

# TUEE

Transforming Undergraduate Education in Engineering

## **Phase I: Synthesizing and Integrating Industry Perspectives**

May 9-10, 2013 Workshop Report



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Arlington, VA

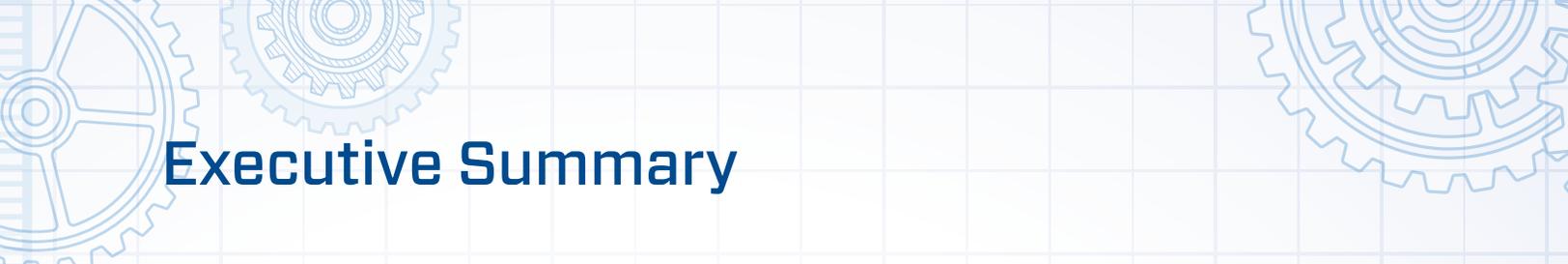
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# Executive Summary

With support from the National Science Foundation (NSF), the American Society for Engineering Education (ASEE) has launched a series of meetings to develop a new strategy for undergraduate engineering education that meets the needs of industry in the 21st century. *Transforming Undergraduate Education in Engineering* aims to produce a clear understanding of the qualities engineering graduates should possess and to promote changes in curricula, pedagogy, and academic culture needed to instill those qualities in the coming generation of engineers. ASEE, in consultation with NSF, envisions a four-phase, multi-year sequence of meetings – the final one being a large workshop in 2018 – that ultimately will produce a flexible framework for transforming the undergraduate engineering experience.

The series' first meeting was a two-day workshop in Arlington, VA that brought together representatives of industry and academia in an intensive exploration of the knowledge, skills, and abilities needed in engineering today and in the coming years. The 34 representatives of industry, four staffers and officials from the U.S. intelligence community, and eight academics identified core competencies that remain key, but added an array of skills and professional qualities that will help students succeed in a dynamic, rapidly changing field. They seek a T-shaped engineering graduate who brings broad knowledge across domains and the ability to collaborate within a diverse workforce as well as deep expertise within a single domain.

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

To instill these skills and qualities in future engineers, changes in approach will be required by academe and industry, participants agreed. Universities will need to adjust faculty reward structures to place more of a premium on teaching, promote more cross-disciplinary instruction, and welcome involvement by industry in supplying case studies, mentorship of students, and shared laboratory experiences. For its part, industry will need to recognize a shared responsibility in developing T-shaped engineers. The workshop produced numerous concrete suggestions of ways industry and academe could collaborate – from faculty internships in industry to company involvement in authentic learning experiences that occur before traditional capstone projects – as well as an awareness that barriers between universities and companies serve neither. When participants were asked for written comments, one declared, “The wall is coming down between industry and academia.”

A post-workshop survey asked participants to assign principal responsibility for development of 36 Knowledge, Skills, and Abilities traits (KSAs) to each or some combination of the following: students; parents and home; academia (K-12 and universities); industry; and government. Apart from education in hard sciences and engineering fundamentals – a responsibility of academia – most KSAs required that two or more parties play a role. Respondents, for the most part, saw only a modest role for government in developing these KSAs.



# Background and Purpose of the Workshop

With support from the National Science Foundation (NSF), the American Society for Engineering Education (ASEE) has launched a series of meetings to develop a new strategy for undergraduate engineering education that meets the needs of industry in the 21st century. *Transforming Undergraduate Education in Engineering* aims to produce a clear understanding of the qualities engineering graduates should possess and to promote changes in curricula, pedagogy, and academic culture needed to instill those qualities in the coming generation of engineers.

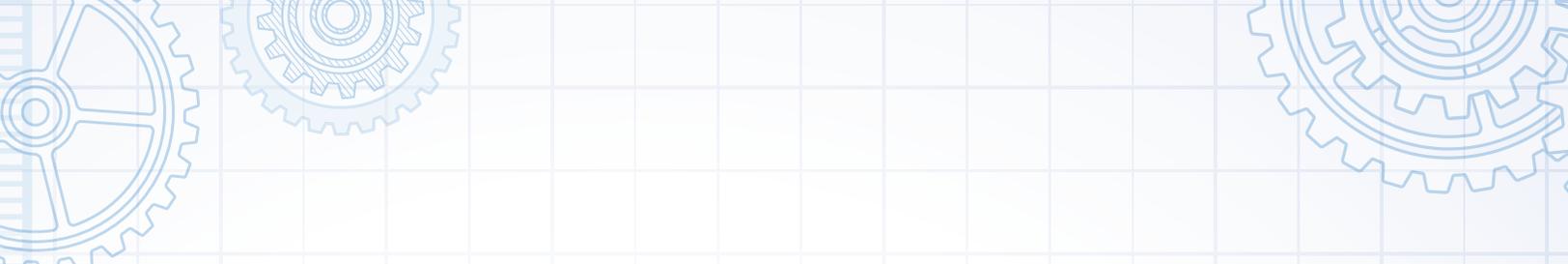
The project is modeled on *Vision and Change in Undergraduate Biology Education*, an NSF-supported effort begun in 2007 by the American Association for the Advancement of Science to better align college teaching with a revolutionary pace of discoveries aided by modeling and simulation, vast data sets,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

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

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

For the initial phase, *Synthesizing and Integrating Industry Perspectives*, ASEE hosted a two-day workshop at the Sheraton Crystal City in Arlington, VA (Appendix C details the meeting agenda). Designed to hear the “voice of the primary customer – employers,” it drew 34 invited representatives of companies with an important stake in training the future engineering workforce. The firms included established and newer U.S.-based global and domestic companies, several major defense contractors, and one Indian-headquartered firm, Infosys. Some companies, such as DuPont, hire engineers from multiple disciplines; others, like information technology giants HP and IBM, employ large numbers of computer scientists, electrical engineers, and software developers. Spanning several decades in age, the industry representatives ranged from a field engineer to managers at various levels, including a vice president, as well as recruiters and people engaged in university relations. Also participating were four staffers and officials of the National Geospatial-Intelligence Agency. All meeting attendees are listed on Appendix D.

