Building Educator Capacity in K-12 Engineering Education

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Building Capacity for Teaching Engineering in K-12 Education

Engineering is increasingly present in US K–12 education and is finding its way into standards, instructional materials, and assessments. Thus, teachers, administrators, and policymakers must consider the capacity of the education system to meet current and anticipated needs for K–12 teachers of engineering. What do these educators need to know and be able to do in order to be effective? Where and how might they develop such expertise?

To help answer these and related questions, the National Academy of Engineering (NAE) in collaboration with the Board on Science Education at the National Academies of Sciences, Engineering, and Medicine convened an expert committee to conduct extensive data gathering and analysis to understand current and anticipated future needs, suggest how to meet these needs, and alert stakeholders in US STEM education to the mismatch between the need for engineering-literate K–12 teachers and the education system's lack of capacity to meet this need.

The committee's report, published in February 2020, presents findings, conclusions, and recommendations from the project, which was funded by the National Science Foundation. This paper summarizes key elements of the report. The full report can be read and downloaded free of charge from the National Academies Press, nap.edu.

Goals for K-12 Engineering Education

The report presents four student-centered goals of K–12 engineering education, derived from a review of existing programs, that suggest a knowledge base for teachers. The most basic goal is for students of all ages to develop engineering literacy. To achieve this goal, teachers themselves must have a basic level of engineering literacy, according to the committee; they need to be able to understand key concepts in engineering, engage in engineering design, and appreciate how engineering has influenced society. In secondary education, one goal of engineering is to improve student achievement in mathematics and science through the integration of concepts and practices across the STEM fields. Another goal of engineering education at the secondary level is to improve student college and career readiness. To achieve both of these goals, teachers need pedagogical content knowledge relevant to the integration of mathematics and science with engineering. Finally, for a small percentage of high school students, a goal of engineering education is to prepare them for matriculation into a postsecondary engineering program. K–12 engineering educators involved in preparing students to enter college engineering programs need to master certain advanced concepts in mathematics and science. The latter might be accomplished through postsecondary engineering coursework, an engineering degree, industry experience, or some combination. According to the report, the breadth and depth of science and mathematics knowledge needed by K–12 teachers of engineering will vary according to grade, the specific curriculum, and instructional goals.

K-12 Teachers of Engineering

Because of limited data and shortcomings of existing national surveys, the committee was unable to determine how many K-12 teachers teach engineering. However, available data show very few K-12 teachers majored in engineering or took any engineering courses during their college

careers [1]. A few programs prepare prospective K–12 teachers engineering, including those in the field of technology education, and a small number of university programs allow undergraduate students to combine a major in engineering with an education degree or certification to teach. There are a number of engineering professional development opportunities available to current K-12 teachers, and these vary in duration and intensity. Overall, the committee found, there are few professional pathways for those hoping to become K–12 teachers of engineering.

The committee examined efforts to spell out learning expectations for K-12 teachers of engineering. For example, the 2014 *Standards for Preparation and Professional Development of Teachers of Engineering* [3], developed by a group of K–12 engineering professional development providers, call for K–12 teachers of engineering to have basic literacy of engineering design and careers; acquire knowledge about how to teach specific concepts (i.e., pedagogical content knowledge), such as how teaching and learning in engineering both resembles and differs from teaching and learning in science and/or mathematics; and appreciate how engineering design can provide context for learning in other subjects (e.g., science, mathematics, language arts, reading).

The report notes there is considerable research describing aspects of high-quality professional development for K-12 educators in general, such as actively engaging teachers, building the capacity of teams of teachers, focusing on content and instructional practices demonstrated to be effective, and providing experiences during and outside of the school day [4]. Limited research in K–12 engineering suggests some potentially promising practices like curriculum design–based professional development, in which teachers learn content by creating instructional materials, providing them with both engineering content knowledge and an active learning experience. Professional development that includes teacher communities of practice, either in person or online, may also provide benefit as teachers learn engineering.

The System Supporting K-12 Teachers of Engineering

Meeting the objectives of any K-12 education reform effort depends not only on the competence and confidence of individual teachers but also on the many components of the larger system within which these educators work. Federal, state, district, and school policies, programs, and practices all affect the extent and quality of preparation of K–12 teachers of engineering. Higher education and the education research community also impact the nation's ability to prepare K–12 teachers of engineering.

State educational standards can serve as an important policy lever in reform efforts, particularly when aligned with curriculum, assessment, and teacher professional learning. The report notes that standards in K-12 technology [5] and science [2] education set expectations that students will learn engineering ideas and practices, which suggests K–12 teachers of technology and science should understand engineering well enough to teach it. However, the committee found little evidence the engineering-related elements of technology education standards are influencing the preparation of technology teachers. It could find no evidence science teacher preparation programs are helping prospective science teachers to science concepts and practices to those of engineering, as called for in the Next Generation Science Standards [2].

The committee found there are relatively few education researchers and social and learning scientists studying issues in K–12 engineering, which helps explain why the evidence base informing effective approaches to preparing K–12 teachers of engineering is thin and uneven. Although funding for K–12 engineering education research exists, it is generally at lower levels than research on K–12 education in other STEM subjects. Encouragingly, a growing number of schools of engineering are establishing departments of engineering education, many of which conduct research on topics relevant to teaching engineering at the K–12 level.

