# A Review of the NAE Report, *Engineering in K-12 Education*

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*Engineering in K-12 Education*, the report recently released by the National Academy of Engineering (NAE) and National Research Council (NRC), takes on the difficult challenge of trying to capture and present the widely varied and scattered field of K-12 engineering education, a discipline that has been growing locally for the past 15 years with very limited coordination, standards, or program expectations. The product of two years of effort by the Committee on K-12 Engineering Education, the report presents an initial compilation of a range of K-12 engineering education programs, their definitions of "engineering," and the curricular practices embodied across them. The report also provides a summary of current research on how students learn engineering concepts. The value and importance of K-12 engineering education programs and learning opportunities for all students is clearly laid out by the authors, who persuasively argue that engineering is a critical component to developing a citizenry and workforce that understands the technical nature of our human-made world. While we applaud the work this report represents, we also highlight in this review several attributes of engineering education not addressed by the report that are critical to practitioners, researchers, and policy makers as the United States expands efforts to bring engineering into K-12 classrooms. While the report includes substantial discussion of engineering education research, the issues of implementation receive less attention. As we bring engineering into the K-12 setting, teacher training (both in-service and pre-service), curricular models, and even parent education are required for system reform. We present our review in three sections: a review of the engineering education research, some thoughts on successful implementations not addressed in the report, and considerations of what it takes to bring engineering into K-12 at the state level through the Massachusetts case study.

## ENGINEERING EDUCATION DEVELOPMENT AND RESEARCH

One helpful offering of *Engineering in K-12 Education* is an insightful beads-and-threads model for the current state of K-12 engineering education efforts. In this model, based on a review of the materials for 34 curriculum programs, the "beads" of particular curriculum activities (such as robotics, clean-energy technology, etc.) surround the interwoven "threads" of science, math, technology, and design. Within the design thread, some thin fibers are described as particularly prone to fragmenting; the themes of analysis, constraints, modeling, optimization, trade-offs, and systems are identified by the committee as very important aspects of design that receive less than ideal treatment in many of the reviewed curricula.

Through its brief summaries of 19 engineering curricula and in-depth analyses of the other 15 in an appendix, the report paints a picture of a K-12 engineering education space already populated with the raw ingredients for both innovative instruction and novel research. Each curriculum analysis inspires an abundance of queries. For example, when the *A World In Motion* curriculum is enacted, how do the student-teacher and student-student interactions unfold? What classroom norms are essential for *City Technology* to be effective? How are student motivation and attitude impacted when Project Lead The Way design challenges have been completed? With its systematic compendium of curriculum programs, the report achieves its goal of providing for educational researchers and cognitive scientists "a rich set of questions related to how and under what conditions students come to understanding engineering." The dedicated reader will find it has the potential to inspire teachers, administrators, and researchers to plan new teaching experiments, new pilot professional development programs, and new lines of inquiry. However, because it does not explicitly articulate the questions related to engineering education as a system, which includes teacher preparation, higher education partnerships, and policy support, it is not yet an entirely complete roadmap for future work.

*Engineering in K-12 Education* also reviews the research on the impact of engineering curricula on students' mathematics and science achievement, on their ability to do engineering design itself, and on their technological literacy. The report summarizes these results as inconclusive, and provides a noteworthy critique of the methodologies used across the impact studies. While the report is justified in its call for studies that feature disaggregation of subgroups and consistent use of pre/post learning measures, we feel that it is also important for the research community to pursue rigorous qualitative studies of classroom practice that result in "thick description" of K-12 engineering education. Lampert's (2001) fascinating fine-grained analyses of children's mathematical problem-solving processes could serve as a model for this work.

The report also provides a useful summary on what the research literature, albeit limited at this time, has to say about the particular engineering concepts and skills that K-12 students can learn. Because of the limited empirical evidence, the report focuses on four conceptual and two skill areas: the concepts of structure-behavior-function, emergent properties, multiple variables, and trade-offs, and the skills of drawing/representing and experimenting/testing. The committee finds that for meaningful learning in any of these domains, students need extended time for design activities (i.e., much more than a single class period) and the chance to do iterative, purposeful modeling. Future work that builds upon this review of research might cast an even wider net to draw upon the efforts of other educational research and cognitive psychology communities. For example, in planning a lesson on design sketches, curriculum developers might consult the extensive knowledge base of the art education field (e.g., Davis, 1997; Hetland et al., 2007). And in studying middle schoolers' development of engineering testing skills, researchers might turn to the literature on developing scientific inquiry abilities (e.g., Wilson et al., 2010). A diversity of theoretical perspectives and analytical lenses will enable our fullest understanding of how to foster learning and teaching of (or through) engineering.