While the industry representatives were asked to identify the knowledge, skills, and abilities (KSAs) they will demand of engineers in coming years, seven engineering academics were invited to offer ideas on how engineering curricula could be altered to meet employers' needs. Moderators of the various sessions included Kenneth Galloway, professor and former dean of engineering at Vanderbilt University and ASEE president-elect, the executive director of ABET, Michael Milligan, and senior staff of ASEE.



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

The workshop opened three days after the announcement that NSF would support a second initiative to improve undergraduate education, this one a five-year effort by the Association of American Universities to improve teaching of STEM at its member schools using evidence-based practices.

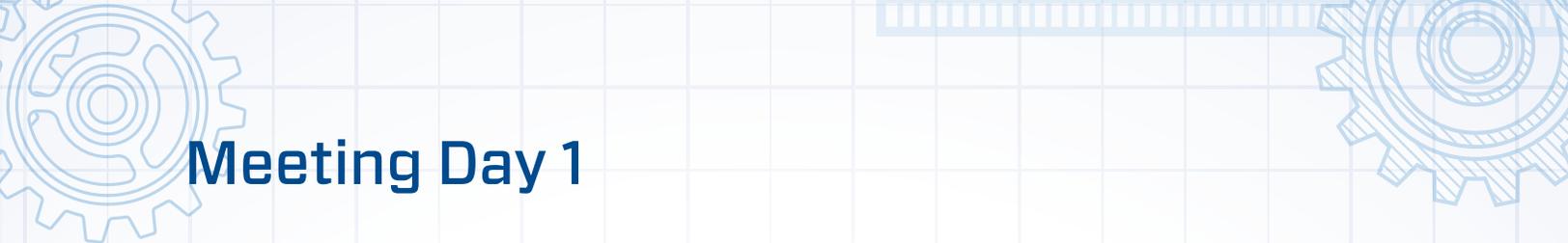
## Pre-Workshop Survey

Prior to the meeting, 26 participants from industry and the seven academics completed a survey on what they consider the most important engineering KSAs for today and 10 years from now, and the perceived quality of preparation in these areas shown by today's graduates. Questions were drawn from *The Engineer of 2020*, the latest ABET accreditation criteria, and ASEE conference papers on attributes of the global engineer (see Appendix B).

Responses depict a profession under pressure from several directions, with current training unable to meet certain existing industry needs and badly out of sync with the requirements expected in 2023. For instance, they show today's students to be very weak in having an international and global perspective, something of middling importance now but the single most important knowledge area in 10 years' time. Likewise, students' weak foreign language skills, while a minor drawback now, could be a serious impediment in the future.

The survey found today's students coming up short in economics and business, project management, stages of product development, and system integration – all areas of growing importance. Students also fail in meeting expectations in several skills accorded growing importance. These include leadership, decision-making, communication, and the ability to synthesize engineering, business, and societal priorities. At the same time, respondents think students are being well trained in physical and life sciences and statistics, math, and information technology. Indeed, their skills outstrip the importance industry attaches to these fields. Strikingly, strength in math is seen as becoming less important a decade hence than today, as is the ability to apply math and science knowledge and Internet and digital competency, areas where today's students perform well. Pre-workshop survey results are described in more detail in Appendix B.

Open-ended questions in the survey prompted "good ideas all over the map," Brian Yoder, ASEE's director of assessment, evaluation, and institutional research, told workshop attendees (presentation slides are available at [http://docs.asee.org/public/TUEE/Phase1/Pre-workshopSurveyResults\\_BrianYoder.pdf](http://docs.asee.org/public/TUEE/Phase1/Pre-workshopSurveyResults_BrianYoder.pdf)).



# Meeting Day 1

## Opening Session

Following welcoming remarks by ASEE Executive Director Norman Fortenberry, Don L. Millard, program director in NSF's Division of Undergraduate Education, presented an overview of the current state of engineering education in relation to industry needs and a "charge" to attendees to be "change agents for the future of engineering."

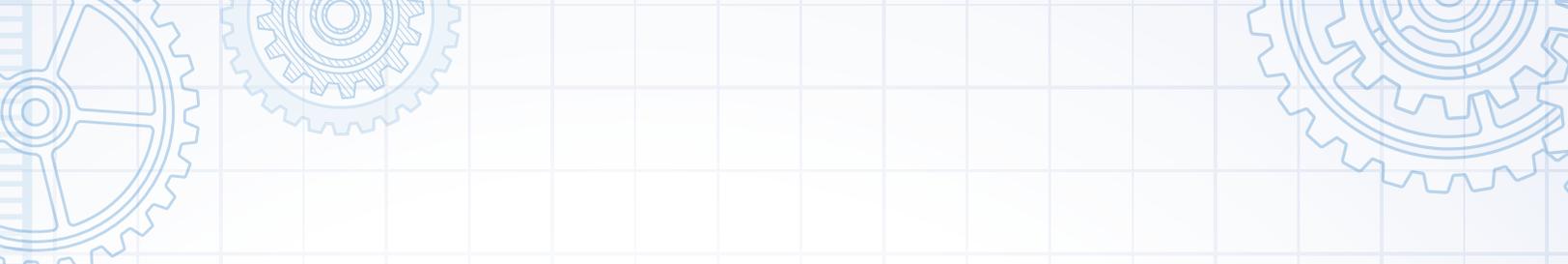
"Engineering schools are heavily influenced by academic traditions that don't always support the profession's needs," he told them. "You have a chance to break the molds." Students abandon engineering in part due to lack of role models (especially women and underrepresented minorities) poor advising and teaching; fear that engineering jobs will be outsourced; and a "lack of connection between what is studied and perceived as exciting practice." Millard asked the group to explore what different skills are needed to do engineering today from the time of the ABET 2000 report, what could reasonably be removed from the jam-packed engineering curriculum, and ways to improve the college experience, given increased opportunity for lifelong learning and access to an array of available learning tools (presentation slides are available at: [http://docs.asee.org/public/TUEE/Phase1/OpeningRemarks\\_DonMillard.pdf](http://docs.asee.org/public/TUEE/Phase1/OpeningRemarks_DonMillard.pdf)).

## Identification of Technical KSAs

After a brief rundown of the survey results by Brian Yoder, participants broke into three moderated groups, for an hour-long breakout session to identify technical KSAs important to industry. Academics were tasked with recording key points. Lively conversations ranged widely over the knowledge and skill sets that participants wanted or found lacking in young engineers. In a room where attendees paired off to brainstorm, depth and breadth were both stressed. One twosome lamented a perceived lack of depth in math. An on-the-job consequence, they agreed, is that young engineers are unable to intuit the boundaries they're working within, and also try to solve problems without truly understanding them. "Students blindly accept what comes out of a model," another participant offered. Comparing undergraduates and grad students, a participant said the former tend to see one straightforward solution, such as  $2+3 = 5$  (an example cited earlier by Millard), whereas "grad students know, 'Here's what you need. How do you get there? There are multiple paths to reach a solution.'" Some knowledge of history, politics, the surrounding community, and the world was urged.

