Preparing Next Generation Engineers for a Changing Global Economy and Work Environments

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American Society for Engineering Education

With support from the National Science Foundation (NSF), the American Society for Engineering Education (ASEE) has launched a series of conversations with stakeholders to prepare next generation engineers. ASEE’s initiative Transforming Undergraduate Education in Engineering is designed to develop a consensus and a clear understanding of the knowledge, skills, and abilities next generation engineering graduates should possess and changes in curricula, pedagogy, and academic culture that will be needed to instill those qualities. The ultimate purpose of this multi-year study is to produce a flexible framework and collaboration that will be needed among universities, industry, public sector organizations and professional societies for transforming the undergraduate engineering experience. Findings from the study’s first phase are presented.

Background

Transforming Undergraduate Engineering Education is modeled on Vision and Change in Undergraduate Biology Education, an NSF-supported effort begun in 2007 by the American Association for the Advancement of Science to better align college teaching with a revolutionary pace of discoveries aided by modeling and simulation, vast data sets, and interdisciplinary research.

Like biology, engineering is advancing rapidly in technology, research, and practice. This is shifting the ground beneath educators, accreditors, and industry recruiters while opening up new opportunities for engineers to address societal problems and power the economy. In response, a series of reports have called for major changes in engineering education to prepare students for a world where international exchange is the norm and the only constant is change. Among them are the National Science Board: Moving Forward to Improve Engineering Education (2007), the University of Michigan’s Millennium Project: Engineering for a Changing World: A Roadmap to the Future of Engineering Practice, Research, and Education (2008), and the National Academy of Engineering, Educating Engineers: Preparing 21st Century Leaders in the Context of New Modes of Learning (2013).

ASEE has proposed a four-phase, multi-year sequence of meetings – the last one being a large workshop in 2018 – that ultimately will produce a flexible framework for transforming the undergraduate engineering experience.

ASEE’s project complements the Administration’s goal of producing one million more graduates in STEM (science, technology, engineering, and math) graduates in the next 10 years. In particular, it addresses two aspects of the strategic objectives for undergraduate education contained in the Five-year Strategic Plan issued June 3, 2013 by the Committee on STEM Education of the National Science and Technology Council: the plan to “identify and broaden implementation of evidence-based instructional practices and innovations to improve undergraduate learning and retention in STEM” and to “support and incentivize the development of university-industry partnerships, and partnerships with federally supported entities,
to provide relevant and authentic STEM learning and research experiences for undergraduate students, particularly in their first two years.”

**Synthesizing and Integrating Industry Perspectives**

The initial phase of the project, *Synthesizing and Integrating Industry Perspectives*, was designed to hear the voice of the primary customer—employers. ASEE hosted a two-day workshop that brought together thirty-four (34) industry and eight academic representatives for an intensive exploration of the Knowledge, Skills, and Abilities (KSAs) needed in engineering today and in the coming years.

Prior to the workshop, 26 participants from industry and the seven academics completed a survey on what they consider the most important engineering KSAs for today and 10 years from now, and the perceived quality of preparation in these areas shown by today’s graduates. Responses depicted a profession under pressure from several directions, with current training unable to meet certain existing industry needs and badly out of sync with the requirements expected in 2023. For instance, responses showed today’s students to be very weak in having an international and global perspective, something of moderate importance now but the single most important knowledge area in 10 years’ time. Likewise, students’ weak foreign language skills, while a minor drawback now, could be a serious impediment in the future. Middling

The survey found today’s students coming up short in economics and business, project management, stages of product development, and system integration—all areas of growing importance. Students also fail in meeting expectations in several skills accorded growing importance. These include leadership, decision-making, communication, and the ability to synthesize engineering, business, and societal priorities. At the same time, respondents indicated students are being well trained in physical and life Sciences and statistics, math, and information technology. Indeed, their skills outstrip the importance industry attaches to these fields. Strikingly, strength in math is seen as becoming less important a decade hence than today, so is the ability to apply math and science knowledge. Internet and digital competency were identified as the areas where today’s students perform well. Survey results are detailed on the workshop report, available at [http://www.asee.org/TUEE_PhaseI_WorkshopReport.pdf](http://www.asee.org/TUEE_PhaseI_WorkshopReport.pdf)

**Core Technical and Professional/Social KSAs**

During the workshop, participants identified core competencies that remain key, but added an array of skills and professional qualities that will help students succeed in a dynamic, rapidly changing field. Based on the discussion and ranking done at the workshop, fifteen KSAs were identified as a priority in terms of engineering education reforms:

- Good communication skills;
- physical sciences and engineering science fundamentals;
- ability to identify, formulate, and solve engineering problems;
- systems integration; curiosity and persistent desire for continuous learning;
- self-drive and motivation;
• cultural awareness in the broad sense (nationality, ethnicity, linguistic, gender, sexual orientation);
• economics and business acumen;
• high ethical standards, integrity, and global, social, intellectual, and technological responsibility;
• critical thinking;
• willingness to take calculated risk;
• ability to prioritize efficiently;
• project management (supervising, planning, scheduling, budgeting, etc.);
• teamwork skills and ability to function on multidisciplinary teams;
• and entrepreneurship and intrapreneurship.