As its authors acknowledge, *Engineering in K-12 Education* follows in the footsteps of two previous, influential NRC summaries of educational research on STEM learning and teaching, *Taking Science to School: Learning and Teaching Science in Grades K-8* (NRC, 2007), and *Adding It Up: Helping Children Learn Mathematics* (NRC, 2001). Taking Science to School (2007) tells us emphatically that we as educators "are underestimating what young children are capable of as students of science—the bar is almost always set too low" (p. vii). Its authors interpret this finding as empowering, as it implies that children come to school ready to engage in sophisticated scientific reasoning and practice. Similarly, *Adding It Up* (2001) urges educators to leverage young children's positive disposition "to do and to understand mathematics when they first encounter it," and to take advantage of their "remarkable ability" to "reason and explain their mathematical activities" (p. 6). *Engineering in K-12 Education* communicates a similar message that we hope all will hear: children come to school with conceptual and practical resources for engaging in engineering, and they can do so in much more sophisticated ways than most of us imagine. However, the engineering instructional experiences provided to students must be based on all that is known about how students learn. The questions raised by the NAE report must be pursued in light of the existing knowledge base on science and math learning and the model of synthesizing that research. Only then will the engineering education community achieve its own body of research comparable to those synthesized in *Taking Science to School* and *Adding It Up*.

## Successful Implementation of Engineering Education

While the NAE report provides a summary of several critical aspects of engineering education, particularly curricula and research on student learning, several additional attributes of engineering education are critical to practitioners, researchers, and policy makers. Engineering education will be greatly enhanced when we clearly define engineering literacy, integrate informal engineering education programs, support engineering-focused schools, and reference international examples of success in engineering education.

In summarizing the various K-12 engineering programs and the research literature, the authors begin to define and provide a framework for what likely constitutes engineering as a K-12 discipline. The authors have, however, left a few essential questions unaddressed. For one, the report describes the distinction between expectations for "technological literacy"—what all citizens should know about engineering concepts and practices to participate in a technical world, and what constitutes engineering education for purposes of preparing future engineers—an "engineering pipeline," but does not then suggest which of these should be the primary goal of K-12 education. Second, the authors focus just on engineering design as the "content" of K-12 engineering education and do not address the range of "technologies" that other organizations (e.g., ITEA) have advocated for as critical to technological literacy. Future consideration of engineering education guidelines, particularly any future articulation of K-12 engineering standards and policies, will have to take these up these questions.

There are many informal engineering programs at science museums and universities across the country, as well as after-school engineering programs. This was not within the scope of the committee's charge for the report but is worth a moment's consideration as an important aspect of engineering learning opportunities for students. Many science (and technology) museums in the United States run engineering camps over the summer for individuals and during the year for school groups. They have engineering exhibits, run "Engineering Days," and continually show the results of some of our most impressive engineering feats (from landing on Mars or peering into other galaxies with the Hubble Telescope, to high speed transportation and the engineering behind popular movies). Many museums also are actively involved with the very successful after-school robotics programs offered by *FIRST*, World Robotics Olympiad, and RoboCup organizations. These programs treat engineering (in particular robotics) as a sport and continue to grow at impressive rates, involving teachers, parents, and kids in engineering competitions. Although informal programs currently engage a small percentage of the total number of U.S. students, the number is quickly increasing and definitely will play a large role in improving engineering literacy as well as "feeding the pipeline."

The report also did not mention any of the for-profit companies with divisions that sell engineering curricula and tools directly to K-12 schools. Pasco has a complete catalog on K-12 engineering. Pitsco and LEGO Education have similar products that are currently being purchased by schools to teach engineering. Prentice Hall has brought engineering into its middle school science books. There are many others (from Vernier Software to small startups) and although not all of their tools are systematically informed by educational research, they are still bringing engineering into the classroom and thus comprise a rich area for empirical investigation.

