



# TUÉE

**Transforming Undergraduate Education in Engineering Phase IV**

**Views of Faculty and Professional Societies**

Workshop Report





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**Transforming Undergraduate Education in Engineering Phase IV: Views of Faculty and Professional Societies.**

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Workshop Report

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Washington, D.C.  
[www.asee.org](http://www.asee.org)



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The meeting planning committee helped us develop an agenda that made best use of limited time, asking the right questions and guiding participants to concrete outcomes; and provided valuable feedback to the report. The committee comprises Christine Grant (North Carolina State University), Russell Korte (The George Washington University), John Krupczak (Hope College), and Ingrid St. Omer (Virginia Tech).

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# Table of Contents

<b>Acknowledgments</b> .....	ii
<b>Executive Summary</b> .....	1
<b>Background</b> .....	3
The Transforming Undergraduate Education in Engineering Initiative .....	3
Synergistic Initiatives.....	5
The Charge from NSF .....	6
<b>Views Of Faculty and Professional Societies</b> .....	7
Towards a Competency Map.....	7
Refining the Competencies.....	8
Assessing Competencies.....	10
Facilitating Competency Attainment .....	12
<b>The Road Ahead</b> .....	13
Looking Ahead to Implementation .....	13
Exploring Contributions by Professional Societies .....	14
Pledges of Individual Action.....	16
Critical Communications for Next Steps.....	16
The Work Ahead.....	17
<b>References</b> .....	18
<b>Appendices</b>	
Appendix A: Workshop Agenda.....	19
Appendix B: Attendee List .....	21
Appendix C: Pre-workshop Survey Results .....	23

# Executive Summary

Thirty-six representatives of professional engineering societies and academia conceived and pledged to begin implementing a series of collaborative initiatives to train the coming generation of engineers in the technical and professional competencies demanded by industry and society. At a workshop held April 18 and 19, 2017, in Washington, D.C., participants—including civil, mechanical, electrical, chemical, manufacturing, and systems engineers and engineering technology faculty—refined a profile of the “T-shaped” graduate, an engineer who is both technically accomplished and able to succeed in a team-driven, culturally and ethnically diverse, and globally oriented workforce. After testing their ideas in small group exercises and plenary sessions, and taking account of possible faculty concern about unrealistic changes, they offered numerous tools to develop and assess the desired competencies and proposed a plethora of classroom, lab, and extra-curricular enhancements with a stress on capstone projects, mentoring and internships. Mixing practical advice with pedagogy, they pondered what attributes students should stress on a résumé and in a job interview. Finally, they put forward tangible ways that professional societies could contribute expertise, influence, and momentum to achieving the workshop’s goals.

*Views of Faculty and Professional Societies* was the fourth in a multiyear series of workshops led by the American Society of Engineering Education (ASEE) as part of the *Transforming Undergraduate Education in Engineering* (TUEE) initiative sponsored by the National Science Foundation (NSF). Besides triggering changes in teaching that will better meet national needs and increase retention of students, TUEE aims to bolster participation of women and underrepresented minorities in the engineering workforce.

Drawing on the knowledge, skills, and attitudes (KSAs) identified during TUEE Phases I (*Synthesizing and Integrating Industry Perspectives*) and II (*Insights from Tomorrow’s Engineers*), participants were led before the workshop through a series of surveys, accompanied by expert analysis, to distill a list of essential KSAs. The list was further refined in small group discussions once the meeting began, opening the way for an examination of how students could acquire the needed competencies.

Examples of proposed improvements to curricula, mentoring, and experiential learning opportunities included

- a “curriculum map” with a body of knowledge for each KSA;
- enlisting societies as “brokers” among industry, faculty, and students;
- creating dynamic repositories for curricular materials or, similarly, a faculty resource portal with guides to training, best practices, mentoring, case studies, and webinars; and
- online learning modules on ethics, leadership, and communications.

Favored programs for students included joint society multidisciplinary student challenges; having professional societies provide industry-academe judges for student challenges and competitions; and internships and co-ops.



Attendees went on to explore three questions: what role professional societies should play in influencing changes in curricula/pedagogy in academia; what role professional societies can and should play in providing experiential learning opportunities; and how professional societies can assist in effecting curricular and pedagogical changes within the constraints of academic environments. They framed specific ways that 13 individual societies and other organizations could contribute. ASEE, for instance, could serve as a leverage point for dissemination, developing materials and assessment instruments, and expanding opportunities for faculty training. IEEE, with its influence, history, and international reach, could encourage local chapters to disseminate information by providing a uniform message.

Toward the close of the workshop, attendees brainstormed how to mobilize their respective organizations to achieve agreed-upon reforms; and how to communicate the results and sustain the momentum of TUEE. The session produced more than 50 individual pledges of specific actions within professional societies and academic institutions, as well as NSF. Within ASEE, new areas of activity would be defined, with corporate members engaged to support cross-society initiatives. Other pledges included helping establish an education track at a society's national convention, incorporating both computational thinking and systems engineering in a Body of Knowledge, and add TUEE information to the agenda of a multi-society area dinner meeting. A publishing organization "would connect with society partners on opportunities to develop publications that support KSA education"—new products and/or components of existing products.

If implemented, these actions will set in motion initiatives that send a message of change through multiple sections and layers of engineering education. Alongside their pledges, participants suggested a variety of communication and dissemination tools to bring these initiatives to scale. While profound institutional change is beyond TUEE's scope, organizers ended the workshop persuaded that a movement toward transforming engineering education had begun.



# Background

## The Transforming Undergraduate Education in Engineering Initiative

Views of Faculty and Professional Societies was the fourth in a series of meetings intended to develop 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).<sup>1</sup>

The first workshop, held May 9 and 10, 2013, 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<sup>2</sup> (KSAs) 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 (American Society for Engineering Education, 2013).

The second workshop, held April 10 and 11, 2015, brought together 41 engineering students to brainstorm the most effective ways to acquire the 36 KSAs identified in the first workshop. Titled *Insights from Tomorrow's Engineers*, the workshop included 22 women and 19 men, the great majority of them undergraduates from a variety U.S. public and private

institutions. Overwhelmingly, students concluded that schools were paying insufficient attention to many of the KSAs needed for a T-shaped professional. While supporting a rigorous grounding in math, science, and engineering fundamentals, they were broadly critical of the teaching they had experienced. Calculus, physics, and chemistry should include examples of real-world engineering applications, and curricula should feature design-based projects and open-ended problems, supplemented by extra-curricular activities, competitions, and Maker spaces, students said. Teaching should be part of the basis for securing tenure and salary increases. Students called for greater faculty diversity in gender, ethnic background, and experience in industry and academe, and for mentoring, whether by older students, faculty, professionals in industry, or even peers (American Society for Engineering Education, 2017b).

Phase III, *Voices on Women's Participation and Retention*, addressed the chronic problem of low female participation and success in U.S. engineering undergraduate programs. ASEE convened a workshop in Seattle, Wash., June 12 and 13, 2015 to develop and refine a set of recommendations and actions to reduce the gender gap, including changes to undergraduate curricula, pedagogy, and academic culture. An eight-member workshop planning committee invited participants with a range of experience and expertise. The 40 attendees represented academic administration, research and teaching; industry; funding agencies; professional organizations; community colleges; a high school; and marketing. Participants were instructed to avoid a debate over data and instead focus on solutions and dialogue. They were urged to provide recommendations that could be implemented for the most part within existing resources. In preparation, four papers were commissioned to serve as “discussion starters.” These included an empirical description

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<sup>1</sup> For more details about the TUEE initiative visit <https://tuee.asee.org>

<sup>2</sup> The three initial phases of the TUEE initiative defined KSAs as knowledge, skills and abilities. In Phase IV we adopted a competency model to frame KSAs, switching the definition to knowledge, skills and attitudes.

of the state of women in engineering; public perception of the field; the undergraduate experience; and promising practices (American Society for Engineering Education, 2017a).