Discussion of the prevalence of teamwork in engineering yielded two insights: One attendee noted that it's now more important to "understand what project management is" than "how to be a project manager." A recruiter from a multinational engineering firm warned that students who show prowess in a particular skill needed by a team can get by without mastering others. She recalled turning down an applicant with a near-perfect GPA from a top-10 engineering school who, while vividly describing a team project, betrayed ignorance of the underlying science.

Altogether, the three rooms listed 22 technical KSAs desired by industry. At variance with survey results shown earlier, two of the three groups emphasized the continued importance of science and math. One group topped their list with "Practice, practice, practice," echoing the view advanced by Malcolm Gladwell in *Outliers* that 10,000 hours is needed for expertise. Other KSAs showed the many and varied ways young engineers are expected to apply their knowledge. They ranged from cybersecurity to entrepreneurship; from grasping the boundaries of problems to confronting novel problems; and from specific skills to interdisciplinary systems integration.



## Identification of Professional/Social KSAs

Breakout sessions on professional and social KSAs explored multiple ways engineers must build on their technical skills to serve companies effectively. While educators frequently mention industry's demand for "soft skills," what makes an ideal engineering professional is seldom explained in detail. In these sessions, discussions focused heavily on the ability to communicate orally and in writing with colleagues, clients, and management and across diverse cultures. Beyond fluency, strategic and flexible communication was cited ("Sometimes it's important to make that phone call.") along with an ability to listen. Clarity ("If you can't explain the design of a substation to the people who are going to build it, what do you get?"), creativity, passion, and commitment were stressed, along with integrity, ethics, informed risk-taking, business etiquette, and ability to prioritize ("How does a new hire know what's important?"). Opinion differed on the importance of overseas experience in encouraging cultural sensitivity, with the representative of one international company saying it's not a matter raised in interviews.

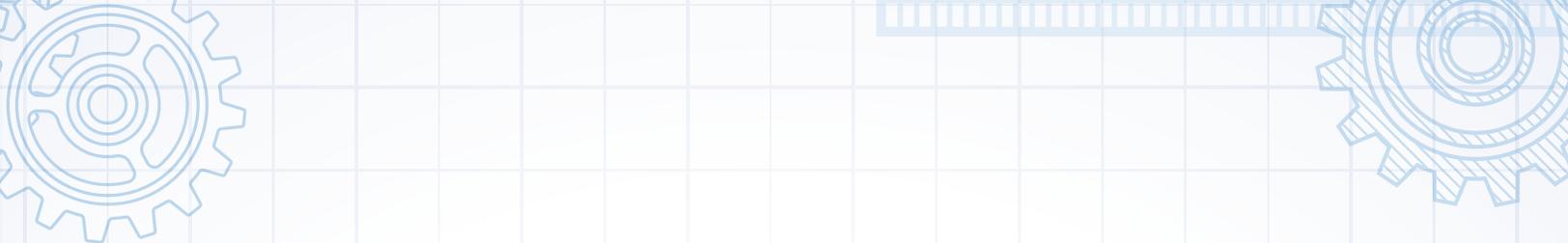
The three simultaneous sessions yielded nearly two dozen attributes. This and subsequent sessions raised questions about whether universities or industry bore prime responsibility for instilling them and what professional societies could contribute. Companies vary in providing training and time for new hires to adjust. While one firm considers internships an important stage of the hiring process ("We interview students for 10 weeks"), an industry participant spoke of getting hired and immediately thrown into the "deep end."

## Reflection Questions

Donna Riley, a DUE program director on leave from Smith College, where she is an associate professor of engineering, led a discussion of how students can be made aware of what KSAs industry needs and the role of educators. Expanding on points made in the previous two sessions, participants faulted a lack of training in technical writing. They cited a need to identify who is successful at a company and what skills they brought. One industry participant wondered aloud whether all the skills mentioned by companies reflected what they actually require. ("Ask a customer what they want, they say 'Everything.'") Another said communication skills shouldn't come at the expense of technical competence: "I would rather have an engineer who can solve my problem." Suggestions from the session included bringing real-life case studies into the classroom, industry internships for faculty, industry mentorship of design projects, more internships for women and minority students, and partnerships between large schools and those enrolling significant numbers of underserved populations.

## Feedback from Academics

Translating industry needs into curricula and teaching styles, academics felt they didn't yet understand the priorities industry assigned to different KSAs. Knowing these would be key to refining the list of important KSAs. There shouldn't just be "one more add-on," as one participant put it. Also needed were a distinction between the KSAs required by graduation and those best developed through on-the-job training, and better predictors for industry success than GPAs. It would be worthwhile to identify KSAs that can be acquired across disciplines and different institutions. Based on the previous sessions, academics recognized a need to develop more interdisciplinary experiences – something that can be hard for faculty to accept – while retaining basic fundamentals, and offer less-contrived projects. Industry research projects could be brought into the classroom, one suggested. In addition, there needs to be a shift in the faculty reward structure with support from university leaders to help catalyze desired changes.



## Industry Responses

Suggesting ways to influence institutions, an industry representative said the accreditation process offered leverage. Besides GPAs, a student could be assessed based on the amount of passion he or she has for an engineering career and the amount of knowledge a student can retain and carry forward. Class activities should be less prescriptive, giving students the chance to “do something they’re personally vested in” and offer different paths to solutions. Academics and industry seemed in general agreement on shifting the faculty reward structure to compensate creative teaching. There could be an “industry-university research partnership with an education component.” An industry representative pointed to barriers that exist between educators and industry (“Yeah – you are industry; you are evil.”). Is academia open to collaboration? One response: Yes, but industry can’t expect to dictate the curriculum.

