TUEE

Transforming Undergraduate Education in Engineering Phase II

Insights from Tomorrow's Engineers

Workshop Report

NSF · ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION

ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION

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ASEE engages with engineering faculty, business leaders, college and high school students, parents, and teachers to enhance the engineering workforce of the nation. We are the only professional society addressing opportunities and challenges spanning all engineering disciplines, working across the breadth of academic education, research, and public service.

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The following ASEE staffers contributed: Stephanie Harrington organized the event and planned the agenda. Tengiz Sydykov provided logistical support that resulted in a seamless two days, allowing participants to focus on the purpose of the workshop. Rocio C. Chavela Guerra and Ashok Agrawal provided conceptual guidance to the project, as well as its overall management. Mark Matthews, Alexandra Longo, and Austin Ryland wrote the initial draft of the report. Francis Igot oversaw the layout and design. Matthews did the final proofreading and edits.

The following individuals facilitated breakout sessions during the workshop, directing group conversations to productive ends:

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Executive Summary

TUEE Phase II, Insights from Tomorrow's Engineers was the second in a multi-year series of meetings intended to build a framework for transforming the undergraduate engineering experience. The multi-phase project, *Transforming Undergraduate Education in Engineering* (TUEE), is funded by the National Science Foundation and led by the American Society for Engineering Education (ASEE). With guidance from engineering deans, ASEE invited a diverse group of 41 undergraduate and graduate students to assess the value of 36 characteristics of engineering graduates most sought by industry, referred to as KSAs (knowledge, skills, and abilities). The students participated in a two-day workshop in Arlington, Va. to share their observations, brainstorm, and suggest ways in which engineering instruction could be improved to meet demands of the contemporary workplace.

Participating students concluded that their institutions were paying insufficient attention to multiple KSAs needed to produce the desired T-shaped professional —one who possesses deep expertise within a single domain, broad knowledge across domains, and the ability to collaborate with others in a diverse working environment. They did not fault the subjects emphasized in their education (particularly the rigorous grounding in math, science, and engineering fundamentals that are a priority of engineering programs), but criticized *how* these and other courses were taught. Urging a greater emphasis on instructor training, students suggested that pedagogy be part of the basis for securing tenure and salary increases. They also called for greater faculty diversity in terms of gender and ethnicity, and stressed that experience in industry can enhance teachers' performance. Certain students also said their institutions could improve accountability by assessing whether courses fulfill the promise advertised in syllabi and by emphasizing the process of learning throughout a course.

Students contended that, from the first year onward, calculus, physics, and chemistry courses should include examples of real-world engineering applications. Design-based projects, supplemented by extra-curricular activities, competitions, and makerspaces, should be included in the curriculum from the outset and incorporated throughout to stimulate learning and creativity. They argued that open-ended problems and exams (as opposed to exclusively quantitative assessments) will train students to think critically. Technology used in the classroom should be kept current in order to keep pace with skills and approaches in demand beyond the classroom. With regard to team-based learning, teams should be intentionally diverse, not only in ethnicity and gender but in personality types, to encourage cultural awareness. Exposure to industry, business training, ethics, and communication skills all require more attention. An oft-repeated demand was for mentoring, whether by older students, faculty, professionals in industry, or peers. The best test of knowledge, one student said, is to try to teach others.

Background

The Transforming Undergraduate Education in Engineering (TUEE) Initiative

TUEE Phase II, Insights from Tomorrow's Engineers, was the second in a multi-year series of workshops intended to build a framework for transforming the undergraduate engineering experience. The *Transforming Undergraduate Education in Engineering* (TUEE) project is funded by the National Science Foundation and led by the American Society for Engineering Education (ASEE). TUEE consists of a multi-phase, multi-year sequence of workshops designed to develop a clear understanding of the Knowledge, Skills, and Abilities (KSAs) that next-generation engineering graduates should possess to succeed in their careers, and the changes in curricula, pedagogy, and academic culture that will be needed to instill those characteristics.

TUEE Phase I, Synthesizing and Integrating Industry Perspectives, was held May 9–10, 2013 and brought together 34 representatives of industry, four staffers and officials from the National Geospatial-Intelligence Agency, and eight academics for an intensive exploration of the knowledge, skills, and abilities (KSAs)[4] needed in engineering today and in the coming years. Participants identified core competencies that remain important for engineering performance, but added an array of skills and professional qualities needed in a T-shaped engineering graduate—one who brings broad knowledge across domains, deep expertise within a single domain, and the ability to collaborate with others in a diverse workforce. Participants found current training to be inadequate to meet present industry needs and badly out of sync with future requirements.[5]

TUEE Phase II, Insights from Tomorrow's Engineers, invited students to express their views on the strengths and weaknesses of the current chronological curricula structure and teaching methodologies. The aim of these discussions was to gain a better understanding of student perspectives on how the engineering education experience can be transformed into an exciting program of study that will attract and motivate students.

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[4] The three initial phases of the TUEE initiative defined KSAs as knowledge, skills and abilities. Phase IV adopted a competency model to frame KSAs, switching to knowledge, skills and attitudes.

[5] For full details about the TUEE Phase I workshop please visit http://www.asee.org/TUEE_PhaseI_WorkshopReport.pdf

Undergraduate Engineering Education in the 21st Century: An Overview

Student Graduation and Engineering Degree Value

The number of engineering bachelor's degrees awarded at U.S. institutions has increased steadily since 2007, and demand for engineering as a field of study continues to grow (American Society for Engineering Education, 2016). In 2015, 106,658 bachelor's degrees were awarded, a 7.5 percent increase from the prior year. At the same time, the number of applicants has far outpaced the number of admitted and enrolled students (Ryland, 2016). One reason for this demand is the likelihood of securing a well-paying job. U.S. census data show that almost all of the highest-paying jobs requiring a bachelor's degree have gone to graduates who majored in engineering (Carnevale, Cheah, & Hanson, 2015). However, several persistent trends cast a shadow over the field and diminish the potential number of engineering graduates. These are a high overall dropout rate and underrepresentation of women, African Americans, and Hispanics. Only 19.9 percent of engineering bachelor's degrees for 2015 were awarded to women. Demographically, the majority of domestic engineering bachelor's graduates are White (64.9%), followed by Asian American (13.4%), Hispanic (10.7%), and African American (4.0%) (American Society for Engineering Education, 2016). To the extent that the engineering curriculum and student experiences influence retention, graduation rates, and diversity, developing curricula that aligns university strengths with student and industry demand will be key to moving forward.

The T-shaped Professional

A major framework for reviewing KSAs is "the T-shaped professional," an individual who has both deep domain knowledge and broad professional skills. The term dates from the early 1990s and the perceived need at that time for computer managers who could combine information-technology and business skills. Domain knowledge, the vertical stem of the T-shaped professional, is balanced by the skills represented by the horizontal bar. Often referred to as soft skills, these include an ability to relate to team members of different backgrounds, skills in project management, leadership, budgeting and administrative tasks, and emotional intelligence (American Society for Engineering Education, 2013). A T-shaped professional also has the ability to think broadly and apply domain knowledge in new, innovative ways across disciplines and teams (Doyle, 2014).

Engineering schools traditionally have accepted responsibility for instilling deep knowledge of a discipline and the ability to apply it in practice. They have placed less emphasis on professional skills. While graduates in the past could expect to acquire those skills on the job, many of today's companies seek employees who can hit the ground running and not need additional training. Universities have not necessarily kept pace with this trend (Doyle, 2014). The concept of the T-shaped professional engineer arose out of a need for university curricula to respond to industry demand. The profile can be modified to fit different engineering sub-fields.