Phase IV drew 36 individuals from professional societies, academia, and federal agencies to recommend changes to curricula and pedagogy that would better prepare graduates to meet industry expectations today and in the future (Appendix A provides a full list of workshop attendees). In surveys and a one-and-a-half day workshop held April 18 and 19, 2017 in Washington, D.C., participants drilled down to refine the essential competencies required of engineers; recommended how they could be assessed, and described how engineering graduates might present their acquired competencies to potential employers

(see Appendix B for detailed workshop agenda). They then explored three questions:

- what role professional societies should play in influencing changes in curricula/pedagogy in academia;
- what role professional societies can and should play in providing experiential learning opportunities; and
- how professional societies can assist in effecting curricular and pedagogical changes within the constraints of academic environments.

The answers served to guide, develop, and implement a plan that has the four groups working together to fulfill the original TUEE goal.

## Synergistic Initiatives

Intended principally to aid engineering educators, this report may be viewed alongside two roughly concurrent efforts with complementary goals:

- an *Engineering Competency Model* developed by the American Association of Engineering Societies (AAES, 2015) and the U.S. Department of Labor’s Employment and Training Administration to serve as a guide for the development of the engineering workforce; and
- a National Academy of Engineering (NAE) study, *The Engagement of Engineering Societies in Undergraduate Engineering Education*.

The National Science Foundation, which is funding the TUEE workshop series, envisions professional societies becoming significant contributors to improving undergraduate engineering instruction, resulting in better-equipped graduates, greater retention of students, and a more diverse workforce. ASEE’s workshop dovetailed with the NSF-funded National Academy of Engineering study, *The Engagement of Engineering Societies in Undergraduate Engineering Education*. As stated on their website, NAE’s project:

*takes an in-depth look at the extent and nature of professional engineering societies’ contributions to improving the quality and effectiveness of US undergraduate engineering education . . . [and] also provides an opportunity for the societies and other stakeholders, such as universities and industry, to share their insights, learn what others are doing, . . . and scope out possible collaborations. (National Academy of Engineering, 2017a, para. 2)*

In one of several data points relevant to TUEE Phase IV, a NAE survey of professional engineering societies found them engaged in “a range of education activities that target a range of audiences” but reported that 87 percent “face some kind of barrier in their engineering education work,” most commonly communication; improving engineering curricula; incentives, and “issues related to time, resources, and funding” (Inverness Research, 2017, p. 2). A summary of 30 interviews with societies, conducted as part of the NAE study, noted “concerns about the ex-

tent to which students graduating from engineering programs are ill-prepared to work in industry were shared by several societies” (National Academy of Engineering, 2017b, p. 68). While the NAE and ASEE initiatives are complementary, ASEE’s TUEE IV focused more on competencies required of engineers and the curricula needed to build them.

## Engineering Competency Model

Published in 2015, the *Engineering Competency Model* was developed by the American Association for Engineering Societies (AAES) in collaboration with the U.S. Department of Labor’s Employment and Training Administration. The six-tier model was “designed as a resource that provides a lifelong learning template of the core competencies and skills necessary for entry into the engineering profession as well as for maintaining proficiency during one’s career” (CareerOneStop, 2017). More details about the model, including ancillary materials can be found at: <http://www.aaes.org/model>.



Image source: American Association of Engineering Societies. (2015). *A look inside the engineering competency model*. [PowerPoint slides]. Retrieved from [http://www.aaes.org/sites/default/files/Engineering%20Competency%20Model%20Presentation\\_final%20.pptx](http://www.aaes.org/sites/default/files/Engineering%20Competency%20Model%20Presentation_final%20.pptx)

## The Charge from NSF

TUEE's outreach to professional societies and industry reflects a recognition that efforts to reform engineering education within academe have not worked on a broad scale, even though our understanding of problems in retention and lack of diversity has increased and instructional methods exist to correct them. As Don Millard, deputy director of NSF's Engineering Education and Centers (EEC) Division, spelled out in opening remarks to TUEE IV attendees, the reasons why students leave engineering are known. These range from a lack of role models—a particular problem in the case of women and underrepresented minorities—to poor teaching, a feeling of isolation, rising costs, and a lack of connection between engineering practice, which can be exciting, and what is studied. Also known, Millard said, is that an institution's intellectual, social, and emotional climate has a significant impact on student perception and outcomes. "We need to change the climate—NSF is really passionate about this," Millard noted. "In none of STEM is it as important as in engineering." Research has also shown that online course-taking is less effective than in-class instruction, and that "active learning trumps passive methods, hands down... period."

NSF is no longer content with research findings and classroom innovations that reach a narrow audience through peer-reviewed journals and conference workshops. Instead, the agency is eager to take proven models of success in engineering education and scale them up. As the EEC's Elliot Douglas explained at an NAE workshop on January 26, 2017, the foundation's new funding model is to support "large, integrated efforts." He cited the REvolutionizing engineering and computer science Departments (RED) initiative and a flagship program in the Education and Human Resources (EHR) directorate, Improving Undergraduate STEM Education (IUSE): EHR. NSF hopes, he said, to "create a national cohort of exemplars." Heather Watson, program director in EHR's Division of Undergraduate Education, said the division is interested in institutional and community transformation. TUEE, she said, is "exactly what we would like to see happen: seeing all the stakeholders get together. . . . One of our goals is to foster the connection between industry, academia, the professional societies, K-12—everything.... We need [students] to learn about the profession, and to make all the connections." A related NSF program, relevant to TUEE IV, is Professional Formation of Engineers, intended to "graduate engineering leaders with a global outlook and the ability to adapt to the rapidly evolving technical environment in industry, academe, and society." Millard challenged TUEE participants to pursue a goal of doubling the percentage of women in engineering—from 20 percent to 40 percent—in the next five to 10 years. Signs of progress should become apparent sooner: "I'd like to see something happen over the next year."

**"We need to change the climate; NSF is really passionate about this... In none of STEM is it as important as in engineering."**

**Don Millard  
Acting Division Director and  
Deputy Division Director of  
the Engineering Education  
and Centers (EEC) Division  
National Science Foundation**



# Views of Faculty and Professional Societies

## Toward a Competency Map

As with each previous workshop in the series, ASEE surveyed participants in the weeks prior to the meeting. These surveys provided a head start, focusing participants' attention on topics they would be discussing and eliciting preliminary views. The TUEE IV pre-workshop survey aimed at identifying, developing, refining, and prioritizing a list of competencies (knowledge, skills, and attitudes, or KSAs) that engineering graduates would be expected to need over the next five to 10 years. The survey was conducted in two phases using a Delphi approach. The responses were distilled to arrive at something close to a consensus view. ASEE sent participants a questionnaire to identify and develop a list of three to 10 essential competencies and their key components (phase 1), and followed up with a detailed summary of responses, which participants were asked to refine and prioritize (phase 2). The TUEE IV survey responses were analyzed by Russell Korte, associate professor of Human and Organizational Learning at George Washington University, who analyzed, synthesized, and mapped the KSAs identified by respondents and their relative importance.