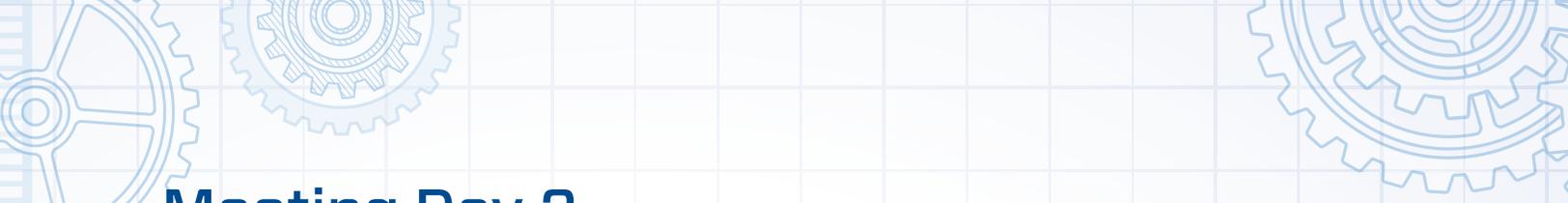
## Integration of Perspectives

Reconfigured groups of industry representatives and academics added more ideas to the mix, working at first in small clusters and then opening up discussions in each of the three conference rooms. The result was a three-column chart of “What,” showing desired KSAs; “Who,” referring to those responsible for fulfillment; and “How” it could be carried out. The “What” column ran to 48 items, including specific technical and professional skills but also character traits, such as “emotional intelligence,” and “persistence and strong work ethic.” The “How” offered specific ways certain attributes could be acquired at universities, during work experiences, or by collaboration between universities and industry.

The longest list of How’s attached to the concept of the T-shaped engineering graduate, someone with breadth of knowledge across domains but possessing enough expertise within a single domain to go in depth on a topic. Industry could provide case studies, be more realistic about providing time to train new hires, and provide learning materials to universities. The list suggested a differentiated curriculum based on a projected career. For instance, a student would not have to take calculus if a job didn’t require it, but would go back and fill in the gap if he or she changed direction. Also suggested was a study of job descriptions to determine what level of knowledge and skill a particular job requires and a “competencies map” to inform student choices.

The T-shape concept would need to be “embedded in university culture, every class.” Included in this chart was a call for foundational math and science to include programming ability and a recommended broad engineering class that provides exposure to all engineering disciplines.

Subsequently, related or overlapping What’s, Who’s, and How’s were grouped together.



# Meeting Day 2

## Key Decisions and Changes

A fourth breakout session strove to specify changes in approach required of both universities and industry and ways the two entities could cooperate in educating the kind of engineers industry needs. One industry representative likened the challenge to turning a battleship. Points that seemed to resonate were the need for sustained engagement and for a program that represents a win for the student, faculty, university, and the country. It was noted that because universities don't carefully track graduates' careers, they don't have a clear idea of the ingredients of success. Universities and industry need to agree on a short list of KSAs – a “common language.” Examples of collaboration included job fairs, industry-sponsored student contests, having faculty shadow a CEO, Skype mentoring of students by industry engineers, and more involvement in education by engineering alumni.

Ideas from open forums included a government-paid pilot in which universities and companies would come up with 100 case studies; an “Adopt a Team” scheme for companies to engage students; shared university-industry labs; industrial labs that implement theories emerging from academe; and lab experiences shared online.

A comparison was drawn between the United States and Germany, where industry-university collaboration is well established and companies provide space for student training. In the U.S. at present, money is lacking for the kinds of changes participants want to see. The morning produced more than two dozen “key decisions,” and a longer list of “key changes.”

## Summing Up

The final session captured important themes to carry forward and produced nine statements, including: “We can't just throw money at the problem;” both industry and academe have to be equally committed to a partnership; there's a recognition that achieving solution directly relates to national competitiveness; and “We're adding more and more, so we need to CUT something out – may need to reprogram some existing dollars and stop some existing activities.”

In closing remarks, Millard said he had heard a number of times that academics put out a product but never look at the customer base. The “very useful” KSAs identified in the workshop include the right mix for lifelong learning. He hopes workshop attendees will stay connected and that the project will bring in new faculty along with tenured department chairs and institutional boards and get them engaged in a groundswell of support for change. He asked the group to consider “How might we as a group be the tipping point” a offered a suggestion: How about a national initiative for internships. Presentation slides are available at: [http://docs.asee.org/public/TUEE/Phase1/ClosingRemarks\\_DonMillard.pdf](http://docs.asee.org/public/TUEE/Phase1/ClosingRemarks_DonMillard.pdf)

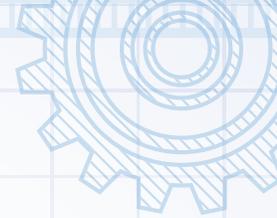
## Participants' Written Feedback

As the workshop ended, attendees were asked to respond in writing to two questions:

*What types of new thoughts do you have as a result of the discussions during the meeting?*

*What ideas have resonated with you the most?*

Overwhelmingly, respondents were encouraged by the prospect of greater industry-academic cooperation in improving the engineering curriculum, with one declaring optimistically: “The wall is coming down between industry and academia.” A few were skeptical about the willingness of universities to change. “I didn't feel that the university folks, even in this meeting, were really that open or optimistic



about change given the current measurement/reinforcement model in higher education,” one participant wrote. Several called for a national-level initiative as well as regional outreach to drive the message of change home to university leaders.

The sheer number of KSAs identified gave a couple of respondents pause. “We are a long way off from coming up with a solution. We really need to prioritize what things we can practically implement in both industry and academia,” one participant wrote. Nonetheless, a number thought a shared industry-academe consensus on KSAs was achievable and, when completed, should be widely disseminated – particularly among incoming students.

Putting forward their own recommendations, respondents repeatedly stressed the need for project-based experiences to be integrated in the curriculum from the earliest years. “Critical thinking, problem solving, prototyping & struggle through failure are not admonished as positive,” one respondent lamented. Another wrote: “Capstone design – undercredited = undervalued by students and faculty.” It was widely accepted that industry could play a useful role in encouraging student projects.

Although most participants focused solely on undergraduates, one suggested that doctoral programs be developed with industry in mind.

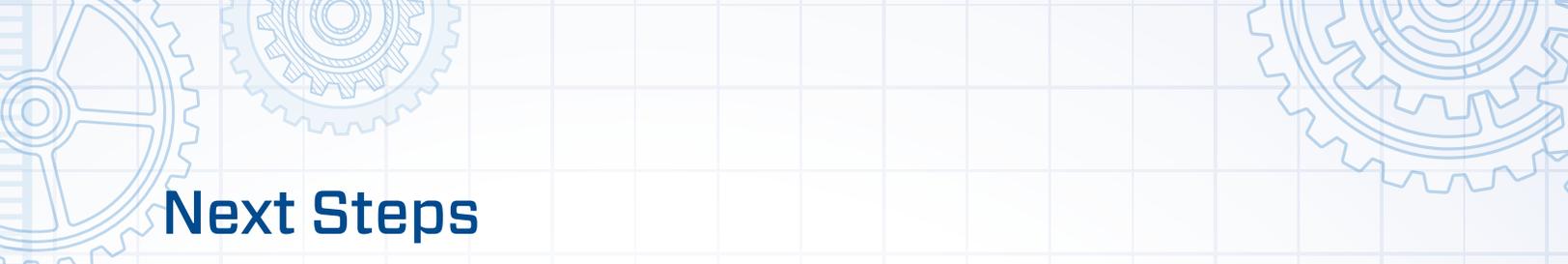
## Post-Workshop Survey

After the workshop, ASEE staff tabulated which KSAs were considered most important, as shown by votes of attendees. These 36 KSAs were then ranked accordingly. On June 3, ASEE distributed another survey to attendees. It asked them to 1) select who should be primarily responsible (industry, academia, government, students, parents, or some combination); and 2) describe what strategies should be implemented to improve desired KSAs’ attainment among engineering graduates. Responses are tabulated in Appendix D.

