ENGINEERING IN K-12 EDUCATION

Statement of

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Good morning, Mr. Chairman, and members of the Subcommittee. My name is Linda Katehi. I am Chancellor at the University of California, Davis, and served as the chair of the Committee on K-12 Engineering Education of the National Academy of Engineering (NAE) and National Research Council (NRC) Center for Education. The NAE and NRC, along with the National Academy of Sciences (NAS) and Institute of Medicine (IOM), are part of the National Academies. The National Academies provide science, technology, and health policy advice under a congressional charter signed by President Abraham Lincoln that was originally granted to the NAS in 1863. Under this charter, the NRC was established in 1916, the NAE in 1964, and the IOM in 1970. My testimony today focuses on the report of the study committee I chaired. The report, *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*, was released a little over a month ago. The bulk of funding for the study came from Mr. Stephen D. Bechtel, Jr., a member of the NAE. Additional support was provided by the National Science Foundation and PTC Inc.

Introduction

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 our research suggests about 18,000 teachers have attended professional development sessions to teach engineering-related coursework. In the past 15 years, our committee estimates, some 6 million K–12 students have experienced 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. In fact, our committee came to the conclusion that engineering education could be a catalyst for more integrated, and effective, STEM education in the United States. I will talk more about this at the end of my remarks.

In recent years, as you know, 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.

However, 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?

In 2006, the NAE and NRC established the Committee on K–12 Engineering Education to begin to address these and related questions. The goal of our effort 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 in science, technology, engineering, and mathematics education.

Principles for K-12 Engineering Education

In part because there are no standards for K-12 engineering and also because the specifics of how engineering is taught vary from school district to school district, the committee felt it important to lay out several general principles that could guide all pre-college engineering education efforts. The first principle is that K–12 engineering education should emphasize engineering design, the approach engineers use to identify and solve problems. The second principle is that K-12 engineering education should incorporate important and developmentally appropriate mathematics, science, and technology knowledge and skills. And the third principle is that K–12 engineering education should promote engineering habits of mind, including systems thinking, creativity, optimism, collaboration, communication, and attention to ethical considerations. These principles are described more fully in our report.

Review of Curricula

A major element of our study involved identifying and reviewing a representative sample of K-12 engineering education curricula. Our analysis included 31 such curricula and examined 15 in great detail. We found that engineering design is predominant in most K-12 curricular and professional development programs. This is encouraging. However, we also found that 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.

In part, these shortcomings may be the result 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.

Although there are a number of natural connections between engineering and the three other STEM subjects, we found that 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.

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.

Based on its review of curricula, the committee recommended that the National Science Foundation and/or U.S. Department of Education fund research to determine how science inquiry and mathematical reasoning can be better connected to engineering design in K–12 curricula and teacher professional development. Our report details a number of specific areas the research should cover.

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. Although only limited reliable data are available to support these claims, we found the most intriguing possible benefit of K-12 engineering education relates to improved student learning and achievement in mathematics and science. The committee believes that 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. To this end, the committee recommended that foundations and federal agencies with an interest in K–12 engineering education support long-term research to confirm and refine the findings of earlier studies of the impacts of engineering education. The committee additionally recommended that funders of new efforts to develop and implement curricula for K–12 engineering education 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.

Professional Development Programs

Compared with professional development opportunities for teaching other STEM subjects, the opportunities for engineering are few and far between. Our study found that 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.

Given this situation, the committee recommended that the American Society of Engineering Education, through its Division of K–12 and Pre-College Education, 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.

Diversity

The lack of gender and ethnic 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. To this end, the committee recommended that K–12 engineering curricula should be developed with special attention to features that appeal to students from underrepresented groups, and programs that promote K–12 engineering education should be strategic in their outreach to these populations. In doing so, the committee suggested, curriculum developers and outreach organizations should take advantage of recent market research that suggests effective ways of communicating about engineering to the public, such as the 2008 NAE publication *Changing the Conversation: Messages for Improving Public Understanding of Engineering*.