With Korte providing a basis in theory, research, and data from the two-phase survey, TUEE IV breakout discussions focused on integrating survey results with findings from TUEE I (industry) and II (students) to refine further the competencies engineers need. From there, participants tackled ways of assessing competencies and figuring out which ones could be addressed through curricular and pedagogical changes. These discussions provided a foundation for subsequent brainstorming sessions on ways that professional societies could contribute to preparing engineers best suited to the needs of the economy. Participants worked with Korte's broad definition of professions as specialized occupation that entail "high uncertainty, complex work, and social responsibility." They possess an "exceptional body of knowledge, provide high level of autonomy, and selectively regulate entry." Further, they "require high levels of judgment, higher order thinking, flexibility, communication, learning, context sensitivity, problem solving, principled action, and self-direction."

Lending urgency to the need for specific competencies, Korte said, is industry's demand for graduates who can "hit the ground running. It used to be the case that industry gave a slack year the first year but industry has compressed that—you do not have that grace period." He pointed to a 2010 Michigan State University study,<sup>3</sup> which noted that "today's employer expectations of coops and interns are comparable to their expectations of entry level employees just five years ago." The study reported on a survey of more than 900 employers on the attributes of entry-level hires sought by employers. "Building and sustaining professional relationships was rated the most important skill that

**“Can do”**  
competencies  
comprise the  
knowledge and  
skills required to  
perform the work  
of an engineer.

**“Will do”**  
competencies  
are the traits  
of personality  
and attitude  
that motivate  
engineers to  
perform.

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<sup>3</sup> See <http://www.ceri.msu.edu/wp-content/uploads/2010/01/skillsabrief1-2010.pdf>

new college hires would be asked to demonstrate in their initial position.” To many students, this is unfamiliar territory. Korte said students have felt blind-sided by the cultural, emotional, and political aspects of the workplace. A specific example of this was reported by a newly hired engineer who wished he had been taught in school how to play the political game on the job. Higher education in general poorly prepares students for the social aspects of the workplace.

The Delphi responses addressed both “can do” and “will do” competencies. “Can do” competencies comprise the knowledge and skills required to perform the work of an engineer. As compiled by Korte, these engineering competencies, in order of importance, were Technical/Analytical; Scientific; Mathematical; and Innovative/Creative/Design Thinking. “Will do” competencies are the traits of personality and attitude that respondents considered valuable for professional engineers today and in coming years. Korte grouped them as intrapersonal and interpersonal. The intrapersonal competencies identified by respondents were, in order: self-directed, lifelong learning; ethical; intellectual, innovative, critical thinking; and conscientiousness. Interpersonal competencies were communication; teamwork; leadership; project management; and social, intercultural skills. Each of these competencies was further broken down into specific KSAs (knowledge, skills, and attributes, see appendix C). For instance, the intellectual, innovative, critical thinking competency was described as “K-knowing/understanding other disciplines (beyond STEM); multi-literate; understand problem solving; comprehending value of diversity; S-adept problem finder/manager/solver; making informed/good decisions; apply



knowledge; deal with ambiguity/conflict/plurality; make inferences/judgments; A-innovative; creative; insightful; open-ended; resourceful; growth/entrepreneurial mindset.”

## Refining the Competencies

The first breakout session asked participants to identify where Delphi respondents, industry representatives, and students were in agreement and where they differed in deciding what competencies were most needed. Participants found it easiest to identify areas where students, and industry agreed on important competencies, although there was some variation among the three separate groups. Most attendees noted that critical thinking and ethics training had been cited by both students and industry representatives. Others found agreement among the three groups in communication, engineering knowledge, cultural and social fluency, and problem identification and solving, critical thinking, ethics, and self-direction.

More challenging was the task of identifying differences in the responses from industry, students, and Delphi participants. Participants noticed that not all competencies appear on the TUEE I, II, and Delphi lists. Students emphasized scientific knowledge, whereas industry representatives may have taken that as a given. Problem formulation is covered better in phases I and II than in the Delphi map. System integration is not as big in the Delphi map. Social and cultural awareness is in the Delphi map, but not in the industry-defined KSAs. One staff note-taker reported: “The general consensus is that it is almost impossible to make comparisons without a shared vocabulary.” Another noted, “the overall impression of the . . . group was that some KSAs from TUEE Phases I and II were hard to match to the Delphi competencies map, where they could be missing or deeply buried.”

In broader discussions among all three groups, participants mentioned that industry appears to care a great deal about systems integration, whereas the Delphi respondents placed greater emphasis on diversity and cultural fluency than did

either industry or students. It was noted that ethics is often not taught in engineering departments, which rely on faculty from other disciplines to teach it. But are engineering faculty prepared to teach it or comfortable doing so? Are faculty prepared to teach interpersonal skills? How well prepared are they to teach, period? “Are we trained to teach anything?” a participant wondered aloud.

The second breakout session focused on the professional competencies identified by Delphi respondents only. Did participants see themselves in the map of Delphi responses, or should it be modified? One point raised was that the trend in engineering education is toward longer times to graduation, suggesting that by 2025, engineering undergraduates would have 1 to 1.5 years added to their degrees. How does that affect industry, students, and the competencies in question? Therefore, the reality of what can be accomplished in a 4-year, or a 5-year, engineering degree needs to be addressed by the competencies—time is a factor.

On specific competencies and how they were grouped together in the Delphi map, participants had a number of comments and suggestions. Grouping intellectual, innovative, and critical thinking competencies was seen as trying to pack a lot into one category and not all seemed to be a natural fit. One

person suggested including “a healthy disrespect for the literature” in this section, or a sort of skepticism. Engineering Competencies (technical, analytical, scientific, and mathematical) are a necessary but not sufficient set of skills engineers must possess. One alternative was to think about competencies as they relate to the practice of engineering, possibly based on the life cycle of a project, or a similar aspect of applied engineering. Another was to condense the boxes dealing with pre-engineering competencies, and then to create more focused engineering-specific competencies. Other suggestions: Merge the Math and Scientific competencies into one box, and restructure the Delphi competencies map to a non-linear map, providing inter-relationships and links between the competencies boxes.

A general conclusion was that the labels here are hard to disagree with generally, but that they could be more helpful by adding nuance and definitions. Another option would be to create a list of very specific KSAs (per that generated in Phase I) and then use this broad distillation of the competencies as a framework for presenting the more specific KSAs. More broadly, a question was raised about the role of “citizen-scholar”—social involvement and contribution to society, government involvement, and public policy—so that engineering competencies could have societal, policy, and cultural impact?





## Assessing Competencies

Compared with discipline-specific content, competencies (KSAs) are more challenging to assess. How do we know students have obtained the desired competencies? What is the evidence? How are competencies demonstrated? What are the indicators of competencies? How do you translate abstract KSAs into concrete examples?