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Engineer of 2020

An additional influence in a review of KSAs is the National Academy of Engineering's 2004 report, *The Engineer of 2020: Visions of Engineering in the New Century,* and its response to two questions: "Should the engineering profession anticipate needed advances and prepare for a future where it will provide more benefit to humankind? Likewise, should engineering education evolve to do the same?" (p.1). The report cited a series of guiding principles expected to shape engineering over the next decade and a half:

- The pace of technological innovation will continue to be rapid (most likely accelerating).
- The world in which technology will be deployed will be intensely globally interconnected.
- The population of individuals who are involved with or affected by technology (e.g., designers, manufacturers, distributors, users) will be increasingly diverse and multidisciplinary.
- Social, cultural, political, and economic forces will continue to shape and affect the success of technological innovation.
- The presence of technology in our everyday lives will be seamless, transparent, and more significant than ever. (p.53)

Attributes of the Engineer of 2020, the report said, should include strong analytical skills, creativity, practical ingenuity, communication skills, a grasp of leadership, professionalism and high ethical standards, and a combination of dynamism, agility, resilience, and flexibility. The report added that engineers must be lifelong learners and stretch their traditional comfort zone to bridge public policy and technology. Their career trajectories "will take on many more directions [...] that include different parts of the world and different types of challenges and that engage different types of people and objectives" (National Academy of Engineering, 2004, p.56). The report anticipated that the magnitude, scope, and impact of the challenges society will face in the future are likely to change, and that "the need for practical solutions will be at or near critical stage" by 2020 (p.55). Being able to connect with stakeholders and collaborate with project team members in new ways will also be a hallmark of the aspirational engineer of 2020.

Educating the Engineer of 2020

Released in 2005 by National Academy of Engineering, *Educating the Engineer of 2020: Adapting Engineering Education to the New Century* offers recommendations on how to better prepare engineering graduates to work in an ever-changing economy.

[The report] notes the importance of improving recruitment and retention of students and making the learning experience more meaningful to them. It also discusses the value of considering changes in engineering education in the broader context of enhancing the status of the engineering profession and improving the public understanding of engineering. Although certain basics of engineering will not change in the future, the explosion of knowledge, the global economy, and the way engineers work will reflect an ongoing evolution (National Academy of Engineering, 2005, p.1).

The Engineer of 2020 is in college right now, a product of the evolution of engineering education since the report's publication. While strides have been made, many problems raised in the report exist today.

Insights of Tomorrow's Engineers: TUEE Phase II Workshop

Student Perspective: Results from the Pre-workshop Survey

The TUEE Phase II workshop was designed to gather data from the students on the 36 KSAs that were identified in Phase I by industry and government representatives.[6] Approximately 160 students were nominated by engineering deans to participate in the workshop, all of whom were invited to take part in a survey beforehand. They represented various fields of engineering and were diverse in gender, race, ethnicity, type of institution, and geographical location. The survey contained a series of questions on each of the 36 KSAs. Students were specifically asked to rate the importance of each KSA for success in the engineering field, the perceived quality of preparation in these areas, and their curricular and extra-curricular experiences in developing these KSAs.

Twenty of the KSAs were rated as "very important" by at least 90 percent of the students. While a grounding in concrete, scientific principles of engineering is necessary, in the students' view, engineers must also acquire less tangible abilities, including leadership, teamwork, communication, time management, prioritization, critical thinking, problem-solving, adaptability, entrepreneurship, self-drive, curiosity, creativity, and risk-taking. Students reported that they and their institutions attached similarly high importance to five KSAs, but in only one case—knowledge of the physical sciences and engineering science fundamentals—did their institutions assign a greater value than they did. Quality of education in the KSAs was generally considered low. A majority of students assigned a "good" or "very good" rating to the inclusion of just one KSA: teamwork and multidisciplinary work. Currently, students reported gaining most of the KSAs through extracurricular activities and student-driven projects, along with membership in professional societies and student organizations, conferences, competitions, co-ops, and workshops. To instill the KSAs as part of engineering education, they called as well for an instructional shift to design projects, capstones, lab work, research, and seminars. Detailed survey results can be found in Appendix C.

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[4] The full list of KSAs can be found in Appendix C (see Table 1). For a more thorough review of the development process for the 36 KSAs, please see the report for the TUEE Phase I workshop at http://www.asee.org/TUEE_PhaseI_WorkshopReport.pdf.

Workshop Overview

A two-day, face-to-face meeting was designed to elicit engineering students' views on the most effective ways to acquire the 36 previously identified KSAs. More broadly, planners sought to encourage students to think about and discuss what currently works well in undergraduate engineering education and what should be improved (see Appendix A for a detailed description of the workshop). From the pool of 160 nominated students, 22 women and 19 men were chosen to participate in the workshop: Thirty eight represented U.S. public and private institutions of various sizes and regions, including historically black colleges and universities and one military college. In addition, participants included one student from the University of Waterloo, a public research institution in Ontario, and two from the University of Qatar. Altogether, there were 37 undergraduate students (33 seniors and 4 juniors) and 4 graduate students or recent graduates. Most were specializing in one of four engineering fields: mechanical and aerospace; electrical and computer; civil; and chemical and bio-molecular. Appendix B provides more details about workshop participants, including names and institutions.

Targeted questions were derived from themes that emerged from the comments and open-ended questions in the pre-workshop survey. Students were given a table of questions for each KSA or group of KSAs to respond to both the comments and ranking of importance. The purpose of these questions was to elicit specific comments and generate discussion among the students. The responses and discussion topics were recorded and reviewed. In all cases, the responses and discussion supported the responses to the pre-workshop survey.

Student feedback was encouraged throughout the workshop. Driving the discussions was an understanding that students' career success would require skills acquired in informal settings, in addition to formal credentials. The importance of the breakout sessions and ensuing conversations was to highlight the current state of engineering curriculum, expose any disconnect between curriculum and real-world engineering applications, and develop action items for educators. Students were encouraged to speak up in order to let their voices and observations be heard in order to "let NSF—and eventually the engineering community—know."

The first hour-long breakout session set the pattern for the three that followed. Each student was assigned to one of four groups, which explored how best to learn a set of KSAs. The sessions began with students being asked to state in writing whether they agreed with conclusions drawn from the student survey and to offer specific ways that learning could be improved. Pairs of students discussed their responses and then contributed to a group-wide discussion.

A closing talk by NSF's John Krupczak pointed out that contributions of engineers are not easily recognized by the public. The media routinely overlook engineering even when reporting high-profile events that spotlight invention, such as Maker Faires and the White House Science Fair. Hollywood publicists dubbed Tony Stark, played by Robert Downey Jr. in The Avengers, a "genius, billionaire, playboy, philanthropist," when in fact he is also an engineer. But the profession offers something important: job satisfaction. Surveys show that two things matter most to people in the workplace, beyond income, intellectual freedom, and recognition. They are "doing something that matters" and "working with good people." From powering cities to medical care to tackling the 14 Engineering Grand Challenges, engineers are embracing a call to service. Engineering also requires teamwork—it is not a solo sport. Success means bringing out the best in others.

At the end of the workshop, Ashok Agrawal (ASEE) asked students to offer single-word highlights from the sessions. The words offered included: "projects"; "diversity"; "skills"; "fun"; "preparedness"; "personal"; "integration"; "makerspace"; "socialize"; "choice"; "mentorship"; "application";" passion"; and "teamwork."

Emergent Themes

Holistic Education: Balancing Technical and Professional Skills

A widespread view held among the sample of students surveyed was that engineering classes tend to focus largely on the technical aspects of engineering and not so much on how engineers interact in a multidisciplinary and interconnected workforce. While the concrete scientific principles of engineering are necessary, being able to interact with others and apply knowledge and education to multiple areas of life is crucial for the success of the engineering professional, students said.

Fundamental engineering and science classes should stress the importance of critical thinking, teamwork, and finding unique ways to solve problems. The engineering curriculum should also include coursework and opportunities to build other important professional KSAs such as communication, leadership, and system integration skills, as well as a level of understanding of economics, business, and public safety. However, in practice, the extent to which institutions and individual professors adhere to these guidelines is varied. Institutions can teach the technical aspects of engineering as they see fit in order to meet the needs of their student body. However, in the eyes of numerous survey respondents, what makes a difference in engineering education is the mix of classwork, practical assignments, and extracurricular activities that prepare students in a full range of KSAs. These components shape them into members of the workforce and of society who

bring strong values, a broad perspective, leadership, the ability to communicate with engineers and non-engineers alike, and quality work and products that tackle real-world problems.