Twenty-one additional KSAs were also listed as relevant.

**Recommendations for What, Who, and How the Identified KSAs Should be Addressed**

The final discussion during the workshop and the post-workshop survey focused on the **What’s**, **Who’s**, and **How’s the identified KSAs should be addressed**. The **What’s** (desired KSAs) included specific technical and professional skills but also character traits, such as “emotional intelligence,” and “persistence and strong work ethic.” The **Who’s** referred to those responsible for fulfillment: students; parents and home; academia (K-12 and universities); industry, and government. The **How’s** offered specific ways certain attributes could be acquired at universities, during work experiences, or by collaboration between universities and industry.

All but one of 25 survey respondents gave academia exclusive responsibility for preparing students in the hard sciences and engineering science fundamentals (see Table 1). Stressing the importance of this teaching, participants suggested that it could be improved by, for instance, updating the curriculum to reflect current and emerging industrial practice, use of problem-based learning, and incorporating hands-on examples to reinforce students’ knowledge of fundamentals. Academia also has the lead in teaching students how to interpret and present data and in developing application-based research and evaluation skills. It bears heavy responsibility as well in stimulating students’ critical thinking, respondents said. Suggestions for the latter included problem-based and collaborative learning built around engineering design; case studies; use of open-ended questions, and “no-calculator” exams.

Apart from education in hard sciences and engineering fundamentals – a responsibility of academia – most KSAs, in the respondents’ view, demand efforts by two or more parties. This was especially true of communication skills – a shared responsibility of students, parents, K-12, academia, and industry – and of nurturing creativity, instilling cultural awareness and high ethical standards, and fostering systems thinking. Respondents didn’t consider industry to have sole responsibility for any KSA, but gave it a leading role in training students for project management and in encouraging them to take calculated risks. Industry and academia together must imbue students with economics and business acumen, respondents said. Frequently, written responses underscored the need for closer cooperation between educational institutions and industry. Participants generally gave government a modest role – for instance, in facilitating and funding student exchanges.
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<th>Table 1. High priority KSAs and responsibility across stakeholders</th>
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The longest list of How’s attached to the concept of the T-shaped engineering graduate, someone with breadth of knowledge across domains but possessed enough expertise within a single domain to go in depth on a topic. Industry could provide case studies, be more realistic about providing time to train new hires, and provide learning materials to universities. The list suggested a differentiated curriculum based on a projected career. For instance, a student would not have to take calculus if a job didn’t require it, but would go back and fill in the gap if he or she changed direction. Also suggested was a study of job descriptions to determine what level of knowledge and skill and particular job requires and a “competencies map” to inform student choices.

Putting forward their own recommendations, respondents repeatedly stressed the need for project-based experiences to be integrated in the curriculum from the earliest years. “Critical thinking, problem solving, prototyping & struggle through failure are not admonished as positive,” one respondent lamented.

Closing Remarks

Industry still values a solid foundation in math and science, although the relative importance of math may diminish slightly in the years ahead. Students must have a sufficient grasp of these fundamentals to grasp the dimensions of a problem without relying on models. That foundation, however, should incorporate programming, systems thinking and ability to use relevant tools. Less well-defined but necessary, in the view of many participants, are good communication skills, persistence, curious learning capability, drive and motivation, economics and business acumen, high ethical standards, critical thinking, and willingness to take calculated risks.

To instill the desired KSAs in future engineers, changes in approach will be required by academe and industry. Universities will need to adjust faculty reward structures to place more of a premium on teaching, promote more cross-disciplinary instruction, and welcome involvement by industry in supplying case studies, mentorship of students, and shared laboratory experiences. For its part, industry will need to recognize a shared responsibility in developing T-shaped engineers. The workshop produced numerous concrete suggestions of ways industry and academe could collaborate – from faculty internships in industry to company involvement in authentic learning experiences that occur before traditional capstone projects – as well as an awareness that barriers between universities and companies serve neither.