### Tools for Faculty

Participants provided a number of existing tools that could be applied to KSAs, including the Association of American Colleges and Universities VALUE (Valid Assessment of Learning in Undergraduate Education) rubrics on communication; Critical Thinking Assessment test (CAT); and a Design Self-Efficacy Survey. Other tools related to specific KSAs included:

- For technical/analytic competence: Each discipline's Body of Knowledge; FE Exam; Concept Inventories (e.g., Thermal and Transport Concept Inventory, TTCI); Readiness Assurance activities
- For scientific/technical competence: Lean Certification; Certificate Manufacturing Engineering (offered by SME); ASCE BOK2; Problem Recognition and Solving and Rubric; undergraduate research publications presented at conferences
- For mathematical competence: Force Concept Inventories; FE Exam; Physics Concepts Inventory; Concept Warehouse; Wiley PLUS; online assessment systems
- For innovative, creative design and critical thinking competencies: Rose-Hulman Rubric for Curiosity, Connections, Creating Value; Critical Thinking Assessment Test (CAT); Design Competition SME; KEEN List of Skills for Entrepreneurial Design; Stanford D-School design-thinking rubric; SAE Collegiate Design Series (Baja; Formula)
- For ethics: Engineering Code of Ethics; Developmental Assets Framework (Search Institute); Leadership Style Inventory

**To show social and intercultural competence, students could tell a story during a job interview that conveys their social conviction in a way that is aligned with the company.**



## Tools for Students and Employers

If industry demands the competencies identified, students will need ways to document mastery. GPAs alone will not cover the full range of KSAs. In an afternoon exercise, participants were asked to consider how students could present this evidence on a résumé, in a cover letter, and during an interview. Besides offering guidance to students, this exercise also revealed curriculum changes and outside activities that are important to the student experience. Some participants voiced concern that focusing on the résumé conveys the impression that engineering is a vocational degree, whereas engineers are prepared for a wider variety of positions. Two competencies that presented difficulties were inclusion and ethics. For inclusion, it was suggested that students who were really passionate could cite such activities as Engineers Without Borders. Others could consider how they integrated inclusion into design. One participant offered an anecdotal example about students who worked on an infrastructure project and built in additional security elements for neighborhoods where vandalism was prevalent. Ethics can be difficult to assess but facilitating debates and opportunities to reflect or write papers on ethical matters will bring those issues to the fore.

Suggested ways students could explain their competencies on résumés, cover letters, and interviews illustrated the importance of extracurricular activities and internships in building professional KSAs. For a résumé, one participant urged students to illustrate personal ethics by pointing to membership in a professional society and volunteer work in the community. In a cover letter, students should “talk about experience in groups,” and in particular handling an

adversary, plus what they did for a professional society and why it was important. Other participants suggested giving reasons for joining the Order of the Engineer. In a job interview, a student could inquire about a company’s community service and be prepared to discuss the firm’s core values.

To illustrate intellectual, innovative, and critical thinking competencies, students were urged to cite leadership experiences in team competitions and the management and negotiation skills required. In a letter, the student could recount how “my engagement with Society X provided extracurricular interdisciplinary skills to solve a societal problem.” As an example of self-directed, lifelong learning, the student could note having been president of an extracurricular activity, exercising leadership and planning; investigating a topic independently; and having gained a particular skill certification. To show conscientiousness, a student could cite the societal impact of a project, recount experience in delegating tasks while maintaining responsibility, and describe having designed a project during an internship with consideration for constraints, user needs, and standards.

Communication skills could be illustrated by showing experience with conference and poster presentations, Toastmasters training, speaking before officials, giving a personalized elevator pitch, and sharing a website the student had designed. Other advice included listening, making a connection and asking questions, and “be[ing] knowledgeable/know your audience.” To demonstrate teamwork, students could go beyond recounting their own team leadership experiences to describe overcoming adversity, and increasing engagement with a group or organization. To show social and intercultural competence, students could tell a story that conveys their “social convictions” in a way “that’s well aligned with the company.” Examples of problem-solving capability could include “involvement in professional society projects,” a senior design project, or undergraduate research.

Even in demonstrating math and science competencies, students could be encouraged to cite internships, club participation, competitions, tutoring and mentoring experiences, and a vision that looks beyond the classroom and lab. Besides reciting GPAs

and completion of advanced courses, students could show, for instance, that they had analyzed an intake manifold for an SAE Formula competition and “found weak areas” required adjustments to “the geometries and material specifications,” or had pondered “what do you want to do with [your] degree . . . how will you impact the world?” Students could gain technical expertise by tutoring underclassmen in electronics as an Eta Kappa Nu peer mentor or developing a YouTube tutorial to explain magnetic hysteresis.

## Facilitating Competency Attainment

Asked what changes in curricula and pedagogy were needed to prepare students for the key KSAs, participants compiled a wide range of suggestions while also pondering obstacles and likely resistance to change.

The group found numerous areas where professional skills—communication, ethics, leadership, and project management—could be incorporated into current academic curricula. For example, honor codes could be established to instill ethical behavior. Ethical dilemmas could be raised in the design-build process. The ethics of measuring and reporting could be made part of research and lab experiences. Online instructional modules could teach students about how to manage data. Students could be asked to write reflections about ethical challenges. Suggestions for improving communication skills might require additions—such as a technical writing course—but some could also be incorporated within existing courses by having students write

an executive summary, develop an elevator speech, or make a video. Students would be encouraged to join professional societies or become engineering ambassadors. It was agreed that intellectual, innovative, and critical thinking should be included in all, or almost all, engineering courses—from first year to capstone—and would be achieved with embedded open-ended design projects in which students learn from failure and reflection. In general education courses, faculty can help engineering students connect the dots between what they’re learning in class and the social responsibilities of engineers. Attention should be given to formation of student teams with an eye to diversity. People from diverse backgrounds should be invited to teach classes or give presentations.

Participants felt that science and math curricula could be improved with approaches similar to ones recommended for professional competencies, including capstone projects, labs, design challenges and experiential learning opportunities—all efforts to get students to understand the “why” of what they are learning.

The capstone project is an obvious platform for developing leadership and project-management skills. Some participants felt, however, that students first need to build skills before reaching that stage. Preparation would include a design-driven curriculum, projects with instruction embedded in them, and guidance in teamwork. All this requires faculty training and support, and rubrics that explain the “hows” as well as the “whys.” Taking this approach a step further, schools could offer courses on entrepreneurship and encourage teamwork among engineering and business students.



# The Road Ahead

## Implementation

Asked to offer a pessimistic outlook, one group cautioned that any approach to curricular change needs to take account of likely resistance. Assessment poses a big challenge. ABET may need to be involved. Faculty will feel at a loss grading reflections, and a lack of clear expectations will cause students to fret. Moreover, engineering faculty cannot control general education requirements. Freshmen, it was noted, are ill-prepared for open-ended projects. Co-curricular activities detract from time devoted to academic activities—and how do you grade them? “When you ask me to do more, I have to do less somewhere else . . . my class is too large . . . Why are we doing this; it’s not our responsibility . . . there’s no budget for it.” At a subsequent plenary session, a participant injected this skeptical note: “Studies miss the import. The reason our colleagues don’t do active learning is that they’re scared of being in a student-centered environment where they might be asked questions they don’t know the answer to.”

In an optimistic counterpoint, another group of workshop attendees found much to recommend open-ended projects. Students learn there can be more than one approach to a problem, stimulating creativity, and they gain resilience and grit by reflecting on and recovering from failure. Students also will see real-world, practical applications of classroom curricula and how competencies relate to each other and can be employed in varied contexts. Such projects also prepare them to tackle unfamiliar problems, as students are likely to encounter in future careers. The result will be a welcome easing of rigid disciplinary silos and career-ready, flexible, and adaptive engineers.