Going beyond hard science and engineering fundamentals in the curriculum, it is important for engineering education to focus on developing the more abstract KSA areas—the professional skills that enable students to apply their education in real life and adapt to engineering workforce situations. Students recognize that such skills can be difficult to instill in a classroom setting. Therefore, extracurricular activities and students' own motivation are both key to developing many of the professional KSAs.

Workshop discussions identified specific technical and professional skills students felt were important. According to the literature, combining skill sets often reveals the ability to have clusters of skills or even take a broader, abstract perspective such as systems thinking. In addition to systems-specific skills, there are the more general skills such as leadership, allocating resources, and factors beyond the scope of engineering. The latter may include the sociopolitical context or system in which a project, team, or individuals operate, including the organizational culture (Frank, 2006). While the overall purpose of TUEE II was to gain a sense of the KSAs needed for engineering as a whole, it should be acknowledged that specific engineering fields may demand different skills.

One of the so-called professional attributes, emotional intelligence, ranks low in importance for institutions, according to the student survey. Industry representatives in TUEE I cited parents as the single greatest influence. Students in one group were in agreement that it meant "paying attention to the human side of things" as opposed to an attitude of, "As long as I'm not hurting you physically, you should be fine." One student wondered whether emotional intelligence could be grasped through personality tests or a seminar with a psychologist. Some felt it could be encouraged outside class ("can't teach it") with teamwork, extracurricular activities, combined engineering school-company mixers, and other social events. Others thought it could be integrated with ethics.

KSA Spotlight: Systems Thinking

One unique KSA is systems thinking. An initial trait is the ability to see an entire system without being bogged down in the details of internal components. Information systems and different subsets of systems thinking have been noted as well (Cheney, Hale, & Kasper, 1990). In the TUEE II pre-workshop survey results, and during the workshop itself, students discussed a number of systems-specific skills, including:

- Calculated risk
- Security knowledge (including security ethics)
- Ability to see interconnections
- Closed-loop thinking
- Big-picture software fundamentals
- Metacognition
- Systems integration

Students urged that schools address systems thinking in more depth, incorporating it earlier into labs and capstones. "Not many people know what systems thinking is," a written comment from the pre-workshop survey observed. Another stated: "Disciplines need to get out of their bubble."

More could be done with instruction and practice in research and with case studies, students said. Schools should find ways for student research to be promoted. Professors can encourage the trend and start to do so by presenting their own research to students in an early seminar. One student suggested that instructors gradually add complexity to problems and have students identify constraints. Professors should encourage students to exercise their own judgment in designing solutions. Yet, as with some other KSAs, "you learn a lot of this outside the classroom," a student said. One group urged that students be called upon to defend design decisions in front of professionals. Whereas business representatives in TUEE I viewed judgment as a core life skill developed over time, some students saw it as akin to creativity. "Thinking outside the box is necessary for success," one wrote. Training in presentation skills should be introduced early, with students learning PowerPoint slide design and how to create graphs that anyone can understand. Flexibility, the ability to adapt to rapid change and cope with ambiguity, is a difficult

skill to acquire—"very frustrating, but helpful in the long run," one student commented, referring to ambiguous problems. It's also tough to teach. "Not enough classes do this well," a student wrote.

Enhancing Pedagogy and Student Support

Students cited teaching styles and techniques as one element of an overall undergraduate experience that needs improvement. They considered problem-based learning to be effective, depending on how it is implemented, but also urged faculty to introduce ethics and accountability in the curriculum and work to build a sense of community around engineering.

Assessments and Assignments

Regarding assessments, many students held a negative view of memorization and of tests that encourage it. While a few saw memorization as a technique for mastering fundamental knowledge, one noted, "it's easy to memorize equations and a week later you forget them." Suggestions to encourage students to think more, memorize less, and learn how information was derived included open-book tests and allowing use of formula sheets while solving engineering problems in class. Students also found that open-ended exam questions prompt them to think critically about real-world problems. Problems offering more than one solution and teamwork were seen as helpful in developing personal and professional judgment as well as critical thinking.

Assignments should require students to think before attempting to solve a problem. One example is having students write how a complex circuit would behave. The best test of a student's knowledge is to try to teach others, such as by explaining to a class how results were reached in a homework assignment. Students suggested an approach to grading that takes into account both whether students get the right answers and their thought processes in arriving at the answer. Students would benefit more from early courses in math, science, and engineering fundamentals if they understood how these fundamentals could be applied. As one student said: "We're shoving math and science classes down their throat and they don't really know what they need them for."

Willing faculty can help students develop needed problem-solving skills. They can also stimulate students' imaginations with open-ended assignments, such as having a class identify a problem and proceed to develop a solution, or by providing an end-game and letting students reach it on their own. Such an approach allows students to innovate using skills they've already learned. Preparing an outline is useful. Not everyone thinks a learning environment free of stress is best; high-stakes pressure helps "force vision creation," as one student said. Universities should recognize and provide a showcase for visionary projects.

Students considered development of communication skills to be important, with some having experienced poor teaching, insufficient feedback, and inconsistent attention to this from faculty. Some favored adding communication as a separate course. Others urged that it be stressed throughout the curriculum, or that skills be built through team-based research projects that incorporate reports and presentations, and through extra-curricular activities.

Community, Ethics, and Accountability

A sense of community among engineering students can be key to helping them persist in the field. This can be built by fostering more student-faculty contact and by reaching beyond the classroom and university setting to the surrounding community and university alumni. Merely setting a goal, however, does not bring about a community atmosphere, as one workshop participant noted: "An open-door policy is great but we need to encourage students to take advantage of this."

Campus climate and cultural awareness should be incorporated in coursework and the broader curriculum. Ways to promote cultural awareness and a more inclusive campus climate include randomly assigning students to group projects instead of having students pick their teammates, real-world design, including projects geared to a cultural setting, and study- and work-abroad opportunities with lower financial barriers.

Faculty can help enhance campus climate in numerous ways. One example is a professor who made a point of getting to know every student in

EPICS: Emphasizing Service Learning and Community Impact

EPICS (Engineering Projects in Community Service), founded at Purdue University in 1995, engages teams of undergraduate engineering students, working in partnership with community organizations, in providing products and services that benefit individuals and communities. In addition to using their technical skills to solve engineering-based problems, EPICS participants also build professional skills—including leadership, communication, and project management skills—through working on diverse teams and building a stronger connection to the community that they serve. In 2006, the program expanded to K-12 schools in an effort to build STEM awareness, while tapping into the rising interest in volunteerism among pre-college students (Purdue University, 2017).

Information about EPICS is available at: https://engineering.purdue.edu/EPICS/about.

a class, to the point of designing projects and labs geared to individual interests. Giving students more freedom to pick topics was urged ("having a choice fosters passion"), along with a connection between departments and such student organizations as Engineers Without Borders. At least one school (of those represented at the meeting) has an innovation challenge-entrepreneurship startup fund.

Tangible institutional support for extracurricular activities helps to sustain the motivation of active members. One college's decision to grant academic credit for extra-curricular projects, such as entries in racecar or concrete canoe competitions, was found to help with retention. Schools can also help by identifying off-campus projects that would benefit from engineering skills, either in the surrounding community or abroad. Such practical experience hones students' technical skills, while community presentations strengthen their communications skills.

Group projects can provide valuable practice in conflict resolution, but students gain the best experience when teams are intentionally diverse and they are forced to "work outside their comfort zone." Diversity in this instance means personality type as well as ethnic and gender diversity. Schools don't emphasize this training enough. Useful examples include a conflict-resolution workshop offered by honor society Tau Beta Pi that featured both activities and open discussion. Schools need to understand that "it can be difficult to hold a leadership position if you are a minority" and should avoid tokenism.

Improved teaching is needed on the part of both full-time faculty and teaching assistants. While competing priorities claim students' attention and undermine motivation, schools can encourage students to strive for success through tutoring, supplemental instruction, and improved advising, including by peers and dedicated staff advisers.

The danger of ethical lapses must be stressed. One student had interned at a firm where abuses occurred. That same student admitted to having cheated on a test. Ethics should be part of every class, every year; professors should bring it up early and often, and students should come to know their respective professional societies' codes of ethics. Other recommendations included a course on the philosophy underlying ethics, leadership classes devoted to ethics, and case studies of "what not to do." While cases of plagiarism should be dealt with firmly and consistently, students need training in what counts as plagiarism. Closely linked with ethics is ownership and accountability. Extracurricular opportunities such as presiding over student associations and student chapters of professional societies teach students leadership, ethics, and ethical conduct.