Policy and Program Issues

Many questions remain to be answered about the best way to deliver engineering education in the K–12 classroom and its potential on a variety of parameters of interest, such as science and mathematics learning, technological literacy, and student interest in engineering as a career. Despite these uncertainties, engineering is already being taught in K–12 schools scattered around the country, and the trend appears to be upward. Given this situation, it is important that we consider the best way to provide guidance and support to encourage this trend.

In the committee's view, there are at least three options for including engineering education in U.S. K-12 schools—ad hoc infusion, stand-alone courses, and interconnected STEM education. These approaches, which fall along a continuum in terms of ease of implementation, are described in greater detail in the report. Each has strengths and weaknesses and is not mutually exclusive. Indeed, the committee believes that implementation of K–12 engineering education must be flexible, because no single approach is likely to be acceptable or feasible in every district or school.

Broader inclusion of engineering studies in the K-12 classroom also will be influenced by state education standards, which often determine the content of state assessments and, to a lesser extent, curriculum used in the classroom. It is worth noting that the No Child Left Behind Act of 2001 (NCLB; P.L 107-110) puts considerable pressure on schools and teachers to prepare K-12 students to take annual assessments in mathematics, reading/language arts, and science, and these assessments are based on state learning standards. Thus NCLB currently provides little impetus for teaching engineering.

The committee believes that plans for implementing engineering education in a school curriculum at any level must take into account places and populations (e.g., small rural schools, urban schools with high proportions of students of low socio-economic status, etc.) with a limited capacity to access engineering-education resources. Such plans also will benefit by approaches that emphasize coherence, that is, the alignment of standards, curricula, professional development, and student assessments, and that include support from school leadership.

Finally, the committee believes that, ideally, all K-12 students in the United States should have the option of experiencing some form of formal engineering studies. To help us reach that goal, <u>the committee recommended that philanthropic foundations or federal agencies with an interest in STEM education and school reform 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</u>

school systems. The research should explicitly address school populations that do not currently have access to engineering studies and take into account the different needs and circumstances of elementary and secondary school populations.

Integrated STEM Education

After considerable discussion and thought, the committee came to the conclusion that the most compelling argument for K–12 engineering education can be made if it is not thought of as a topic unto itself, but rather as part of integrated STEM education. After all, in the real world engineering is not performed in isolation—it inevitably involves science, technology, and mathematics. The question is why these subjects should be isolated, or "silo-ed," in schools.

Although the committee did not target K–12 STEM education initiatives specifically, we believe that the great majority of efforts to promote STEM education in the United States to date focus on either science or mathematics (generally not both) and rarely include engineering or technology (beyond the use of computers). By contrast, the committee's vision of integrated STEM education in U.S. K–12 schools sees all students graduating from high school with a level of "STEM literacy" sufficient to (1) ensure their success in employment, post-secondary education, or both, and (2) prepare them to be competent, capable citizens in a technology-dependent, democratic society. Engineering education, because of its natural connections to science, mathematics, and technology, might serve as a catalyst for achieving this vision.

To begin to tackle this critical issue, the committee recommended that the National Science Foundation should support research to characterize, or define, "STEM literacy," including how such literacy might develop over the course of a student's K-12 school experience. 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 a goal of STEM literacy in K–12 will require a paradigm shift by teachers, administrators, textbook publishers, and policy makers, as well as by scientists, technologists, engineers, and mathematicians involved in K–12 education. Standards of learning, instructional materials, teacher professional development, and student assessments will have to be re-examined and, possibly, updated, revised, and coordinated. Professional societies will have to rethink their outreach activities to K–12 schools in light of STEM literacy. Colleges and universities will have to cope with student expectations that may run counter to traditional departmental stovepipe conceptions of courses, disciplines, and degrees.