Adopting a novel approach, a third group proposed a new curricular track called Engineering Workplace in a Box, with coursework in various competencies, illustrations of ethical dilemmas, capstone projects during each of at least three years, industry experience, and active development of professional skills (such as role-playing for communication). The senior capstone would have an industry client and aim for social and societal impact. The premise of this approach is that competencies are all connected and can be made to build on each other. Teaching that reflects what students can expect in the workplace will serve to demonstrate and reinforce the needed competencies. Other unconventional suggestions included combining studio sculpture with structural engineering; combining theater, communications, and ethics training (“theater students are amazing presenters”); intensive history-writing courses; engaging undergraduates in research; and adding service components to courses.

With discussions converging around common themes of experiential learning and a greater emphasis on professional skills development, two questions arose: How do you sell it—meaning, how can these themes be widely disseminated and adopted—and how do you do it? In other words, how do you implement appropriate teaching techniques across institutions with quality and consistency? Answers would come in part from examining the roles of professional societies, such as having IEEE help develop a pilot that could be adopted by certain select institutions.

**Innovative and critical thinking should be included in all, or almost all, engineering courses—from first-year to capstone.**



## Exploring Contributions by Professional Societies

None of the participants expressed any doubt that professional societies could provide a significant boost to developing, disseminating, and implementing a reform agenda in engineering education. Indeed, societies already are engaged with undergraduates through campus chapters. They also share an interest in recruiting members among newly minted engineers. As a summary of 30 interviews conducted by Inverness Research (2017) for the NAE noted,

*for the smaller or specialty societies, a common priority goal is to spread awareness of their particular branch of engineering. They also have some expertise in outreach to pre-college and undergraduates to educate engineers and others about their particular specialty. Other goals and activities that interviewees mentioned include: engaging students in the community and service learning; . . . ensuring the next generation of engineers is prepared to practice engineering; . . . [and] promoting quality engineering education through ABET.*

Academically, the American Society of Civil Engineers' Body of Knowledge (BOK), which describes the KSAs civil engineers should possess, "has influenced course design in existing subdisciplines, such as construction engineering," according to an NAE literature review, which adds: "A number of other engineering societies have developed guidance similar to ASCE's BOK." (National Academy of Engineering, 2017c, page 2)

The workshop's challenge was less one of stimulating ideas—which poured forth after only short periods of brainstorming—than of refining the list and figuring out ways to carry out the most useful ones and reach the widest possible audience. Initial suggestions ranged from society sponsorship of student projects and grand challenges to bumper stickers, bake sales, and student-produced Snapchat videos. Participants from professional societies were also exhorted—as were attendees at NAE's January workshop—to come up with specific ways they could begin immediately to spur their societies to act on the workshop's goals and outcomes.

## What role can professional societies play in providing experiential learning opportunities?

Out of dozens of suggestions prompted by this question, the ones favored most by participants included having faculty develop a “curriculum map” with a body of knowledge for each KSA; enlisting societies as “brokers” among industry, faculty, and students; creating dynamic repositories for curricular materials or, similarly, a faculty resource portal with guides to training, best practices, mentoring, case studies, and webinars; and online learning modules on ethics, leadership, and communications. Favored programs for students included joint society multidisciplinary student challenges; having professional societies provide industry-academe judges for student challenges and competitions; and helping arrange internships and co-ops.

Participants felt professional societies could play a particularly useful role in acquainting students with the workplace and guiding their transition—in particular, explaining what to do and what not to do, how to dress and communicate professionally, and topics to avoid. Societies could provide such career services as coaching students with elevator speeches. Participants endorsed societies’ role in promoting technological and engineering literacy for all, and in facilitating students’ attendance at conferences, including helping with funding.

So important is professional societies’ potential contribution to education that a number of participants suggested that every society have a Secretary of Education, an in-house advocate. Also helpful, they suggested, would be society workshops for teaching specific KSAs; videos on professional skills featuring stories of young alumni; internships of other opportunities for faculty to get industry experience; rewards for people/faculty/teachers/programs implementing and supporting novel KSAs; and society recognition of KSAs comparable to an “energy Star” rating or “LEED” certification. Online courses and webinars were frequently mentioned, though there is little information about what is available or shared across societies. Events such as conferences can be used to greater effect. These include regional conferences, which are often easier for students and fac-

ulty to attend. Community colleges, relied upon by many low-income students and students of color, are often ignored in outreach work and lack budgets for faculty to attend national conferences. Industry partners might be persuaded to support travel. Transfer between two- and four-year colleges can be a challenge, particularly when students transfer from community colleges to engineering bachelor’s degree programs. Societies could be instrumental in making that transition smoother by connecting faculties with each other. Institutions need to share information about how to make that transition run smoothly. Part of this could come simply from initiatives to get community colleges more involved in conferences by, for instance, recognizing their smaller budgets and waiving conference fees.

## How can professional societies assist in affecting curricular and pedagogical changes within the constraints and mechanisms of academic environments?

Participants had been invited to the workshop in part because the Planning Committee considered them to be thought leaders within their institutions or organizations. They could thus influence the role their organizations play in attempting to move the needle in engineering education. At the same time, as Christine Grant noted, they could expect resistance among some faculty, who might hesitate to take on a bold initiative because of tenure review.

Accepting the challenge, workshop attendees explored new—and in some cases radical—ways their professional societies or institutions could stimulate reform and how they as individuals could act as motivators and catalysts.

One stratagem would be to “create tension/disruption supported by research and data” by publishing articles for various audiences, including political entities, faculty, students, parents, K-12 teachers, and counselors, “on pointed topics which challenge convention and encourage communication around innovation in achieving KSAs.” Institutions could be spurred to reevaluate program criteria, with proposals presented several times to key groups of depart-

ment heads. Besides such repetition, reforms could be encouraged by presenting awards (presumably from societies) for faculty, departments, programs, and even colleges that go “above and beyond” their normal duties to achieve change. Societies could provide teaching workshops and forge inter- and multi-society collaborations. The latter could assume a variety of forms, including reciprocal membership, partnerships on professional skill development, student-oriented career fairs, internships, and job opportunities. Various communication and meeting possibilities were discussed, including social media, contacts with deans and associate deans, and society participation in conferences with diverse audiences, such as community colleges.

Participants also identified specific ways that 13 individual societies and other organizations could contribute. ASEE, for instance, could serve as a facilitator/catalyst for all societies to disseminate activities; increase opportunities for people to join the annual National Effective Teaching Institute through other means; develop materials that enable faculty to instill KSAs; provide assessment instruments and a train-the-trainer workshop module; reevaluate program criteria, collaborating with ABET and professional societies to integrate new KSAs into program assessment; and collect best practices and minimum standards. IEEE, with its influence, history, and international reach, could encourage local chapters to disseminate information by providing a uniform message and access to KSA’s and promoting a joint society student challenge. Together, the Society of Manufacturing Engineers, the American Institute of Chemical Engineers, and the Society of Professional Engineers could collaborate on a directory for societies and designate a point person, with SPE exploring how societies can partner with universities and AIChE and SME leveraging resources between societies.