Design Centers

University-industry partnerships serve both to incorporate product innovation in the engineering curriculum and help students transfer seamlessly from lab to industry once they graduate. In the Design Center at the University of Colorado, Boulder, for instance, mechanical engineering students gain practical KSAs by working on projects for industry partners using the latest technology. Teamed with professional engineers—either in a school laboratory or industry worksite—students acquire technical skills developing and designing a prototype or a working product while gaining experience in time management and materials budgeting. (University of Alabama Manderson Graduate School of Business, 2012; University of Colorado, 2017).

Public safety should be emphasized more. Students must learn its importance not just in labs but also in design and learn how to read and understand safety codes. Workshops that present case studies are a good teaching method. Universities must set an example by following safety codes. Public safety should be a required part of students' plans in projects across all disciplines. Instruction in safety should extend to safeguarding information and protecting intellectual property.

Curriculum Improvements

Students' recommendations for modifications, updates, or expansion of curricula generally aligned with research on ways that new graduates can meet workforce demand (e.g., Karjalainen, Koria, & Salimäki, 2009; Oskam, 2009). Currently, freshman and sophomore years of college engineering tend to focus on the fundamentals. Much-needed professional skills, context, and practical project and design opportunities only come during the junior and senior years. Students did not dispute the importance of a grounding in math and science, but stressed the need for project-based learning from the very beginning and design classes and team-based projects throughout the undergraduate experience. Fundamental scientific concepts and professional skills should have continuous refreshers so they do not fade away. Students also need time-management training so they can incorporate extracurricular activities.

Colleges should have mandatory courses in programming and quantitative methods. The focus of teaching should be on how programs produce results, on collection and storage of information in every discipline, networking, and information security. In reality, college is too late to learn basic information technology. It should be taught in elementary and secondary school.

Multidisciplinary learning experiences can be instrumental in providing a range of KSAs. One example cited by students is a minor in engineering leadership development where business, education, and engineering majors are able to work together in culturally and professionally diverse teams. Their projects teach leadership, business fundamentals (finances, budgets, project proposals, and business plans), technical presentations, ethics, global

perspective, cultural awareness, and how they all connect to the field of engineering to solve societal needs. Some schools also require students to take an engineering clinic every semester in which student teams work on a multidisciplinary research-based project. Clinics aim to stimulate curiosity, a desire for continuous learning, and motivation. Research topics tap varied disciplines and topics, including economics, ethics, and global, social, intellectual, environmental, and technological responsibility.

Need for Industry Exposure

Students see many benefits from exposure to industry, which some of them had experienced. Among the advantages: Students can learn from real-world professionals, witness demands on companies that require on-the-spot decisions "without having a formula sheet," recognize that a business plan can trump the best design, and improve their communication skills by addressing audiences of engineers and non-engineers. While engineering schools tend to forge more ties with industry than does academia generally, most external funding at research-intensive universities comes from government. As a result, less importance may be attached to industry-faculty contacts that would lead to real-world projects.

Industry ties can be enhanced in a number of ways, including industry-university partnerships, informal faculty contacts, and curriculum updates for companies. At Canada's University of Waterloo, every graduate will have had 20 months of on-the-job experience through a co-op program. Workshop participants felt that schools should be encouraged to hire faculty with industry experience, and faculty need to be persuaded of the importance of economics. Industry seminars and workshops can be offered, and curricula should incorporate the kind of open-ended questions encountered in industry. An accepted national standard could spur the business and economics training that industry seeks in engineering graduates, and students should be given opportunities to apply that knowledge. Teaching materials might be streamlined and incorporated into electives. Other routes could include a business-economics minor or certificate program, including business students in design teams, and partnerships with MBA programs toward a joint engineering-business master's degree.

Greater attention could be paid by professional organizations and discipline-based clubs.

Knowing how to apply engineering science in the real world presents another example of the need for close ties with industry, in the students' view, and is a skill worth spending school resources to develop. In written comments, students tended to view the "ability to prioritize efficiently" through the prism of time-management challenges faced by undergraduates, rather than as an industry management skill. Nonetheless, many recognized this as important. As to training, not all thought workshops were the solution. Several agreed that early training would be useful and that requesting help should not carry a stigma.

Design competitions and makerspaces were seen as training grounds for entrepreneurship, but students saw a need as well for a connection with industry and introduction to actual entrepreneurs. Guest speakers and video conferences were suggested, as well as collaboration with the business school. "Not everyone wants to be an entrepreneur," a written comment stated, so such training should be an option but not forced.

Cooperative education, or work-study, offers a long-established way to gain industry exposure. First launched in the United States more than a century ago, it was intended to bridge the gap between theory and practice and equip engineers for the nation's expanding industrial workplace (Haddara & Skanes, 2007). Research has found that graduates with co-op experience earn higher starting salaries and gain positions with more responsibility at the outset of their careers. However, this relative advantage over graduates without co-op experience appears to diminish over time (Haddara & Skanes, 2007). Cooperative learning and experiential learning have overlapping theoretical roots (Kolb, A. & Kolb, D., 2012), which include aspects of reflective learning and can serve as a foundation for lifelong learning.(Kolb, D., 2014). Some schools have mandatory cooperative education as part of their engineering programs. Where these provide successful student experiences, they serve to strengthen institutional partnerships with industry. Companies can use the co-op program as part of recruitment and job screening efforts in order to bring on board employees with more experience and knowledge of their work settings (Haddara & Skanes, 2007).

Project-based, Problem-based Learning and Experiential Learning

Both project-based and problem-based learning processes can benefit engineering education, especially related to KSA development and attainment. Project-based learning (which typically results in a tangible completed project) can replicate a workplace setting, allow for a one-to-one relationship with an industry professional, and potentially stimulate a student's career thinking. Problem-based learning (which is more specific, structured, and sequential) may allow students to gain the kind of KSAs they would acquire in a structured setting at times when replicating such a setting is unrealistic—for instance, due to safety concerns. Recognized "essential" best-practice elements of problem-based learning include a problem, inquiry, authenticity, student voice/choice, reflection, critique and revision, as well as a public product (Buck Institute for Education, 2015).

Project-based learning can give students a chance to apply technical knowledge and skills learned through coursework. It may include design projects, capstones, lab work, research projects, co-ops and internships, membership in professional societies and student organizations, conferences, competitions, and seminars (offered each year of the student's college experience). Projects can bridge technical knowledge with applied skills in industry, society, and the real world, introducing a variety of necessary skills not covered in regular course work and setting students up for professional success. Multidisciplinary teamwork combining project-based learning and extracurricular activities can serve to develop important professional skills, such as leadership, teamwork, communication, time management, prioritization, critical thinking, problem-solving, adaptability, entrepreneurship, self-drive, curiosity, creativity, and risk-taking. Semester-long student-directed projects without a set schedule of checkpoints could serve as an incubator for these professional skills.

Design projects and competitions, student design clubs, and capstones were frequently highlighted by

students in the pre-workshop survey as beneficial examples of project-based learning. One response offered the example of a required a yearlong senior engineering design course that stresses all of the first 12 KSAs. In the course, students work in teams of four or five to design a product for a local sponsoring company that solves a real-life engineering problem. They work with a faculty advisor and liaison engineer(s) from the sponsoring company throughout the year in product development. During the course, students prepare a proposal, create and follow a project budget, communicate with necessary stakeholders, apply fundamental engineering principles, and inquire about further knowledge necessary to create a solution to the presented engineering problem. Students show their finished products at the end of the year to the university, sponsoring companies, and the public in the form of a 20-minute formal presentation, as well as a poster session. Other engineering departments specifically assign design projects at the end of every semester, very much like a senior design course, to help prepare students for engineering tasks, instead of focusing on exams.

Extracurricular activities such as volunteering with Engineers Without Borders allow students to apply the academic concepts they learn in their classes to projects that have real-world impact. It is an opportunity for aspiring engineers to go through the entire project cycle, from concept-generation to financial management, component design, systems integration, and construction on the ground, while at the same time developing strong communication skills and cultural understanding among diverse communities.

