminating existing curricular material. Stand-alone courses would also require teacher professional development and approval of the program at various levels. This option has the potential advantage of providing a more in-depth exposure to engineering.
- Fully integrated STEM education, that is, using engineering concepts and skills to leverage the natural connections between STEM subjects, would almost certainly require changes in the structure and practices of schools. Research would be necessary to develop and test curricula, assessments, and approaches to teacher professional development. New integrated STEM programs or "pilot schools" might be established to test changes before they are widely adopted.

These three options, as well as others that are not described here, are not mutually exclusive. Indeed, the committee believes that implementation should be flexible, because no single approach is likely to be acceptable or feasible in every district or school.

Whichever options are implemented, planners must take into account the "technical core" of education, that is, what happens in the classroom between the teacher, the student, and the content. One way to access the technical core is to work toward "coherence" by creating educational systems with standards, curricula, professional development, and student assessments and school leadership that supports the need for change.

RECOMMENDATION 6. Philanthropic foundations or federal agencies with an interest in STEM education and school reform should fund research to identify models of implementation for K–12 engineering education that embody the principles of coherence and can guide decision making that will work for widely variable American school systems. The research should explicitly address school populations that do not currently have access to engineering studies.

The need for qualified teachers to teach engineering in K–12 classrooms raises a number of policy and program issues. The current ad hoc approach of mostly in-service training may not be adequate to train enough teachers, if K–12 engineering continues to grow. A variety of traditional and alternative mechanisms should be evaluated as part of the initiative suggested in Recommendation 4.

INTEGRATED STEM EDUCATION

During the course of this project, the committee focused increasingly on the potential of using engineering education as a catalyst for improving STEM education in general, about which serious concerns have been raised among policy makers, educators, and industry managers. So far, the role of either technology education or engineering education has rarely been mentioned in these concerns. The STEM acronym is more often used as shorthand for science or mathematics education; even references to science and mathematics tend to be "siloed," that is, treated largely as separate entities. In other words, as STEM education is currently structured and implemented in U.S. classrooms, it does not reflect the natural connections among the four subjects, which are reflected in the real world of research and technology development.

The committee believes the "siloed" teaching of STEM subjects has impeded efforts to increase student interest and improve performance in science and mathematics. It also inhibits the development of technological and scientific literacy, which are essential to informed citizens in the 21st century. The committee believes that increasing the visibility of technology and, especially, engineering in STEM education in ways that address the interconnections in STEM teaching and learning could be extremely important. Ideally, all K–12 students in the United States should have the option of experiencing some form of formal engineering studies. We are a long way from that situation now.

In the committee's vision for STEM education in U.S. K–12 schools, all students who graduate high school will have a level of STEM literacy sufficient to (1) ensure their successful employment, post-secondary education, or both, and (2) prepare them to be competent, capable citizens in our technology-dependent, democratic society. Because of the natural connections of engineering education to science, mathematics, and technology, it might serve as a catalyst for achieving this vision. The committee was not asked to determine the qualities that characterize a STEM-literate person, but this would be a worthwhile exercise for a future study.

RECOMMENDATION 7. The National Science Foundation and the U.S. Department of Education should support research to characterize, or define, "STEM literacy." Researchers should consider not only core knowledge and skills in science, technology, engineering, and mathematics, but also the "big ideas" that link the four subject areas.

Pursuing the goal of STEM literacy in K–12 schools will require a paradigm shift by students, teachers, administrators, textbook publishers, and policy makers, as well as by the many scientists, technologists, engineers, and mathematicians involved in K–12 education. However, the committee believes that, as a result of that shift, students would be better prepared for life in the 21st century and would have the tools they need to make informed career decisions or pursue post-secondary education. In addition, integrated STEM education could improve teaching and learning in all four STEM subjects by forcing a reevaluation of the currently excessive expectations for STEM teachers and students. The committee is not suggesting a "dumbing-down" process. On the contrary, this is a call for more in-depth knowledge in fewer key STEM areas and for more time to be devoted to the development of a wider range of STEM skills, such as engineering design and scientific inquiry.

Meaningful improvements in the learning and teaching of engineering—and movement toward integrated STEM education—will not come easily or quickly. Progress will be measured in decades, rather than months or years. The necessary changes will only happen with a sustained commitment of financial resources, the support of policy makers and other leaders, and the efforts of many individuals in and outside K–12 schools. Despite these challenges, the committee is hopeful, the potential for enriching and improving K–12 STEM education is real, and engineering education can be the catalyst.