Why do we suggest such a comprehensive change? First, the committee believes that STEM-literate students would be better prepared for life in the 21st century and better able to make career decisions or pursue post-secondary education. Second, integrated STEM education could improve teaching and learning in all four subjects by reducing excessive expectations for K–12 STEM teaching and learning. This does not mean that teaching should be “dumbed down,” but rather that teaching and learning in fewer key STEM areas should be deepened and that more time should be spent on the development of a set of STEM skills that includes engineering design and scientific inquiry.

The Important Role of Research

A major component of our study was the collection and synthesis of research evidence related to 1) how children learn engineering concepts and skills and 2) what impact K-12 engineering education has had on a variety of parameters of interest. In the former case, we learned that certain experiences can support sophisticated understanding and skill development, even in young children, but several conditions seem important: students need sufficient classroom time; there must be opportunities for iterative, purposeful revisions of designs, ideas, models; and learning is most successful when ideas are sequenced from less to more complex. Overall, however, there are still significant gaps in our understanding of how K-12 students learn and might best be taught engineering.

In the latter case, as noted previously, the most intriguing possible benefit of K-12 engineering education relates to improved student learning, achievement, and interest in mathematics and science. Interestingly, some of the evidence suggests that learning gains may be greatest for minorities and low-SES students. Limited data support other possible benefits, including that engineering experiences can increase awareness of engineering and engineers, improve understanding of engineering design, and increase interest in engineering-related careers. But none of these benefits have been shown to occur universally, which reinforces the need for more and higher quality evaluation and assessment research. As my testimony demonstrates, many of the committee's recommendations address this need.

One major obstacle to determining whether and how K-12 engineering education is having an impact is that, in many cases, curriculum developers do not build in adequate time or resources for this kind of research. Assessments require advanced planning and viable pre-tests. Longitudinal research demands even greater planning and financial support. Another weakness of much of the extent literature on impacts is a tendency to study self-selected populations. Thus the findings about effectiveness cannot be generalized to students who choose not to participate. And a great many impact studies neglect to collect information on subgroups, such as girls or underrepresented minorities. This kind of disaggregation is only possible, of course, if the research includes a sufficiently large study population.

We also attempted to uncover what was known from a research and practice standpoint about the professional development of K-12 engineering teachers. There is a considerable literature on teacher professional development in other domains, including science education, and we believe that many of these findings can be applied to engineering education. However, there is almost no documented pre-service teacher professional development in K-12 engineering, and only a small number of qualitative studies have been done that examine in-service training initiatives.

Our project did not attempt to calculate the amount of investment in research related to K-12 engineering. It is clear, however, that the greatest investment over time has been on curriculum development. A much, much smaller amount has been devoted to research on cognition and learning, on assessment and evaluation, and on professional development. K-12 engineering education could benefit from a major infusion of research dollars, as suggested by many of our recommendations.

Conclusion

In the course of our efforts to understand and assess the potential of engineering education for K–12 students, the committee underwent an epiphany of sorts. To put it simply, for engineering education to become more than an afterthought in elementary and secondary schools in this country, STEM education as a whole must be reconsidered. The teaching of STEM subjects must move away from its current silo-ed structure, which may limit student interest and performance, toward a more integrated whole. The committee did not plan to come to this conclusion but reached this point after much thought and deliberation.

We feel confident that our instincts are correct, but other organizations and individuals will have to translate our findings and recommendations into action. Meaningful improvements in the learning and teaching of engineering and movement toward interconnected STEM education will not come easily or quickly. Progress will be measured in decades, rather than months or years. The changes will require a sustained commitment of financial resources, the support of policy makers and other leaders, and the efforts of many individuals both in and outside of K–12 schools. Despite these challenges, the committee is hopeful that the changes will be made. The potential for enriching and improving K–12 STEM education is real, and engineering education can be the catalyst.

I thank the Subcommittee for the invitation to testify today and welcome your questions.