## Pledges of Individual Action

Toward the close of the workshop, attendees explored how to mobilize their respective organizations to achieve agreed-upon reforms and how to both communicate the results and sustain the mo-

mentum of TUEE. The effort produced more than 50 individual pledges of specific actions within professional societies and academic institutions, as well as NSF. If implemented, these actions would launch initiatives that send a message of change through multiple sections and layers of the engineering education community. Within ASEE, new areas of activity would be defined, with corporate members engaged to support cross-society initiatives. Engineering technology leaders would publicize their approaches to KSAs as best practices and host a session at the Engineering Technology Leadership Institute on this topic with societies on how they can work with ET leaders to incorporate the KSAs in courses. Members of other societies pledged, among other things, to “help establish an education track at [a society’s] national convention,” incorporate both computational thinking and systems engineering in the Body of Knowledge, and add TUEE information to the agenda of a joint ASME-IEEE-ASCE-ABET area delegation dinner. A publishing organization “would connect with society partners on opportunities to develop publications that support KSA education”—new products and/or components of existing products. Participants pledged to “engage other societies to co-sponsor a student regional summit,” “use my multiple society memberships to advocate for collaborative efforts around diversity and Inclusion,” and “recruit faculty, administrators, and local professional society partners to engage in a [Women in Engineering Pro-active Network] conference [on] gender equity, biases, etc.” They also pledged to “share the framework with the [Iowa State University] College of Engineering department chairs and chair of the COE Curriculum committee,” and “initiate lecture/video on topics related to ethics, innovation, critical thinking.” Within NSF, support would be generated for a Dear Colleague Letter on building the TUEE IV competencies.

## Critical Communication For Next Steps

Participants offered a number of ideas for maintaining communication among themselves to advance the workshop’s goals and to broadcast the results to various audiences within their organizations. One group suggested that before anything happens, all

involved must have a clear understanding of what TUEE is and, just as important, what it is not. Attendees could continue substantive exchanges by joining a team on a Slack platform, which one participant has found to be a useful collaboration tool. Besides e-mails to deans, provosts, and other institutional officials announcing “what I learned (at TUEE) and why it will be beneficial,” participants suggested creating an open-source, open-access evolving textbook to capture best curriculum practices for KSAs and presenting panel discussions on interpersonal and intra-personal competencies. It was suggested that ASEE could bring staffs of professional societies together, present TUEE results to engineering deans as a way of helping to fulfill diversity pledges, and reach out through ASEE to the Diversity Committee, Corporate Member Council, and professional interest councils, as well as to student chapters of professional societies. Presentations could be made before PTAs, chambers of commerce, and Rotary Clubs.

## The Work Ahead

NSF’s Heather Watson, the program director overseeing TUEE IV, praised the “wealth of information and knowledge” generated by the workshop. She challenged participants to find the gaps that “will take it to the next level” beyond workshops, identify those stakeholders still missing from the table and ask: “Have we truly gotten groups together to learn from each other? . . . Why haven’t we leveraged all

this work together to see that we’re all speaking the same language? . . . Who can be the backbone organization?” NSF has resources to assist institutions seeking to collaborate with one another, she noted. Then, speaking for herself and not the foundation, Watson introduced a “tree of life” metaphor to illustrate the current state of engineering education and why TUEE alone is insufficient. Leaves dropping off the “tree” represent students falling away from engineering. When watering and attention fail to restore leaves to a healthy state, the problem is deeper. “The root is rotten—and nobody’s paying attention to the root.” In her view, the root is the academic realm: institutions. “Something’s happening there that is very rotten. So we need to change that because that is actually what is feeding our plant.”

John Krupczak, who had been program director overseeing TUEE II, said Phase IV was unique in the many engineering disciplines represented. He chose a dystopian metaphor to make a positive point about dissemination. TUEE IV was like the airport in the thriller *The Plague* by Victor Methos—the place where passengers caught a deadly pathogen and then carried it to far-flung destinations, he said. Because of all the engineering fields now involved in TUEE, “we can actually spread this message widely.” Among ideas from the workshop that could be carried forward, he argued, was the concept of engineers as citizen professionals contributing to society and of engineering as a desirable component of general education for everyone.





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# Appendix A: Workshop Agenda

Tuesday, April 18, 2017

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8:30 AM - 9:00 AM **Welcome and Overview**

*Ashok Agrawal*, Managing Director, American Society for Engineering Education

**Keynote**

*Don Millard*, Acting Division Director and Deputy Division Director of the Engineering Education and Centers Division, National Science Foundation

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9:00 AM - 10:00 AM **Session 1: Identifying Critical Competencies for Engineering Students**

Review and discussion of results from the Delphi Process

*Russell Korte*, Associate Professor, George Washington University

*Christine Grant*, Professor, North Carolina State University

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10:15 AM - 12:15 PM **Session 2: Final Refinement of Competencies**

What final modifications are needed from the results of the Delphi Process? Should any competencies or KSAs be given a higher priority in implementations?

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*John Krupczak*, Professor, Hope College

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1:45 PM - 3:15 PM **Session 3: Assessment of Competencies**

How do we know students have obtained the desired competencies?

*John Krupczak*, Professor, Hope College

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3:30 PM - 5:00 PM **Session 4: Curriculum Locations**

Which competencies can and should be addressed through curricular and/or pedagogical changes?

*Ingrid St. Omer*, Senior Instructor, Virginia Tech

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## Wednesday, April 19, 2017

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8:30 AM - 8:45 AM **Setting Expectations for Day 2**

*Ashok Agrawal*, Managing Director, American Society for Engineering Education

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8:45 AM - 10:15 AM **Session 5: Role of Professional Societies in Experiential Learning and Influencing Changes in Curriculum**

What role can professional societies play in providing experiential learning opportunities?

*Ingrid St. Omer*, Senior Instructor, Virginia Tech

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10:30 AM - 12:00 PM **Session 6: Improving Academic Environments**

How can professional societies assist in affecting curricular and pedagogical changes within the constraints and mechanisms of academic environments?

*Christine Grant*, Professor, North Carolina State University

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# Appendix B: Attendee List

More than forty individuals, representing a diverse array of backgrounds and institutions, attended the *TUEE Phase IV Views of Faculty and Professional Societies* workshop. The affiliations listed below are those at the time of the event.

**Kashy Aminian**

West Virginia University

**Paul J. Benkeser**

Biomedical Engineering Society

**John Blake**

Austin Peay State University

**Patsy Brackin**

The American Society of Mechanical Engineers

**Peggy Brouse**

The International Council on Systems Engineering

**Christopher Carr**

National Society of Black Engineers

**Burton Dicht**

Institute of Electrical and Electronics Engineers

**Liza Wilson Durant**

The International Council on System Engineering

**Patricia Fox**

Engineering Technology Council (ASEE)

**Terrence L. Freeman**

St. Louis Community College

**Kenneth J. Fridley**

American Society of Civil Engineers

**Christine Grant**

North Carolina State University

**Linda Serra Hagedorn**

Iowa State University

**Scott Hamilton**

American Society of Civil Engineers

**Carl O. Hilgarth**

Shawnee State University; Technological and Engineering Literacy-Philosophy of Engineering Division (ASEE)