One of the topics touched upon in the pre-workshop survey and at the workshop was the need for different forms of experiential learning. Select aspects may occur within the formal class setting or curriculum, while additional aspects may occur outside class. Students urged that courses on fundamentals include experiential learning opportunities to provide "a taste of what [they're] getting [themselves] into— fun things—then you know why the fundamentals are worth it." More attention should be paid to understanding the process of engineering, many felt, and real-world experiences. Suggestions of ways to achieve this included working with company clients, practicing with state-of-the-art industry equipment, inviting alumni to speak and share both successes and failures, more undergraduate research

opportunities, credit-based practical and experiential learning, and capstone-type projects as early as freshman year. Project-based activities should be promoted throughout the entire curriculum from the beginning. Waiting until the senior year to complete a single capstone project is insufficient. To develop critical thinking, students stressed the importance of lab and project design assignments.

Design projects with interdisciplinary teams and training in entrepreneurship can spur an innovative mindset, students suggested, particularly if they present an actual design challenge. Team leadership should be rotated to give every student practice. When it comes to creating an entrepreneurial vision, only so much can be accomplished in a classroom; "the best results often come in the real world." Schools should offer opportunities for interdisciplinary senior design projects, which may allow for a more real-world experience.

The informal curriculum, including extracurricular activities and makerspaces, can be a worthwhile form of experiential education and deserves more faculty attention than is now common. Extracurricular activities such as involvement in, or leadership of, project management (design, lab, capstones, etc.), student clubs and organizations, student chapters of professional societies, and community work are also highly effective in developing KSAs. These activities can cultivate strong leadership, teamwork, management and communication skills, self-motivation, critical thinking, problem-solving, and system thinking and system integration abilities. All of these activities involve working with a number of different stakeholders, ranging from executives to volunteers, full-time staff, administration, and external groups. Extracurricular activities could also be multidisciplinary, providing opportunities to work with peers from other majors.

Project-based activities should be promoted throughout the entire curriculum from the beginning. Waiting until the senior year to complete a single capstone project is insufficient.

The Road Ahead

Recommendations

At the workshop, students concluded that schools were paying insufficient attention to an array of knowledge, skills, and abilities (KSAs) needed to produce the desired T-shaped professional. Importantly, they did not fault the rigorous grounding in math, science, and engineering fundamentals that are a priority of engineering programs, but criticized how these and other courses were taught. Urging a greater emphasis on instructor training, students suggested that teaching be part of the basis for securing tenure and salary increases. They also called for greater faculty diversity in gender, ethnic background, and experience in industry and academe. Schools could improve accountability, some noted, by assessing whether courses fulfill the promise advertised in syllabi.

From the first year onward, calculus, physics, and chemistry courses should include examples of real-world engineering applications. Design-based projects, supplemented by extra-curricular activities, competitions, and makerspaces, should be part of the curriculum from the outset and incorporated throughout to stimulate learning and creativity. Open-ended problems and exams will train students to think critically. Technology should be kept up to date. Teams should be intentionally diverse, both in ethnicity and gender but also in personality types, to encourage cultural awareness and other desired traits. Exposure to industry, business training, ethics, and communication skills all require more attention. An oft-repeated demand was for mentoring, whether by older students, faculty, professionals in industry, or even peers. The best test of knowledge, one student observed, is to try to teach others.

Workshop Action Items

Assembled in small groups around tables, students were asked to come up with three or four urgent needs in undergraduate engineering education and propose steps that universities and faculty, student organizations, industry, and students themselves should take in response. One student spoke for each table. Recommendations included:

Community:

- Foster early access to mentoring, engineering experiences, and advising, with an entire community—students, faculty, student organizations, and industry—each playing a role.
- Enhance the connection between students and professors, thus creating a sense of community.
- Include team design projects starting in freshman year that benefit someone or some organization.

Project-based learning and experiential learning:

- Include open-ended, interdisciplinary projects undertaken by groups that change composition over time, forcing students to adapt to new partners.
- Redistribute grading to increase the value of project-based learning as opposed to exams. Build design projects into upper-level courses.

Application and impact:

- Have a focus on real-world impact, so as to show students the importance of what they're being taught. The impact could be illustrated by case studies and reinforced with internships, co-ops, and guest speakers.
- Show the applications to engineering in first-year math and science courses—calculus, physics, and chemistry.
- Encourage faculty to be creative in supplying real-world examples.

Faculty Improvements:

- Seek more diversity in gender, ethnic background, and balance of industry and academic experience.

- Instead of rotating instructors of required courses, allow faculty members to teach subjects they're passionate about or really skilled at teaching.
- Make teaching quality part of the basis for securing tenure. For tenured faculty, evaluate teaching as part of salary reviews.
- "Actually make it required for professors to learn how to teach." For instance, instruction in teaching could be incorporated into Ph.D. programs. Improve accountability by assessing whether courses fulfill the promise suggested in syllabi. For instance, did students reach ABET-level outcomes?

Balancing Technical and Professional Skills:

- Incorporate writing and presentations in various courses to build students' communication skills.
- Offer minor credit or certificates of proficiency in professional skills.
- Offer a single course combining ethics, business, and entrepreneurship. Alternatively, ethics and safety could be integrated into existing courses.
- Include a course, already offered at one school, called Concepts of Professional Practice, that includes resume writing and career-oriented instruction.

In an open follow-up discussion, one student reflected that the workshop had motivated her to "really sit down with other students" on her return to school "and see what the issues are." She learned of worthwhile initiatives at other institutions and wondered, "Why don't we have that? What can I do to get that?" She encouraged other attendees to initiate discussions on their campuses on "what we need to do to create positive change for our institutions."

Ashok Agrawal picked up the same theme in leading a final discussion. He encouraged attendees to "let your deans know" what insights they had gained. He then went around the room and asked each student to attach a one-word adjective to the previous two days. The responses included: Stimulating; enlightening; thought-provoking; intriguing; eye-opening; engaging; intriguing; and well-organized.

Future Directions

The Knowledge, Skills, and Abilities (KSAs) developed by industry and government representatives and academics in the TUEE Phase I workshop provided a starting point for subsequent workshops, where they can be refined and adjusted through rigorous exercises and discussion. By the culmination of the TUEE initiative, these KSAs should serve as a platform for curriculum development and reform in engineering education that meets the changing demands of society and the economy.

TUEE Phase II made students full partners in the transformation effort, recognizing that they have a great deal at stake and that so much of the nation's future well-being rests on their success. Their insights will be considered carefully in subsequent workshops and should be reflected in future curricula and collaborations between higher education institutions and industry.

TUEE PHASE III, Voices on Women's Participation and Retention, will test how well the KSAs developed to date coincide with the challenge of reversing the persistently low representation of women in engineering. Although the proportion of women in the Phase II cohort was larger than that among students generally, Phase III will provide additional insights on whether the KSAs can increase the motivation of women to enter engineering and reduce the barriers they encounter in the curriculum and beyond the university setting.

TUEE Phase IV, which brings in professional societies, will indicate how well the KSAs complement the societies' ongoing efforts in engineering education and provide tools for greater involvement by these organizations. Professional societies often serve as a bridge between the academy and industry, and can communicate the importance of the KSAs and promote new ways for students to attain them.

While identifying the needs and contributions of industry, students, and professional societies, TUEE highlights some requirements of engineering education shared by all four groups. One is systems thinking and the need for graduates who can apply it to their respective disciplines. Today's students need to master the data and computational tools and the ability to work across disciplines in diverse teams to take a systems approach to many future work assignments. Another requirement is to get industry and higher education working more closely together. Several of the students' recommendations show that they recognize this. Experiential and applied learning opportunities were often cited as ways to bridge the divide. Project-based and problem-based learning could be incorporated into the curriculum to a greater degree in order to simulate workforce settings. One way for industry to influence engineering education is to provide the technology and labs that many schools need.