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

Most KSAs, in the respondents’ view, demand efforts by two or more parties. This was especially true of communication skills – a shared responsibility of students, parents, K-12, academia, and industry – and of nurturing creativity, instilling cultural awareness and high ethical standards, and fostering systems thinking. Respondents didn’t consider industry to have sole responsibility for any KSA, but gave it a leading role in training students for project management and in encouraging them to take calculated risks. Industry and academia together must imbue students with economics and business acumen, respondents said.

Frequently, written responses underscored the need for closer cooperation between educational institutions and industry. Participants generally gave government a modest role – for instance, in facilitating and funding student exchanges.



# Next Steps

ASEE proposes to engage in an expansive, coordinated, and sustained effort:

- To solicit, distill, and share the views of the engineering community (including academe [faculty, chairs and deans, and students], industry, government and professional societies) with respect to future visions for engineering education appropriate to the full spectrum of:
  - Challenges and opportunities faced by practicing engineers in a variety of operational contexts,
  - Faculty culture and incentives across disciplines within individual institutions of higher education and faculty culture and incentives within individual engineering disciplines across institutions of higher education, and
  - Emerging and established knowledge of how people learn and discipline-based education research.
- To facilitate a continual discussion among various elements of the engineering community to develop a consensus on needed improvements in engineering education to achieve the distilled visions;
- To identify and flesh out possible collaborative (among academia, industry, and others) implementation models that address the prioritized “what,” “who” and “how;”
- To enunciate desired outcomes and the metrics by which progress toward the outcomes may be measured;
- To identify and facilitate operational pilots to test combinations of “what,” “who” and “how;” and
- To facilitate, document, and publicize efforts by various parts of the engineering community to implement the needed changes.

These follow-up activities should validate, augment or compress the listing and priority of various KSAs – “what” – as well as “who” and “how;”

ASEE envisions a three phase project spanning five years with the ultimate goal of developing a flexible framework that fosters transformative changes to engineering curriculum, pedagogical approaches and academic culture.

# Appendix A. Post-Workshop Survey Results

During the workshop, participants discussed the results of the pre-workshop survey and generated a list of 36 Knowledge, Skills, and Abilities (KSAs) items crucial for the engineering profession. The post-meeting survey listed those 36 KSAs and asked respondents to identify which stakeholder should be responsible for each KSA, and how they should be taught, implemented, or reformed. This appendix summarizes the survey findings. Based on the discussion and ranking done at the workshop, fifteen KSAs were identified as a priority in terms of engineering education reforms. Those 15 KSAs are analyzed separately in Section 1, followed by the additional 21 KSAs in Section 2.

## Section 1: High Priority KSAs for Engineering Education

Table 1 summarizes the distribution of responsibility vis-à-vis each of the 15 high priority KSAs, as identified by workshop participants who responded to the survey.

**Table A.1. KSA responsibility across stakeholders, high priority KSAs\***

	Single stakeholder					Combination of two or more stakeholders						
	Students (ST)	Parents (PA)	Academia (AC)	Industry (IN)	Other	ST-PA	ST-AC	ST-IN	PA-AC	AC-IN	ST-AC-IN	PA-AC-IN
Good communication skills			23%			15%			50%	7%		4%
Physical sciences and engineering science fundamentals			96%							4%		
Ability to identify, formulate, and solve engineering problems	4%		40%	4%					26%	25%		
Systems integration			13%	13%	4%					60%		10%
Curiosity and persistent desire for continuous learning	28%	8%	8%	4%	4%	24%			24%			
Self-drive and motivation	28%	20%	4%		4%	44%						
Cultural awareness in the broad sense (nationality, ethnicity, linguistic, gender, sexual orientation)		16%	12%	4%		50%			18%			
Economics and business acumen			20%	20%						50%		10%

\* percentage totals may not equal 100% due to rounding.

**Table A.1. KSA responsibility across stakeholders, high priority KSAs\* (Cont.)**

	Single stakeholder					Combination of two or more stakeholders						
	Students (ST)	Parents (PA)	Academia (AC)	Industry (IN)	Other	ST-PA	ST-AC	ST-IN	PA-AC	AC-IN	ST-AC-IN	PA-AC-IN
High ethical standards, integrity, and global, social, intellectual, and technological responsibility	4%	12%	12%			4%			68%			
Critical thinking	4%	4%	71%						15%			5%
Willingness to take calculated risk	8%	4%	8%	29%	4%	23%						23%
Ability to prioritize efficiently	8%	17%	17%	8%					50%			
Project management (supervising, planning, scheduling, budgeting, etc.)	4%		21%	29%						46%		
Teamwork skills and ability to function on multidisciplinary teams	13%		33%	4%			12%	12%			26%	
Entrepreneurship and intrapreneurship	17%		17%	4%	9%		12%	12%			28%	

\* percentage totals may not equal 100% due to rounding.

### KSA 1: Good communication skills (skill)

Responsibility of:	Academia	Combination of two or more	Other	Total count
Good communication skills	23%	73%	4%	26

The majority of respondents stated that communication skills should be the responsibility of two or more stakeholders. In their open-ended comments, they said students, parents, K-12, academia, and industry were jointly responsible for developing those skills. Communication skills are critical for both life and a successful career, so the focus on them should begin early on with parents and K-12 educators. Later on, academia can introduce key concepts and can model communication skills in group projects. The skills should be integrated directly in the core engineering curriculum and not be taught in a separate course outside of engineering. Students should be presented with opportunities and encouraged to work on their communication skills, getting feedback all along the way. They should arrive in industry already prepared for presenting, public speaking, writing, and general communication (verbal, email, phone). Several comments emphasized that development of writing skills (e.g. technical writing; report writing; business writing) needs to be part of engineering education as well.

The role of industry is to provide real world examples, internships and experience. If there is one fault that novice and sometimes more seasoned engineers and professors exhibit in the workplace, it is the failure to communicate effectively with the non-engineers who may control their fate in the company or who have a vested interest in the engineer's projects. For instance, debate practice can help improve that. To debate effectively, you need to deconstruct a situation or hypothetical example, leverage your relationships, understand your audience (including comprehension levels), identify points you can use to sway the audience, be persuasive, make your case in terms that they understand, provide a convincing outcome, and convince others to make a decision they think they made themselves. Those are all really useful skills in the workplace.