Engineering in K–12 Education

UNDERSTANDING THE STATUS AND IMPROVING THE PROSPECTS

Committee on K–12 Engineering Education

Linda Katehi, Greg Pearson, and Michael Feder, *Editors*

NATIONAL ACADEMY OF ENGINEERING *AND*
NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

THE NATIONAL ACADEMIES PRESS 500 Fifth Street, N.W. Washington, DC 20001

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This study was supported by a grant between the National Academy of Sciences and Stephen D. Bechtel, Jr. Additional support was provided by the National Science Foundation (Contract/Grant No. DRL-0935879) and PTC, Inc. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

Library of Congress Cataloging-in-Publication Data

Engineering in K–12 education : understanding the status and improving the prospects / Committee on K–12 Engineering Education ; Linda Katehi, Greg Pearson, and Michael Feder, editors.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-309-13778-2 (pbk.) — ISBN 978-0-309-13779-9 (pdf) 1. Engineering—Study and teaching (Elementary)—United States. 2. Engineering—Study and teaching (Secondary)—United States. I. Katehi, Linda. II. Pearson, Greg. III. Feder, Michael. IV. Committee on K–12 Engineering Education.
LB1594.E54 2009
620.0071—dc22
2009028717

Copies of this report are available from the National Academies Press, 500 Fifth Street, N.W., Lockbox 285, Washington, DC 20055; (800) 624-6242 or (202) 334-3313 (in the Washington metropolitan area); Internet, http://www.nap.edu

Printed in the United States of America

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

www.national-academies.org

COMMITTEE ON K–12 ENGINEERING EDUCATION

LINDA P.B. KATEHI, NAE (*chair*), University of California, Davis
LYNN BASHAM, Virginia Department of Education, Richmond, Virginia
M. DAVID BURGHARDT, Hofstra University, Hempstead, New York
KATHLEEN CONN, Neumann College, Aston, Pennsylvania
ALAN G. GOMEZ, Sun Prairie High School, Sun Prairie, Wisconsin
CRAIG KESSELHEIM, Great Schools Partnership in Maine, Portland, Maine
MICHAEL C. LACH, Chicago Public Schools, Chicago, Illinois
RICHARD LEHRER, Vanderbilt University, Nashville, Tennessee
DEBORAH MCGRIFF, NewSchools Venture Fund, Boston, Massachusetts
ROLAND J. OTTO, University of California, Berkeley
RICHARD J. SCHAAR, Texas Instruments, Plano, Texas
MARK SCHROLL, The Kern Family Foundation, Waukesha, Wisconsin
CHRISTIAN D. SCHUNN, University of Pittsburgh, Pennsylvania
JACQUELYN F. SULLIVAN, University of Colorado, Boulder
ROBIN WILLNER, International Business Machines Corporation, Armonk, New York

Project Staff

GREG PEARSON, Study Director and Senior Program Officer, National Academy of Engineering
MICHAEL FEDER, Senior Program Officer, National Research Council
CAROL R. ARENBERG, Senior Editor, National Academy of Engineering
MARIBETH KEITZ, Senior Program Associate, National Academy of Engineering
ROBERT POOL, *Freelance Writer*
KENNETH WELTY, *Research Consultant*, Professor, University of Wisconsin-Stout

Preface

This report is the final product of a two-year study by the Committee on K–12 Engineering Education, a group of experts on diverse subjects under the auspices of the National Academy of Engineering (NAE) and the Board on Science Education at the Center for Education, part of the National Research Council (NRC). The committee's charge was to determine the scope and nature of efforts to teach engineering to the nation's elementary and secondary students. In fulfilling that charge, the committee considered a number of specific questions, such as What types of curricula and teacher professional development have been used? How does engineering education "interact" with science, technology, and mathematics? And what impact—on student learning, interest in engineering, and other outcomes—have various initiatives had?

Engineering education is a relatively new school subject in U.S. K–12 education. Up to this point it has developed in an ad hoc fashion, and its spread into classrooms has been fairly modest. Even so, the presence of engineering in K–12 classrooms is an important phenomenon, because it casts new light on the very important issue of STEM (science, technology, engineering, and mathematics) education. There is broad agreement today among educators, policy makers, and industry leaders that the teaching of STEM subjects in American K–12 schools must be improved. Many of the concerns about STEM education tie to worries about the innovation capacity of the United States and its ability to compete in the global marketplace.

This report will be of special interest to individuals and groups interested in improving the quality of K–12 STEM education in this country. Engineering educators, policy makers, employers, and others concerned about the development of the country's technical workforce will also find much to ponder. The report should prove useful to advocates for greater public understanding of engineering, as well as to those working to boost citizens' technological and scientific literacy. Finally, for educational researchers and cognitive scientists, the document exposes a rich set of questions related to how and under what conditions students come to understand engineering.