Despite the workshops' effort to anticipate the future, the KSAs of today are not carved in stone and may need to be adjusted, expanded, or replaced in the years ahead in keeping with rapid advances in technology. For instance, computer science inside and outside engineering is likely to change how various fields of engineering develop. New fields of engineering are likely as well, some of them hybrids of existing fields. This prospect underscores the imperative of lifelong learning and the need for engineering educators to instill that habit in their students. Without this transcendent skill, the T-shaped engineers that are today's ideal will not fulfill their potential.

Students pinpointed certain KSAs that their instructors appeared unable to teach. They suggested that these could be learned in informal learning environments and extra-curricular activities, such as makerspaces, as well as industry internships. One challenge for higher education will be to connect these real-world experiences with the advanced theoretical knowledge required of professional engineers.

This report is intended to help stakeholders across the engineering spectrum advance the profession. These stakeholders include administrators and faculty in higher education and companies seeking to improve training of newly hired engineers. Students— and their parents as well—may find the report useful in guiding their professional development.

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Appendix A: Workshop Agenda

Friday, April 10, 2015

2:00 PM – 2:30 PM	**Registration**

2:30 PM – 3:15 PM **Welcome & Overview**

Ashok Agrawal, Managing Director, Professional Services,
American Society for Engineering Education

Pre-workshop Survey Results

Brian Yoder, Director Assessment, Evaluation and Institutional Research,
American Society for Engineering Education

Student Introductions

Christopher Carr, Program Manager, Outreach & Public Affairs GRFP,
American Society for Engineering Education

3:15 PM – 4:15 PM	**Breakout I**

4:15 PM – 4:30 PM **Break**

4:30 PM – 5:30 PM	**Breakout II**

5:30 PM – 5:45 PM **Break**

5:45 PM – 6:45 PM	**Day 1 Collective Debrief**

7:00 PM – 8:00 PM **Dinner**
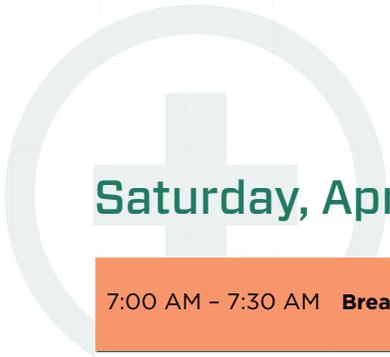
Saturday, April 11, 2015

7:00 AM – 7:30 AM **Breakfast**

7:30 AM – 8:30 AM **Breakout III**

8:30 AM – 8:45 AM **Break**

8:45 AM – 9:45 AM **Breakout IV**

9:45 AM – 10:00 AM **Break**

10:00 AM – 11:00 AM **Day 2 Collective Debrief**

11:00 AM – 11:15 AM **Break**

11:15 AM – 12:30 PM **Open Discussion**

12:30 PM – 1:00 PM **Break**

1:00 PM – 2:00 PM **Lunch & Overall Reflections**

2:00 PM – 2:00 PM **Adjourn**

Appendix B: Attendee List

More than forty individuals, representing a diverse array of backgrounds and institutions, attended the *TUEE Phase II Insights from Tomorrow's Engineers* workshop. The affiliations listed below are those at the time of the event.

Skylar Addicks
Texas Christian University

Joshua Alcala
New Mexico State University

Mashail Khalifa Al-Kaabi
Qatar University

Bryan Bonnet
Stevens Institute of Technology

Bethany Brigandi
Rowan University

Jordan Burns
University of Colorado, Boulder

Lupita Carabes
University of Portland

Nicolas Corrales
Arizona State University

Miriana Doghan
University of Michigan, Dearborn

Erica Flores
Seattle University

Melissa Flores
California State University, Northridge

Robert Christian Ford
North Carolina A&T State University

Thomas Foulkes
Rose-Hulman Institute of Technology

Braden Gourley
Penn State

Alison Grady
Smith College

Kia Graham
Southern University and A&M College

Brian Grau
Santa Clara University

Amy Haddix
West Virginia University Institute of Technology

Hayden Hast
Valparaiso University

Emily Hernandez
Missouri University of Science and Technology

Jenna Humble
Embry Riddle Aeronautical University

Bill Kim
Johns Hopkins University

Keoponnreay Kim
Concordia University

Allison King
Swarthmore College

Dalia Abo Mazid
Qatar University

Melinda McClure
Texas A&M University

Kevin McNamara
University of Waterloo

Chloe McPherson
Iowa State University

Amber Mills
The Citadel

Mary Osetinsky
Tulane University

Mackenzie Peterson
James Madison University

Lucius M. Rice IV
Tuskegee University

Bryan Ricksecker
University of South Alabama

Austin Smith
University of Arizona

Andrew Sousa
University of Massachusetts, Amherst

Hayley Spears
University of South Florida

Brian M. Van Nortwick Jr.
New Jersey Institute of Technology

Michael Vartan
California State University, Long Beach

Brian Ward
Bucknell University

Antoinette Winckel
South Dakota School of Mines and Technology

William Zygmunt
Wayne State University

Faculty

Majeda Khraisheh
Qatar University

Russell Korte
Colorado State University

NSF Staff

Amy B. Chan-Hilton
Program Director

Karen E. Crosby
Program Director

John Krupczak
Program Director

Don Millard
Acting Division Director,
Engineering Education and Centers

Yvette Pearson Weatherton
Program Director

Bevlee Watford
Program Director

ASEE Staff

Ashok K. Agrawal
Managing Director, Professional Services

Christopher Carr
Program Manager, Outreach & Public Affairs GRFP

Yvette Deale
User Interaction Design Manager

Stephanie Harrington Hurd
Manager, K-12 Activities

Rachel Levitin
Program Director, NDSEG

Mark Matthews
Editor

Ray Phillips
Program Assistant

Tengiz Sydykov
Assistant Program Manager

Rossen Tsanov
Senior Research Associate

Brian Yoder
Director, Assessment, Evaluation,
and Institutional Research

Appendix C: Pre-Workshop Survey Results

In preparation for the *Insights from Tomorrow's Engineers* workshop, 165 students were invited to complete a survey on what they consider the most important *Knowledge, Skills and Abilities* (KSAs) for engineering, the perceived quality of preparation in these areas, and their curricular and extra-curricular experiences to develop such KSAs. Eighty one percent of the students responded, providing a diverse representation of fields of engineering, student-body demographics, institution type and size, and geographical location.

Summary of Responses to Closed-ended Questions

The thirty-six KSAs defined in Phase I by industry were presented to engineering students in the pre-workshop survey. Students were asked to rank the importance of each of the KSAs to the engineering profession as they perceived it. Additionally, they were asked to rank the importance of each KSA as it is currently conveyed to them by their institution, as well as the quality of education they are currently receiving in each respective KSA area. The reported results for each of the 36 KSAs are listed in Table 1, divided into three sections consisting of 12 KSAs each. The table shows many areas in which the curriculum is closely aligned with students' and academics' perception of its importance. It also highlights areas of discrepancy, where students and academia perceive the importance of certain KSAs differently. More importantly, Table 1 indicates which areas of engineering education are perceived to lack quality and where updates and improvements may be needed.

Table 2 cross-tabulates results from the student pre-meeting survey with data gathered from industry in Phase 1, juxtaposing the importance of each KSA for the engineering profession as perceived by students and industry, as well as anticipated industry needs in the next decade. Overall, the comparative data in the table shows a tendency for students to be more closely aligned with what industry perceives will be important in the next decade and less closely aligned with industry's priorities today.