## KSA 2: Physical sciences and engineering science fundamentals (*knowledge*)

Responsibility of:	Academia	Combination of two or more	Total count
Physical sciences and engineering science fundamentals	96%	4%	25

Respondents stated quite explicitly that responsibility for providing this knowledge falls solely on academia. Only one person said academia and industry shared that responsibility. Consistently, respondents also emphasized the importance of learning the sound fundamentals of engineering, which, unlike tools and technology, do not change. One recommendation was to review and update the curriculum with current and emerging industrial practice in mind, and to employ instructional strategies that research has shown to be effective (problem-based learning, collaborative learning, etc.) to teach and demonstrate the fundamentals in the context of engineering design and real-world examples. Students must experience a hands-on example of every fundamental taught in order to reinforce it. Without reinforcement, most fundamentals are never digested by the students. Another suggestion was to extend engineering programs to five years and to place more emphasis on electives.

One participant also addressed creativity and flexible thinking in engineering education and instruction in problem solving. The classroom instruction formula of one answer path per problem places boundaries on problem solving. In engineering, absolutes are scary things and “close enough” is often sufficient. The simpler the route to a “close enough” answer, the better. Unfortunately, pretty little perfect answers that don’t require one to experiment with multiple methods in order to find the best solution are not adding value to the students’ ability to assess a problem and determine a solution. (“There is more than one way to skin a cat.”)

The role of teachers in developing fundamental science skills was also addressed. All teachers hold personal beliefs and dispositions about teaching, learning, and learners. Some teachers believe their responsibility is to teach the material, and the students’ responsibility is to learn what is taught. If students struggle or fail to learn, the responsibility is believed to rest only with the students. Effective teaching is a purposeful means to an important end, not the end itself. Teachers in engineering should: accept some measure of responsibility for their students’ struggles and failure to learn; believe that all students can and will learn; respect and accept the unique perceptions of individual learners; commit to the learning and intellectual growth of all learners; reflect on and consider learners’ prior knowledge and interests when selecting and using specific teaching strategies and techniques; create a challenging, but non-threatening, learning environment; believe that one can teach effectively and that effective teaching will lead to positive learning outcomes.

## KSA 3: Ability to identify, formulate, and solve engineering problems (*skill*)

Responsibility of:	Industry	Academia	Students	Combination of two or more	Total count
Ability to identify, formulate, and solve engineering problems	4%	40%	4%	52%	25

Those who answered that abilities to identify, formulate, and solve engineering problems should be the responsibility of two or more stakeholders provided some further clarifying comments, stating that the process should begin with parents teaching basic problem-solving skills. It should continue into K-12, progress further in college, particularly with engineering problem solving, and be completed in the early-career professional stage – in industry or government. Furthermore, industry and academia should partner at the community level to provide real-world examples that can be taught in a university setting and then be reinforced by industry through internships and mentoring for new engineering graduates and junior engineering professionals.

Schools develop students’ ability to think critically. Students can learn concepts, theories and applications in lectures and in labs, but lack a forum to apply what they have learned in problem-solving. (Labs contain too much in the way of step-by-step instructions.) Suggestions to address that included teaching concepts such as Six Sigma and fishbone analysis; expanding senior projects to multiple years; or adopting club activities (like FIRST robotics, racing cars, or airplane engineering) and treating national competitions as formal courses. Another suggestion addressed teamwork and developing team skills for engineering problem-solving. Universities could aim problem-solving instruction slightly beyond what students can do alone but within the boundaries of what they can do with assistance from others, designing discussions and negotiations among students as on-going learning experiences. Furthermore, problem-solving as a core engineering skill should be cultivated through multiple iterations of design throughout the curriculum. Design consists of several small problems; academia should provide more open-ended questions and show that there isn’t always a “right” answer, thus encouraging creativity and flexible thinking and allowing students to identify the problem and figure out possible avenues to solve it. A common fault is to try to solve a problem without fully understanding it.

#### KSA 4: Systems integration (*knowledge*)

<b>Responsibility of:</b>	<b>Industry</b>	<b>Academia</b>	<b>Combination of two or more</b>	<b>Other</b>	<b>Total count</b>
Systems integration	13%	13%	71%	4%	<b>24</b>

Those who answered that system-integration knowledge should be the responsibility of two or more stakeholders stressed that academia should partner with industry. Some respondents said students and parents bear responsibility for stimulating intellectual curiosity and the engineering mind, and said government should provide incentives and support more open standards for industry. All technical challenges and designs are generally at the systems level, so students need to be introduced to systems engineering early in their undergraduate programs. Academia’s responsibility is teaching the concepts and the principles of how systems have been evolving, and showing that science topics are not stand-alone pieces of information but are all interrelated. Therefore, academia should mix different engineering disciplines and multidisciplinary assignments in capstone projects. Courses should feed off each other - while students are learning about derivatives in calculus, they should simultaneously be solving derivative problems in physics. With creativity, academia could craft curriculum schedules that sync and help to reinforce concepts.

One respondent cautioned that it is challenging for academia to provide authentic experiences in systems integration other than in a capstone design experience. Therefore, academia should partner with industry to provide a formal framework for what is meant by system integration and to determine which elements can be effectively addressed in the academic setting. Industry’s responsibility, as

stated by respondents, is also to provide the hands-on opportunities, tools and resources at low or no cost, as well as knowledge of their company-specific systems. Also, industry can encourage the interdisciplinary nature of system integration by occasionally switching job roles. As far as balance is concerned, although academia's role is critical in teaching the basics of system integration in an interdisciplinary fashion, ultimately only industry can convert systems integration knowledge into a systems integration skill set. Industry is where those abilities evolve and develop the most.

#### KSA 5: Curiosity and persistent desire for continuous learning (*ability*)

Responsibility of:	Industry	Academia	Students	Parents	Combination of two or more	Other	Total count
Curiosity and persistent desire for continuous learning	4%	8%	28%	8%	48%	4%	25

The majority of respondents believed that curiosity and desire for continuous learning lie with the individual student. Engineering students should be interested enough to seek new opportunities and challenges and ask for additional assignments to challenge themselves. Those who indicated that more than one group could contribute cited parents, teachers, academia, and industry as each having a role. Parents need to provide an environment that encourages children to want to learn how industry, engineering, and things surrounding us function, as well as an environment that accepts failure as long as it moves a project or knowledge forward. The easiest thing for a person to do when asked a factual question is to just tell them the answer. But when children and young adults ask a question, consideration should be given to showing them how to research the answer and find out for themselves. An interesting suggestion under “other” urged that K-12 educators do more to foster intellectual curiosity from an early age. Currently, the K-12 system may stifle innovation and curiosity as standardized tests become the norm.