**Beth Holloway**

Purdue University

**Allison Hostetler**

Society of Automotive Engineers

**Mary Kasarda**

American Society of Mechanical Engineers

**Russell Korte**

The George Washington University

**John Krupczak**

Hope College

**Tanya Kunberger**

American Society of Mechanical Engineers

**Suzanne Marzano**

Society of Manufacturing Engineers

**Mani Mina**

Iowa State University

**Ivan Mutis**

American Society of Mechanical Engineers

**Leslie Nolen**

American Society of Mechanical Engineers

**Simeon Ntafos**

University of Texas at Dallas

**Ingrid St. Omer**

Virginia Tech

**Gregory S. Parnell**

International Council on Systems Engineering

**Stephen M. Phillips**

Institute of Electrical and Electronics Engineers

**Teri Reed**

Women in Engineering ProActive Network

**Karl W. Reid**

National Society of Black Engineers

**Rachelle Reisberg**

Northeastern University

**Dan Sayre**

Wiley

**Darlene Schuster**

American Institute of Chemical Engineers

**Bartlett M. Sheinberg**

Materials Research Society

**Tom I-P. Shih**

American Institute of Aeronautics and Astronautics

**Christopher Smith**

National Action Council for Minorities in Engineering

**Yvette Pearson Weatherton**

Rice University

**Steve Yalisove**

Materials Research Society

## NSF Staff

**Karen E. Crosby**

Program Director

**Don Millard**

Acting Division Director, Engineering  
Education and Centers

**Heather Watson**

Program Director

## ASEE Staff

**Ashok K. Agrawal**

Managing Director, Professional Services

**Rocio C. Chavela Guerra**

Director, Education and Career Development

**Norman Fortenberry**

Executive Director

**Alexandra Longo**

Program Manager, Education and  
Career Development

**Mark Matthews**

Director, Editorial

**Ray Phillips**

Assistant Program Manager, Education  
and Career Development

**Rossen Tsanov**

Senior Research Associate, Assessment, Evaluation  
and Institutional Research

**Tom Walker**

Program Assistant, External Affairs

# Appendix C: Pre-workshop Survey Results

The primary aim of the pre-workshop survey was to collect, synthesize, and map a set of engineering student competencies (KSAs) identified by selected members of the engineering professional societies and faculty. We designed this survey as a Delphi technique to gain the participation of professional society members and faculty. The goal was to develop a set of key competencies that engineering students should have by graduation over the next 5 to 10 years.

Participants were provided a **definition of a competency**<sup>4</sup> as having two dimensions: personal attributes and work requirements. Because work is extremely variable and unpredictable, we want to focus on key competencies at the personal (student undergraduate) level. Competencies are multi-dimensional, and in the personal dimension are sets of “can do” components of knowledge and skills, and “will do” components of *personality* and attitudinal traits. (For example: the competency of teamwork might include a set of knowledge of group dynamics and . . . , skills in collaboration, negotiation, and . . . personality/attitude for empathy, respect and . . .).

The Delphi survey had two phases:

**Phase 1:** Instructions were sent to 39 participants along with the definition of a competency (above) and a simple template asking them to identify three to 10 key competencies that engineering students should have as graduates, as well as specifying key knowledge, skills, personality/attitude, or other components related to the specific competencies they identified. Nineteen participants returned the questionnaire (Q1). The responses were summarized and grouped into categories based on similarity of responses. Fourteen categories emerged from the first round of survey responses. These categories were returned to participants for their review and elaboration in phase 2.

**Phase 2:** The summary and supporting responses of the first round were returned to participants. Instructions for the second round were as follows:

1. Review the synthesized data for the competency groups in the attached worksheets. You will find the following worksheets attached: 1) Competency Groups from Q1—the individual competencies you provided in Q1 grouped by similar themes (affinity groups or clusters); 2) Synthesis of Q1 Complete—the inclusion of related competency components—knowledge, skills, and personality/attitudes that belong to each competency group; and 3) Raw Data from Q1—the raw data provided by respondents to Q1 just for your information if needed
2. Fill out the columns in the first worksheet (Competency Groups from Q1) by suggesting any changes to the groups; such as combining two or more competency groups or moving elements from one group to another, or subdividing a group into sub-competencies.
3. After any changes, suggest a simple name for each competency group in your final list.
4. Identify the most important competencies in your final list. The top 5 – 7 3 competencies that students should have by the time they graduate with an engineering degree.  
*If you have the time and interest:*
5. Review the competency components of knowledge, skills, personality/attitude provided in the second worksheet (Synthesis of Q1 Complete) and identify a simpler set of Knowledge, Skills, Personality/Attitudes for the top competencies you identified in #4 above.

The responses from the second round were again analyzed, summarized and mapped. The resulting competency map, along with a brief review of the competency literature was provided to participants at the workshop on April 18, 2017. The competency maps developed from the Delphi survey are shown in figures C.1-4.

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<sup>4</sup> Schippmann, J. S. (1999). Strategic Job Modeling. Mahwah, NJ: Lawrence Erlbaum Associates Inc.

Figure C.1. Overall Competency Map (Working draft: April 16, 2017).

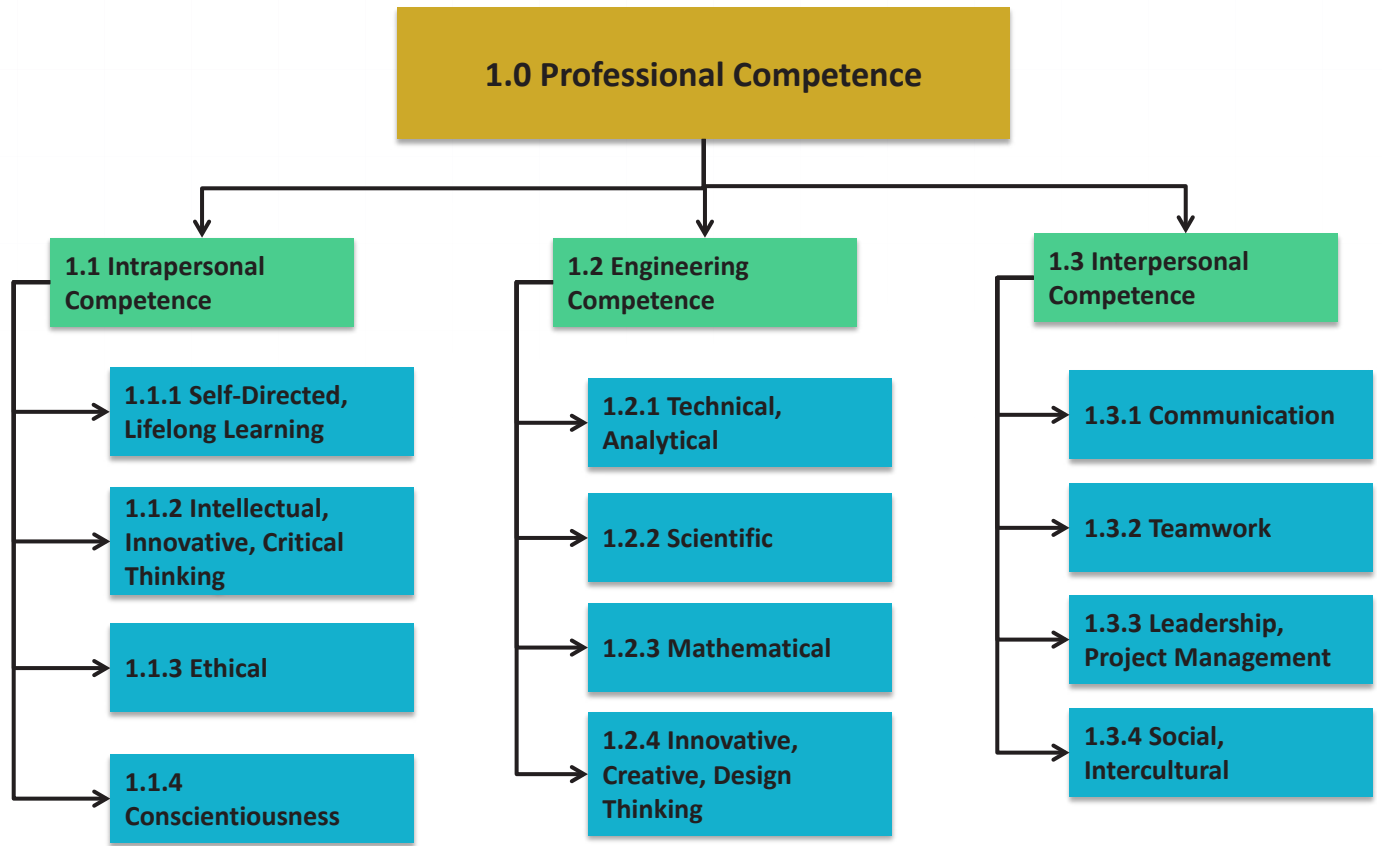


Figure C.2. KSAs of Interpersonal Competencies (Working draft: April 16, 2017).