Table 1. Students' perceptions of KSAs' importance for the engineering profession and quality of education received in each area

Knowledge, Skills and Abilities (KSAs)[1]	A. Importance for the engineering profession								B. Quality of education[4]			
	Very Important*		Moderately Important		Unimportant **		Not sure		VG-G	F	P-VP	NS
	Personal perception[2]	Conveyed by institution[3]	Personal perception[3]	Conveyed by institution[3]	Personal perception[2]	Conveyed by institution[3]	Personal perception[2]	Conveyed by institution[3]				
KSA 1: Good communication skills	100%	82%	0%	16%	0%	2%	0%	0%	44%	43%	13%	1%
KSA 2: Hard sciences and engineering science fundamentals	90%	96%	8%	3%	2%	1%	0%	0%	46%	46%	7%	1%
KSA 3: Ability to identify, formulate, and solve engineering problems	99%	94%	1%	6%	0%	1%	0%	0%	48%	40%	12%	0%
KSA 4: Systems integration	79%	44%	12%	40%	1%	9%	8%	8%	10%	38%	39%	13%
KSA 5: Curiosity and persistent desire for continuous learning	96%	58%	4%	29%	0%	12%	0%	1%	35%	39%	25%	1%
KSA 6: Self-drive and motivation	99%	62%	1%	27%	1%	11%	0%	0%	32%	38%	30%	1%
KSA 7: Cultural awareness in the broad sense (nationality, ethnicity, linguistic, gender, sexual orientation)	68%	41%	24%	37%	6%	19%	2%	2%	29%	33%	30%	9%
KSA 8: Economics and business acumen	71%	36%	28%	42%	1%	19%	0%	2%	10%	48%	39%	4%
KSA 9: High ethical standards, integrity, and global, social, intellectual, and technological responsibility	99%	86%	1%	9%	0%	5%	0%	0%	46%	40%	12%	1%
KSA 10: Critical thinking	98%	91%	2%	9%	0%	0%	0%	0%	43%	44%	12%	1%
KSA 11: Willingness to take calculated risk	76%	37%	20%	40%	3%	17%	1%	7%	12%	42%	37%	9%
KSA 12: Ability to prioritize efficiently	95%	70%	5%	25%	0%	4%	0%	1%	32%	51%	16%	1%

Note. N=141

[1] KSAs are ordered by priority as initially defined by industry representatives at the TUEE Phase I Workshop, see report at http://www.asee.org/TUEE_PhaseI_WorkshopReport.pdf

[2] Level of importance as perceived by students.

[3] Level of importance communicated to students through orientation, advising, classes and other activities at their institutions.

[4] Quality of curricular and extra-curricular activities to help develop each area.

VG-G = very good/good; F = fair; P-VP = poor/very poor; NS = Not Sure

*Combines Extremely Important and Important. **Combines Relatively Unimportant and Completely Unimportant

Table 1. Students' perceptions of KSAs' importance for the engineering profession and quality of education received in each area

Knowledge, Skills and Abilities (KSAs)[1]	A. Importance for the engineering profession								B. Quality of education[4]			
	Very Important*		Moderately Important		Unimportant**		Not sure		VG-G	F	P-VP	NS
	Personal perception[2]	Conveyed by Institution[3]	Personal perception[2]	Conveyed by Institution[3]	Personal perception[2]	Conveyed by Institution[3]	Personal perception[3]	Conveyed by Institution[3]				
KSA 13: Project management (supervising, planning, scheduling, budgeting etc.)	93%	74%	6%	17%	2%	10%	0%	0%	37%	37%	26%	1%
KSA 14: Teamwork multidisciplinary work	99%	93%	1%	10%	0%	2%	0%	0%	58%	31%	10%	0%
KSA 15: Entrepreneurship and intrapreneurship	61%	39%	33%	39%	5%	20%	2%	2%	20%	31%	46%	3%
KSA 16: Use new technology and modern engineering tools necessary for engineering practice	93%	69%	7%	21%	0%	10%	0%	1%	19%	47%	32%	2%
KSA 17: Public safety	97%	85%	2%	12%	0%	2%	1%	2%	33%	47%	15%	6%
KSA 18: Informational technology (IT)	67%	48%	26%	34%	5%	15%	2%	4%	5%	53%	32%	10%
KSA 19: Applied knowledge of engineering core sciences for the real world	91%	88%	7%	7%	1%	4%	1%	2%	40%	42%	18%	1%
KSA 20: Data interpretation and visualization	92%	78%	7%	18%	0%	4%	1%	1%	29%	45%	25%	2%
KSA 21: Security knowledge (cyber, data, etc.)	66%	31%	22%	36%	12%	27%	1%	7%	8%	32%	52%	8%
KSA 22: Leadership	99%	77%	1%	18%	1%	5%	0%	0%	47%	36%	17%	1%
KSA 23: Creativity	95%	58%	5%	32%	0%	9%	0%	1%	26%	42%	31%	0%
KSA 24: Systems thinking	78%	58%	9%	19%	2%	8%	12%	15%	17%	37%	30%	16%

Note. N=141
[1] KSAs are ordered by priority as initially defined by industry representatives at the TUEE Phase I Workshop, see report at http://www.asee.org/TUEE_PhaseI_WorkshopReport.pdf
[2] Level of importance as perceived by students.
[3] Level of importance communicated to students through orientation, advising, classes and other activities at their institutions.
[4] Quality of curricular and extra-curricular activities to help develop each area.
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	Very Important*		Moderately Important		Unimportant **		Not sure		VG-G	F	P-VP	NS
	Personal perception[2]	Conveyed by institution[3]	Personal perception[2]	Conveyed by institution[3]	Personal perception[2]	Conveyed by institution[3]	Personal perception[2]	Conveyed by institution[3]				
KSA 25: Emotional intelligence	72%	29%	20%	34%	6%	29%	3%	10%	14%	36%	32%	19%
KSA 26: Application based research and evaluation skills	86%	77%	11%	17%	1%	4%	1%	2%	41%	38%	15%	6%
KSA 27: Ability to create a vision	85%	49%	10%	30%	2%	16%	3%	4%	17%	44%	34%	4%
KSA 28: Good personal and professional judgment	99%	78%	1%	17%	0%	4%	0%	1%	39%	43%	17%	1%
KSA 29: Mentoring skills	86%	51%	12%	25%	2%	22%	0%	2%	31%	44%	23%	2%
KSA 30: Flexibility and the ability to adapt to rapid change	98%	68%	2%	25%	0%	7%	0%	0%	28%	43%	28%	1%
KSA 31: Ability to deal with ambiguity and complexity	95%	81%	3%	15%	1%	3%	1%	1%	36%	41%	21%	3%
KSA 32: Innovation	92%	77%	7%	17%	0%	5%	1%	2%	34%	36%	29%	2%
KSA 33: Technical intuition (metacognition)	78%	66%	15%	20%	1%	3%	7%	12%	19%	50%	17%	15%
KSA 34: Understanding of design	97%	91%	3%	7%	0%	1%	0%	1%	38%	49%	12%	1%
KSA 35: Conflict resolution	94%	60%	7%	25%	0%	14%	0%	1%	28%	41%	28%	3%
Q36: Ownership and accountability	98%	83%	1%	14%	0%	2%	1%	1%	43%	39%	15%	3%

Note. N=141

[1] KSAs are ordered by priority as initially defined by industry representatives at the TUEE Phase I Workshop, see report at http://www.asee.org/TUEE_PhaseI_WorkshopReport.pdf

[2] Level of importance as perceived by students.

[3] Level of importance communicated to students through orientation, advising, classes and other activities at their institutions.

[4] Quality of curricular and extra-curricular activities to help develop each area.

VG-G = very good/good; F = fair; P-VP = poor/very poor; NS = Not Sure

*Combines Extremely Important and Important. **Combines Relatively Unimportant and Completely Unimportant

Table 2. Industry vs. Students: Perceptions of the importance of high priority* KSAs for the engineering profession**

Knowledge, Skills and Abilities (KSAs)	Very Important			Moderately Important			Unimportant		
	Students	Industry in 2013	Industry in 2023	Students	Industry in 2013	Industry in 2023	Students	Industry in 2013	Industry in 2023
Good communication skills	100%	81%	84%	0%	19%	16%	0%	0%	0%
Hard sciences and engineering science fundamentals	90%	53%	51%	8%	46%	48%	2%	2%	2%
Ability to identify, formulate, and solve engineering problems	99%	75%	88%	1%	25%	13%	0%	0%	0%
System Integration[1]	79%	53%	75%	12%	44%	25%	1%	3%	0%
Curiosity and persistent desire for continuous learning	96%	75%	84%	4%	25%	16%	0%	0%	0%
Self-drive and motivation	99%	81%	91%	1%	19%	9%	1%	0%	0%
Cultural awareness in the broad sense (nationality, ethnicity, linguistic, gender, sexual orientation)[2]	68%	38%	84%	24%	56%	16%	6%	6%	0%
Economics and business acumen	71%	44%	59%	28%	56%	41%	1%	0%	0%
High ethical standards, integrity, and global, social, intellectual, and technological responsibility	99%	88%	88%	1%	13%	13%	0%	0%	0%
Critical thinking	98%	81%	88%	1%	19%	13%	0%	0%	0%