At the university level as well, most assignments are “canned” and therefore do not promote or elicit any exploration or creativity on the part of the student. They are canned primarily so they can be graded more easily, but such assignments end up doing a disservice to the students. To support curiosity and interest in engineering, the importance and the “grandness” of engineering methodologies should be explained to younger students in an accessible and motivating way. There needs to be a fundamental mindset change, one harboring less meeting of requirements and more of an environment for exploration. Engineering curricula need to have more authentic engineering experiences that stimulate creativity and curiosity. In college, this would be followed up by case studies, projects, guest lectures, demonstrations, and applications that reinforce the romance of engineering. This is a mentality that needs to be reinforced constantly throughout the student’s life, demonstrating that there is value behind it. Professors also could get students to recognize the importance of professional associations (e.g. IEEE, AIChE, ASME, ASEE, etc.) in contributing to leadership development, networking, and awareness of current topics of interest in the field.

Industry can encourage curiosity and continuous learning by setting set aside time and providing money for employees to learn new things and experiment.

### KSA 6: Self-drive and motivation (*ability*)

Responsibility of:	Academia	Students	Parents	Combination of two or more	Other	Total count
Self-drive and motivation	4%	28%	20%	44%	4%	25

Many respondents thought that self-drive, motivation, and a work ethic start at home and are mostly the responsibility of students and parents. One person also mentioned pre-college/K-12 as a contributing factor. Numerous respondents said that this is a mentality that needs to be reinforced constantly throughout a student's life and that parents, academia, and industry can all play a role. Students need to push themselves to learn more, to seek different experiences, and perhaps reach out to engineers for inspiration. They can create development teams, similar to an incubator, where students can come and brainstorm. Parents need to provide an environment that encourages children to want to learn and succeed. That effort should be further supported by K-12 and academia, making students feel that there is a fair effort-versus-reward system. Universities should provide development contests and incentives for class participation.

Industry, on the other hand, needs to provide an environment where failure might be the best road to success, and where success is also rewarded. Both university professors and industry managers should provide direct feedback, encouragement, and context to young and aspiring engineers to motivate them and create the sense that they're not just performing "a job" but contributing to something bigger.

One respondent provided a reference to a specific motivational resource, Brian Tracy's *Time Power and No Excuses: The Power of Self-Discipline* – suggesting that each be required reading in engineering school.

### KSA 7: Cultural awareness in the broad sense: nationality, ethnicity, linguistic, gender, sexual orientation (*knowledge*)

Responsibility of:	Industry	Academia	Parents	Combination of two or more	Total count
Cultural awareness in the broad sense (nationality, ethnicity, linguistic, gender, sexual orientation)	4%	12%	16%	68%	25

Participants gave parents and academia the most important role in shaping cultural awareness in students. The majority, however, agreed that understanding and acceptance of different cultures can't be shaped by any one factor. Students, parents, pre-college K-12, academia, industry, and government have a responsibility to encourage an inclusive environment in which everyone's opinion, thoughts and ideas are valued and welcomed. Cultural awareness starts before students even make it to university and should be cultivated and encouraged by parents, but ultimately the responsibility lies with the student. Parents can encourage this by making sure their children accept people from other cultures and don't bully them. K-12 and academia can support that by embedding cultural awareness in the technical and general education curriculum. They can also mix students of different cultures (including foreign exchange students) in projects and foster collaboration in courses, and provide opportunities

for study abroad. Most of the awareness (and more importantly, acceptance) comes from being around diverse people and getting to know them as friends. Alternatively, using modern communication technology, two geographically distant universities could create teams composed of students from both schools who would share problems and tasks remotely. Companies that seek cultural awareness in employees should specify this as a requirement when they screen co-ops. This will encourage students to become familiar with other cultures while at university. At the workplace, industry can conduct cultural training (related to the particular industry), language lessons, and multi-national teleconferences for tech discussions. Government has a role in facilitating and funding academic exchange programs, although this is becoming more challenging now with fiscal and visa constraints.

### KSA 8: Economics and business acumen (*knowledge*)

<b>Responsibility of:</b>	<b>Industry</b>	<b>Academia</b>	<b>Combination of two or more</b>	<b>Total count</b>
Economics and business acumen	20%	20%	60%	<b>25</b>

Respondents here were evenly split on whether academia or industry bore the greater responsibility for nurturing economic knowledge and business sense in students. However, many respondents believed that responsibility should be shared between academia and industry; some would also include parents, K-12, and government. Parents, but also the education system, need to demonstrate and teach how bad economic decisions and habits can have real-life consequences. K-12 and academia could teach business and economics fundamentals that would later be applied in context by the new engineering graduates in their industry jobs. One respondent noted that there is a market for universities to help teach engineers business skills and provide lower cost options than business school. One option would be to have business and economics embedded in the engineering curriculum as elective courses. A specific suggestion was that a mixed class of basic engineering economics and basic personal finance can go a long way in helping students become more cognizant of the world of economics. Such a class is also a bit more practical and provides a better engagement than a theoretical micro or macro-economics class. Also, academia can incorporate more project planning, project management, and business impact case studies into projects (i.e. development, production, cost, revenue, etc.).

Despite the shared responsibility of academia and industry for business and economics acumen, several respondents argued that industry is better positioned than academia to make a true impact here. Industry could be very instrumental in providing hands-on perspective and mentoring. A company is also best suited to provide engineers with a streamlined and relevant mix of business concepts and tactics tailored to that particular industry. It would be very beneficial for engineering professionals to gain an understanding of the business side of their craft and how their efforts impact the business of the companies they work for.

### KSA 9: High ethical standards, integrity, and global, social, intellectual, and technological responsibility (*ability*)

Responsibility of:	Academia	G'ment	Students	Parents	Combination of two or more	Total count
High ethical standards, integrity, and global, social, intellectual, and technological responsibility	12%	4%	4%	12%	68%	<b>25</b>

Most participants agreed that ethics, integrity, and technological responsibility are complex and fundamental virtues that all members and institutions within society are obliged to uphold. Therefore, parents, academia, industry, and government all share the responsibility to promote and oversee ethics. In the words of one respondent, “There is wanting to do the right thing, and learning what is right. Parents, colleges, and industry must always review and define what is ‘right’ and what is ‘wrong.’” A person’s values and a sense of ethics, integrity and responsibility should be taught first by parents as fundamental values in upbringing. Ethical standards should be further cultivated throughout a student’s education, starting with primary school. In academia, ethics is normally handled as a separate course, which is likely not the most effective way to teach it. Ethics is deeply embedded into everyday decisions and interactions in engineering work and should be addressed throughout the curriculum. What is more, academia needs to convey that engineers are the keepers of the public’s safety. Schools could also introduce students to IEEE and ACM and similar forums, or invite business leaders to speak to students on how ethics are applied in the business world.