Postsecondary engineering education institutions can support teacher professional learning by sending undergraduate or graduate engineering students into K-12 classrooms or bringing K-12 teachers on campus to learn about engineering. These institutions can also supply the content expertise needed by programs that prepare new teachers of K–12 engineering. Expanding and improving teacher preparation programs for engineering may require collaborations between major components of the education system: researchers, engineers, teacher educators, and teachers.

Recommendations

Based on its data collection and analysis, the committee developed 10 recommendations for improving the preparation of K–12 teachers of engineering in the United States. Every recommendation calls for action by one or more stakeholders, and each is supported by one or more conclusions, which appear in the full report.

> RECOMMENDATION 1: To better understand the extent to which US K–12 educators are teaching engineering, the National Center for Education Statistics should revise the National Teacher and Principal Survey so that (1) answer choices for items that query respondents about teaching assignments and certification do not combine engineering with other fields, and (2) respondents can indicate whether they are engaged in teaching engineering less than full-time or as other than a main teaching assignment (e.g., as part of a science course).
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> RECOMMENDATON 2: To begin to address the systemic lack of capacity to prepare preservice K–12 teachers of engineering, federal agencies, such as the Department of Education and National Science Foundation, and private foundations with an interest in STEM education should convene a collaborative dialogue among K–12 STEM educators, leaders at organizations involved in the preparation of K–12 STEM educators, colleges of education, colleges of engineering and engineering technology, postsecondary science departments, K–12 teacher accrediting bodies, state departments of education, and technology-focused industry. The goal should be to identify practicable steps that the stakeholders and others can take to address the capacity issue.
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> RECOMMENDATION 3: Programs that prepare prospective teachers of engineering need to make greater efforts to recruit and retain teacher candidates from populations currently underrepresented in STEM education and careers.

Likewise, professional development programs should proactively encourage the participation of teachers with these characteristics. Programs for both prospective and practicing teachers should explicitly include instruction on the use of inclusive pedagogies.

RECOMMENDATION 4: In the short term, both providers of professional development opportunities and educators of prospective K–12 teachers of engineering should align their work with guidance documents that draw on the most up to date understanding of research and best practices in teacher education and professional development. As new knowledge accumulates about the professional learning of K-12 teachers of engineering, adjustments in programs should reflect new insights gained from rigorous, high quality scholarship

RECOMMENDATION 5: As evidence accumulates about effective approaches to preparing K–12 teachers of engineering, it will be important to establish formal accreditation guidelines for K–12 engineering educator preparation programs, such as those developed by the Council for the Accreditation of Educator Preparation. The National Science Teaching Association, International Technology and Engineering Educators Association, and American Society for Engineering Education should work together to determine the appropriate content for such guidelines. Such an effort should take account of new NGSS-aligned accreditation standards for science teacher education programs, which become effective in 2020 and include student learning expectations related to engineering. It should also consider how the guidance needs to vary based on the grade level to be taught.

RECOMMENDATION 6: Programs that prepare preservice K–12 science educators or provide professional learning to in-service science teachers need to address the call in the *Framework* and NGSS for students to connect their science learning to engineering ideas and practices. To this end, the Association for Science Teacher Education, National Science Teaching Association, and American Society for Engineering Education should work together to assist these programs in identifying and implementing actions that will fulfill the engineering components of the new vision for K–12 science education.

RECOMMENDATION 7: Postsecondary engineering and engineering technology programs should partner with schools/colleges of education to design and implement curriculum for the preparation of K–12 teachers of engineering. Such efforts should be conducted in consultation with teacher professional organizations that have a stake in K–12 engineering, such as the International Technology and Engineering Educators Association and the National Science Teaching Association, as well as the American Society for Engineering Education.

RECOMMENDATION 8: States should work together to reach high-level agreement about what constitutes appropriate preparation and credentialing for

teachers of engineering at various grade levels and what education and work-related pathways satisfy the credential process. The Council of Chief State School Officers should organize such discussions, in consultation with appropriate science and engineering professional societies and test development organizations.

RECOMMENDATION 9: Federal agencies, higher education institutions, state education agencies, industry, informal learning institutions, cultural and community organizations, and other stakeholders in the preparation of K–12 teachers of engineering should work in partnership with the schools and educators targeted by the interventions. When possible, such partnerships should leverage the expertise of teacher leaders in K–12 engineering education. Investments by these stakeholders should be allocated and used in ways that are consistent with findings from education, social science, and learning sciences research as well as the guidance provided by relevant policy documents.

RECOMMENDATION 10: Federal agencies, such as the National Science Foundation and Department of Education, with a role in supporting K–12 STEM education should fund research on topics relevant to the professional development of practicing and the education of prospective K–12 teachers of engineering. To the extent practicable, the efforts should take advantage of methods, such as design research, that encourage collaboration with stakeholders and existing reform efforts.

Pressing issues include:

- Describe the subject-matter content knowledge and pedagogical content knowledge required for high-quality K–12 engineering education and how this knowledge varies across grade levels.
- Describe pedagogical approaches and specific instructional practices that effectively support students' integration of engineering with concepts and practices from the other STEM subjects.
- Document student learning progressions, age-appropriate expectations for engineering design thinking, and student conceptions in engineering, which will have implications for how K–12 educators at different grade levels are prepared and supported.
- Develop valid measures of teacher knowledge and instruction, as well as of student outcomes, that can be used to judge the effects of K–12 engineering educator preparation and professional learning programs.
- Characterize the current cadre of educators of K-12 teachers of engineering and their learning needs.

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