*These high priority KSAs were initially selected by industry representatives at the TUEE Phase I Workshop, see report at http://www.asee.org/TUEE_PhaseI_WorkshopReport.pdf
**Percentage totals may exceed 100% due to rounding
[1] 8% of Students responded with 'Not Sure'
[2] 2% of Students responded with 'Not Sure'
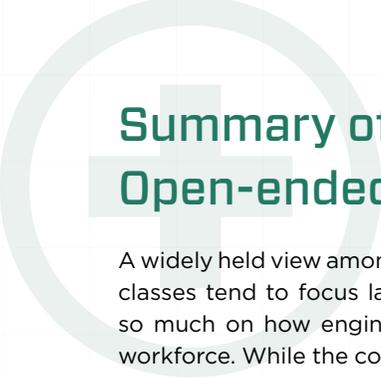
Summary of Responses to Open-ended Questions

A widely held view among the sample of students surveyed was that engineering classes tend to focus largely on the technical aspects of engineering and not so much on how engineers interact in a multidisciplinary and interconnected workforce. While the concrete scientific principles of engineering are necessary, being able to interact with others and apply knowledge and education to multiple areas of life is crucial for the success of the engineering professional. Generally, fundamental engineering and science classes do stress the importance of **critical thinking**, **working in teams**, **prioritizing**, and finding unique ways to **solve problems.** Varying from institution to institution, and depending on the individual professors and their backgrounds, the engineering curriculum also often includes coursework and opportunities to build other important professional KSAs such as **communication, leadership, and system integration skills,** as well as a level of understanding of **economics, business, and public safety.**

According to students, however, hardly any one university teaches the theory of engineering better than another, and it is unlikely that curriculum and theory alone could make a noticeable difference in the quality and preparedness of engineering graduates. In the absence of the "soft skills" to understand context, identify critical problems, connect the dots, and influence others, theory and technical skill become far less valuable. Ideally, engineers must take classes that will provide them with a **holistic education** in addition to prolific technical expertise. In the eyes of numerous students, what does make a difference in engineering education is the mix of classwork, practical assignments, and extracurricular activities that prepare students across the board of KSAs. These shape them into members of the workforce and society who bring **strong values,** a **broad perspective, leadership,** the ability to communicate with engineers and non-engineers alike, and **quality work** and **products** that tackle real-world problems.

Going beyond hard science and engineering fundamentals in the curriculum, it is important for engineering education to focus on developing the more abstract KSA areas—the soft skills that would help students learn how to apply their education into real life and adapt to engineering workforce situations. According to students, as central as these soft skills are, many are difficult to teach academically. Therefore, it comes down to extracurricular activities, teamwork, and students' own motivation to develop many of the professional KSAs.

Project-based learning and opportunities such as design projects, capstones, lab work, research projects, co-ops and internships, membership in professional societies and student organizations, conferences, competitions, and seminars every single year of school build upon the scientific theory. They also bridge **technical knowledge** with **applied skills** in industries, society, and the real world, introducing a great variety of necessary skills not covered by the curriculum. They set students up for professional success. Such multidisciplinary teamwork activities combine project-based learning and extracurricular work to develop some of the most important soft skills students will need throughout their

engineering program and beyond: **leadership, teamwork, communication, time management, prioritization, critical thinking, problem-solving, adaptability, entrepreneurship, self-drive, curiosity, creativity, and risk-taking.** Classes that do not have a syllabus, but consist of semester-long student-directed project work without a set schedule of checkpoints could serve as a real incubator for these crucial soft skills.

Design projects and competitions, student design clubs, and capstones were frequently highlighted as prime examples of project-based learning that allowed students to apply their theoretical knowledge in practice and acquire additional vital skills through hands-on engineering work. For instance, one surveyed institution requires their seniors to take a yearlong senior engineering design course. This course stresses all of the first 12 KSAs and more. In the course, students work in **teams** of 4-5 student members to **design** a product for a local sponsoring company that **solves a real-life engineering problem.** They work with a faculty advisor and liaison engineer(s) from the sponsoring company throughout the year in **product development.** Throughout the course, students **prepare a proposal,** create and follow a **project budget, communicate** with necessary stakeholders, **apply fundamental engineering principles,** and inquire about further knowledge necessary to create a solution to the presented engineering problem. **Students present finished products** at the end of year to the university, sponsoring companies, and the public in the form of a 20-minute formal presentation, as well as a poster session. Other engineering departments specifically assign design projects at the end of every semester, very much like a senior design course, to help prepare students for engineering tasks, instead of focusing on exams. Furthermore, extracurricular activities such as **volunteering** with *Engineers Without Borders* allow students to apply the academic concepts they learn in their classes to projects that have real-world impact. It is an opportunity for aspiring engineers to go through the **entire project cycle,** from concept-generation to financial management, component design, systems integration, and construction on the ground, while at the same time developing strong communication skills and cultural understanding of diverse communities.

One of the students provided another illustration of the benefits of design projects when they recounted their experience with a Formula SAE car. Almost none of the new members to the Formula team initially had knowledge of what goes into the cars. Because of this, experienced members **mentored** others to ensure that knowledge was passed down through the team, and that a larger group was available for **problem solving.** Ultimately, these new members grew into **leadership** roles during their junior or senior years, which provided exposure to additional lessons, and **mentorship** and knowledge continuity. Furthermore, with any leadership role there is a degree of **accountability,** along with the ability to create and lead the **design and vision.** Students were able to work with one another to apply their pre-existing knowledge to the **design and fabrication** of the car, along with its testing and maintenance. Ultimately, through the mentorship and **applied knowledge,** students and instructors saw **innovation** in every car. The team was able to work together through not only the engineering and design challenges, but also through **conflict resolution,** thus building **interpersonal skills** and **emotional intelligence.** As a whole, the experience in Formula SAE provided students not only access to technology

and applied engineering knowledge to tackle problems, but also the experience of working with others on a human level.

Overall, many students agreed that freshman and sophomore years of college engineering tend to focus on the fundamental. The much-needed soft skills, context, and practical project and design opportunities only come during the junior and senior years. Students believe that in order to create modern and well-prepared engineers, classes and extracurricular activities should focus on both hard science and soft skills simultaneously from the very beginning and continue throughout the entire degree. At the same time, fundamental scientific concepts and core soft skills should have continuous refreshers so they do not fade away. These could be established and applied in practice. Moreover, applied project design assignments should be attached at the end of each course in engineering school, not just as a senior-year design class.

Multidisciplinary learning experiences can also be instrumental in teaching students a diverse range of KSAs. The students highlighted a particular multidisciplinary engineering program as an example. The program is running a minor in engineering leadership development where business, education, and engineering majors are able to work together in culturally and professionally diverse teams on projects. It teaches **leadership, business fundamentals** (finances, budgets, project proposals, and business plans), **technical presentations, ethics, global perspective, cultural awareness,** how these all connect to the field of engineering to solve societal needs. Some schools also require students to take an engineering clinic every semester. The clinic is a class where students work in a **team on a multidisciplinary research-based project.** This helps cultivate **curiosity** and a persistent desire for **continuous learning,** along with **self-drive** and **motivation.** During the clinics, students learn a lot about not just **economics,** but also **ethics** and **integrity** by researching and presenting an engineering ethics case. This teaches students about high ethical standards, integrity, and global, social, intellectual, environmental, and technological responsibility.

Extracurricular activities such as involvement in, or leadership of, project management (design, lab, capstones, etc.), student clubs and organizations, student chapters of professional societies, and community work are also highly effective in developing KSAs. These activities can cultivate strong **leadership, teamwork, management** and **self-motivation, critical thinking, problem-solving,** and **system thinking and system integration** abilities. All of these activities involve working with a number of different stakeholders, ranging from executives to volunteers, full-time staff, administration, and external groups. Extracurricular activities could also be multidisciplinary, providing opportunities to work with peers from other majors.