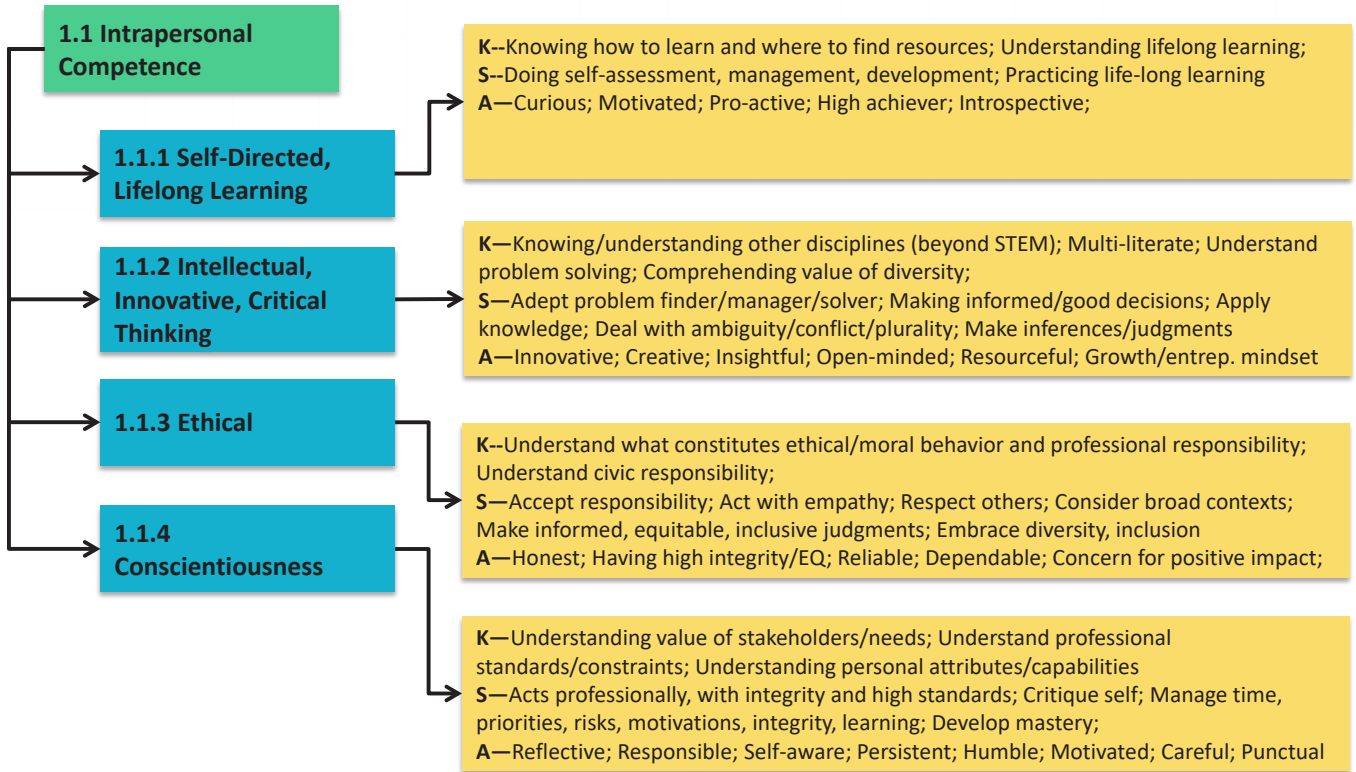
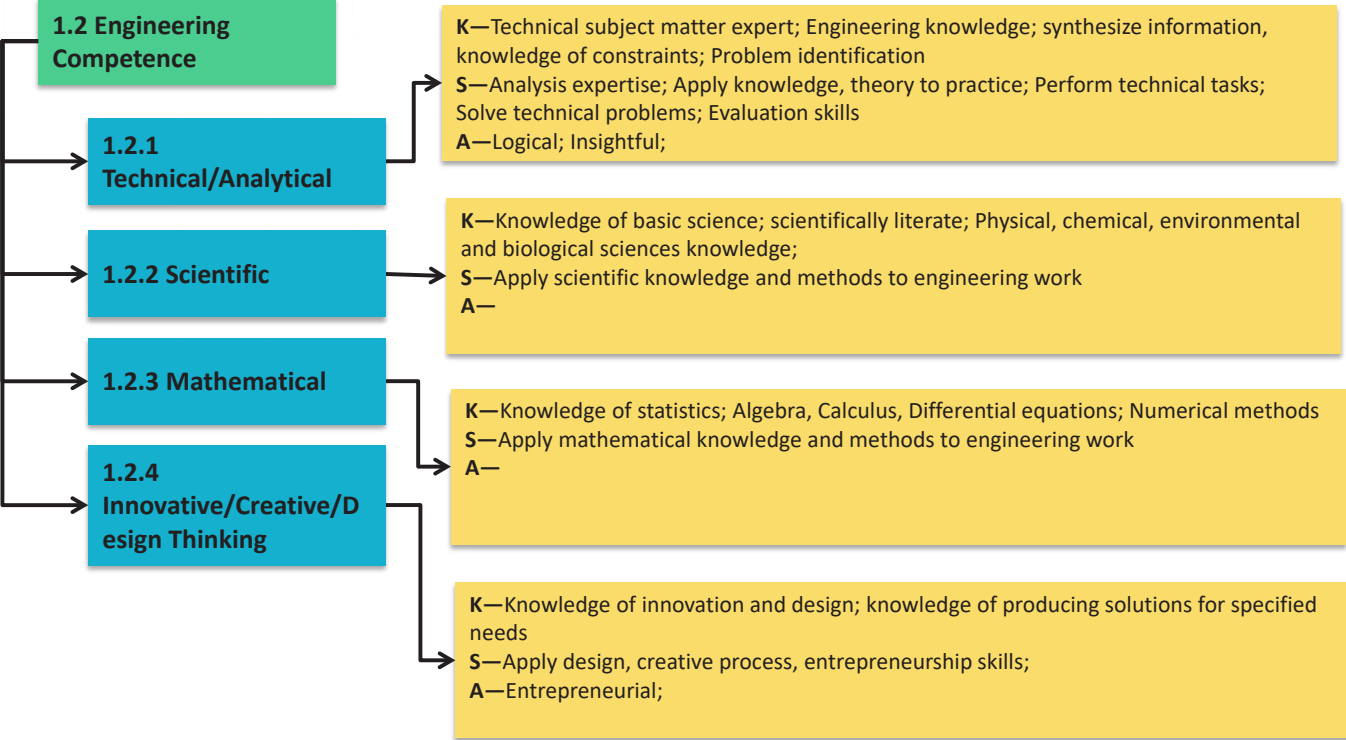




Figure C.3. KSAs of Engineering Competencies (Working draft: April 16, 2017).



**Figure C.4. KSAs of Interpersonal Competencies (Working draft: April 16, 2017).**