The committee met five times, sponsored two data-gathering workshops, and solicited online input from the public midway through the project. The committee also commissioned an analysis of a number of existing K–12 engineering curricula; conducted reviews of the literature on areas of conceptual learning related to engineering, the development of engineering skills, and the impacts of K–12 engineering education initiatives; and collected preliminary information about a few pre-college engineering education programs in other countries. Beyond this data gathering, the report reflects the personal and professional experiences and judgments of committee members.

Linda P.B. Katehi, *Chair*
Committee on K–12 Engineering Education

Acknowledgments

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

William F. Bertrand, Bureau of Teaching and Learning Support, Division of Standards and Curriculum, Pennsylvania Department of Education
Lizanne DeStefano, Bureau of Educational Research, College of Education, University of Illinois at Urbana-Champaign
David P. Driscoll, Consultant, Melrose, Massachusetts
Katie M. Dodge, Cooper Upper Elementary, Livonia Public Schools, Livonia, Michigan
Susan Hackwood, Office of the Executive Director, California Council on Science and Technology

Joseph G. Langhauser, Fleet and Commercial Sales, Mobility Program, General Motors Corporation
Karl S. Pister, Department of Civil and Environmental Engineering, University of California, Berkeley
Mark Sanders, Integrative STEM Education, Virginia Tech
Reed Stevens, Cognitive Studies in Education, University of Washington
Carl Truxel, Technology Education Department, Dulaney High School, Baltimore County Public Schools, Baltimore, Maryland
Yannis C. Yortsos, Viterbi School of Engineering, University of Southern California

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by William G. Agnew, Retired Director, Programs and Plans, General Motors Corporation, Corrales, New Mexico. Appointed by the NRC, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

In addition to the reviewers, many other individuals assisted in the development of this report. Anthony J. Petrosino and Vanessa Svihla, University of Texas at Austin, and Sean Brophy, Purdue University, prepared a commissioned paper examining cognitive science research related to engineering skills; Eli M. Silk and committee member Christian D. Schunn, University of Pittsburgh, prepared a commissioned paper examining cognitive science research related to core concepts in engineering; Vanessa Svihla, Jill Marshall, University of Texas at Austin, and Anthony J. Petrosino prepared a commissioned paper examining the impacts of K–12 engineering education efforts; Jonson Miller, Drexel University, prepared a commissioned paper reviewing the history of engineering and technical education in the United States; and Marc J. de Vries, Eindhoven University of Technology/Delft University of Technology, The Netherlands, prepared a commissioned paper examining pre-college engineering education initiatives outside the United States.

Thanks are also due to the project staff. Maribeth Keitz managed the study's logistical and administrative needs, making sure meetings and workshops ran efficiently and smoothly. Christine Mirzayan Science & Technology Policy Graduate Fellow Carolyn Williams did extensive research on pre-college engineering education programs outside the United States, work that led to the commissioned paper by Marc de Vries. Freelance writer Robert Pool helped write several chapters of the report. NAE Senior Editor Carol R. Arenberg substantially improved the readability of the report. Special thanks are due to Kenneth Welty, University of Wisconsin, Stout, who conducted an extensive analysis of K–12 engineering curricula that substantially informed the committee's work. Michael Feder, at the NRC Board on Science Education, helped guide the project from its inception. Greg Pearson, at the NAE, played a key role in conceptualizing the study and managed the project from start to finish.

Contents

*Appendix C is reproduced on the CD (inside back cover) and in the PDF available online at http://www.nap/edu/catalog.php?record_id=12635.

List of Acronyms

AAAS	American Association for the Advancement of Science
ASCE	American Society of Civil Engineers
ASEE	American Society for Engineering Education
AWIM	A World in Motion®
CAD/CAM	computer-aided design/computer-aided manufacturing
CLT	cognitive load theory
CD	compact disk
CO_2	carbon dioxide
DPS	Denver Public Schools
DSST	Denver School of Science and Technology
DVD	digital video disk
EPICS	Engineering Projects in Community Service
FBS	function-behavior-structure
FIRST	For Inspiration and Recognition of Science and Technology
HSCE	Higher School Certificate in Engineering

INSPIRES	INcreasing Student Participation, Interest, and Recruitment in Engineering and Science
ITEA	International Technology Education Association
K–12	kindergarten through grade 12
M/S/T	mathematics/science/technology
MWM	Material World Modules
NAE	National Academy of Engineering
NAEP	National Assessment of Educational Progress
NAGB	National Assessment Governing Board
NCETE	National Center for Engineering and Technology Education
NCLB	No Child Left Behind
NSF	National Science Foundation
PD	professional development
PLTW	Project Lead the Way
SAE	Society of Automotive Engineers
SBF	structure-behavior-function
SMET	science, mathematics, engineering, and technology
STEM	science, technology, engineering, and mathematics
TCNJ	The College of New Jersey
TIMSS	Trends in International Mathematics and Science Study
TISD	Texarkana Independent School District