As new programs, schools, or policies emerge, we hope that their developers take advantage of U.S. and international successes in engineering education. The NAE report provides descriptions (in the final Annex) of several engineering-focused schools, the development of which we hope to see more of in the future. These case studies provide an interesting glimpse into how the report's recommendations may "come to life" in the real world of a school. Given limited time and funding, the NAE committee was only able to briefly touch on international initiatives. Clear lessons can be learned from Australia and the United Kingdom, for instance, who have had design strands in their curriculum for decades; in the U.K., a nationalized "Design and Technology" curriculum has been in use since the 1988 Education Reform Act.[1] In Australia, there is not a national curriculum but Queensland has a compulsory Design, Technology and Engineering curriculum (with robotics) and it is an elective in Victoria, Western Australia, and South Australia. Many Asian countries have a strong engineering and robotics initiative both in school and in after school programs. Both the Singapore and Mayasian departments of education have incorporated robotics as a topic in their Design and Technology strand. China began a technology strand in 2003 in four provinces and has now implemented it across 20 (out of 30) provinces; the mandatory Design and Technology curriculum for high schools includes five electives, including robotics. Japanese schools are required to provide a "technology and home management" class in the middle school that includes materials and processing, energy technology, biotechnology, and information technology, including robotics. All of these examples can provide valuable insights to the development of innovative engineering-focused schools, programs, and policies.

## Engineering in an Educational System

The NAE report provides credence to the value and import of K-12 engineering education programs and learning opportunities for all students, and an initial framework for what that may look like. At the policy level, this support and framework is critical to developing standards, assessments, and related policies that will lead to a citizenry and workforce that understands the technical nature of our human-made world. Massachusetts is a good case for considering the value of such a resource, where after ten years of work, engineering education has been successful yet slow to develop. A number of successes have been achieved across the state, including the development of policies at the Department of Education for engineering that have helped schools and districts enhance engineering instruction, develop new courses, provide highly qualified teachers, and assess student achievement of engineering standards. A number of public and charter high schools with a strong engineering focus have opened across the state, including in urban centers. More state organizations explicitly include engineering in their missions and work, including organizations that had been focused exclusively on science for many years. These results have been fairly recent, however, as much of the ten years of work had been spent working to agree on what constitutes quality engineering education and getting districts to see its value. Even today much of what has been implemented across the state is widely varied in goals, methods, and quality. The NAE report can provide states with an articulation that begins to define, shape, and coordinate these programs.

The NAE report considers how a variety of aspects of the educational system must change to support engineering education, highlighting the need for policy and implementation to be aligned across the system. State standards, assessment, and licensure requirements must be aligned with teacher preparation, professional development, curriculum, and even college admissions. The NAE report also advocates for a clear articulation of the relationship between engineering and other STEM subjects. While not a focus of the report, these considerations raise the need to consider higher education as well. Take, for example, the challenge that some Massachusetts students have had in getting high school engineering credits recognized in their college or university admissions review. Some colleges and universities have not recognized high school engineering as an academic subject and hence rejected the students' credits. This is in part a reflection of how the universities themselves view engineering in relation to science (particularly physics) and mathematics. Colleges and universities often require one or two years of science and math before allowing the students to take engineering. With an increase in the number of students arriving at higher education with experience and an interest in pursuing engineering, those institutions will be well served to better engage students in early engineering experiences (and there are some excellent examples of first year engineering seminar courses across the country). In addition, higher education will also play a critical role in the preparation of K-12 engineering teachers, or in the training of in-service teachers to bring engineering into their existing classrooms. The recommendations of the NAE report, and work that follows from it, will be useful in the development, implementation, and enhancement of engineering education across the K-16 system.

[1]The U.K. national D & T curriculum has six key learning goals: 1) developing, planning, and communicating ideas, 2) effectively using tools, equipment, materials, and components to produce products, 3) evaluating processes and products, 4) understanding materials and components, 5) understanding systems and control, 6) understanding structures.

## Conclusion

The NAE report is a key first step to raise awareness of the importance and the difficulties of growing K-12 engineering education in the United States. We strongly believe in the arguments set forth in the report and agree there is much to be done before we can have an engineering-literate populous. Although the committee restricted its examination and recommendations to education research and K-12 engineering curriculum, it is clear this is only part of the solution and hope that future work on K-12 engineering will include additional facets. We look forward to the development of a more complete picture and implementation of K-12 engineering education in the coming years.

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