The legal and social consequences and impact of ethics would be later quantified for young engineering professionals by specific companies in their respective industry. One respondent mentioned that it is worth noting that there is a formal framework for ethics – laws – and this should be collaboratively framed by government, institutions, and industry. The responsibility here falls predominantly on government to enforce guidelines of ethics across industries and stricter penalties against unethical behavior (white collar crime).

### KSA 10: Critical thinking (*skill*)

Responsibility of:	Academia	Students	Parents	Combination of two or more	Total count
Critical thinking	71%	4%	4%	21%	<b>24</b>

Most respondents agreed that it is largely academia’s responsibility to teach critical thinking, but a few people also said parents, academia, and industry can shape critical thinking in unison.

According to respondents, critical thinking closely relates to problem solving (a separate KSA discussed in this report). Knowing that there is no wrong answer and encouraging creativity will allow students to think differently about problems and to be more open-minded about solutions.

Parents can begin the process by encouraging critical thinking at home in early childhood, and academia can continue developing these skills through different courses, project work, and by giving real examples where multiple approaches and creativity are encouraged. Critical thinking should be

taught using instructional strategies that research has shown to be effective (problem-based learning, collaborative learning, etc.), and in the context of engineering design. Exposing students to case studies, as is done in law schools and business schools, is also an excellent way to develop this KSA. Furthermore, academia can sharpen these skills by giving students more requirement-based problems and mini-problems like the TV show “Mythbusters”, and by giving students the opportunity to pose such questions as “What is the problem?”; “What are we going to do?”; and “How are we going to do it?” The complexity of the problems would evolve over time. Another effective approach for academia is to develop problem sets that have a ripple effect on other problems (e.g. “Developing this amplifier creates additional noise for the next component.”). Also, colleges should consider giving “no calculator” exams to see if students can show basic understanding of conceptual ideas. Critical thinking is a clear outcome of engineering design and should be measured and improved in academia as it relates to open-ended problems. Courses should be evaluated on the amount of critical thinking they stress and, if not currently geared towards developing critical thinking, should be re-tuned.

Industry can provide real-world examples of active critical thinking that leads to problem solving. Because critical thinking also comes from practice, demonstrating how to apply it in a real environment would be helpful.

### KSA 11: Willingness to take calculated risk (*ability*)

<b>Responsibility of:</b>	<b>Industry</b>	<b>Academia</b>	<b>Students</b>	<b>Parents</b>	<b>Combination of two or more</b>	<b>Other</b>	<b>Total count</b>
Willingness to take calculated risk	29%	8%	8%	4%	46%	4%	<b>24</b>

In the words of respondents, risk-taking is in the nature of engineering, and therefore teachers and industry should reward risk-taking and not be afraid of failure. To foster that ability in students and young engineers, they need to secure an environment that allows for taking risks without serious repercussions. According to one respondent, risk taking is also linked to creative and open problem-solving (a separate KSA in the report). Knowing that there is no wrong answer will allow students to take more risk.

Many respondents stated that the ability to take calculated risk should be cultivated by industry through case studies and real-life experience, because industry is best suited to provide the environment for experimenting and risk-taking in practice. Risk has many definitions based on context and it’s more challenging for academia to provide an authentic experience in that sense. At the same time, risk-taking should not be reckless; industry should provide a favorable environment, guide young engineering professionals, and educate them on risk levels and potential outcomes. There are specific risk assessment techniques that can be taught and used in the case studies analysis. Students, parents, and academia can also contribute to industry in shaping such abilities, according to 11 respondents.

Students should also seek and embrace opportunities to take risk, although it was acknowledged by respondents that it sometimes comes down to personality and individual risk-taking tolerance. Collaborations across academia, industry, and government in the form of public-private partnerships or company-to-company alliances are of increasing importance. By working together, engineers have the best chance of discovering, developing, and delivering the most innovative capabilities. In the sense of collaboration, one particular suggestion is to expose students to incubator companies on campus.

### KSA 12: Ability to prioritize efficiently (*skill*)

<b>Responsibility of:</b>	<b>Industry</b>	<b>Academia</b>	<b>Students</b>	<b>Parents</b>	<b>Combination of two or more</b>	<b>Total count</b>
Ability to prioritize efficiently	8%	17%	8%	17%	50%	<b>24</b>

The respondents who thought that prioritizing skills are the responsibility of more than one party paired parents with mentors, and industry with academia. Instruction could start at home with parents and in K-12 education, with both environments offering meaningful experiences at an early age. Parents could suggest an efficient prioritizing scheme for tasks and objectives and let their kids follow it, while monitoring results.

Later on, academia could enhance the learning process by syncing projects across classes and years in order to help stagger the workload for students. Academia provides prioritizing skills indirectly by making students take a lot of courses, but a separated short mandatory course focused on such skills could be also introduced. It is a challenging skill to master because it relates to reflection and metacognition. Particular areas of study that help students develop prioritizing skills are math and operations research, systems engineering, and risk management practices and processes. A few additional ideas to support prioritizing skills included seminars and self-help podcasts for students to help them understand that organizational skills are important and further, spending minimal time on certain things will improve performance. Students might also be paired with mentors or coaches to help them navigate through challenges and learn techniques to prioritize and manage sometimes conflicting schedules or priorities.

Businesses and industry can also provide mandatory training on prioritizing skills, as well as real-world experience, which is the best way for students to learn. However, it also depends on the context – there is prioritization in the sense of time management, engineering decisions, etc., and they are equally important but may need to be prioritized themselves, depending on industry context and needs.

### KSA 13: Project management: supervising, planning, scheduling, budgeting, etc. (*skill*)

<b>Responsibility of:</b>	<b>Industry</b>	<b>Academia</b>	<b>Students</b>	<b>Combination of two or more</b>	<b>Total count</b>
Project management (supervising, planning, scheduling, budgeting, etc.)	29%	21%	4%	46%	<b>24</b>

A combination of academia and industry support is key to developing project management skills, participants said. Although these skills could be taught in school, they also need to be learned and applied in practice through internships, apprenticeships, and work experience. While it's a shared responsibility, several respondents commented that it falls more heavily on industry than on academia, including the cost of training. Academia could provide a basic foundation and introduce concepts and real-world project scenarios to apply the concepts (e.g. one group develops firmware, a second develops OS components, and each team must manage itself and coordinate with the other). Opinions as to how to do that varied. Some thought that it could be done through an elective course (but should not be mandatory), while others suggested that engineering schools should be required not only to enforce project management, but also provide certification for completed course and project work.

In order to develop this skill fully, however, industry exposure is required and students must have the opportunity to manage real projects to completion (e.g. “Develop this sensor, which will be used for a particular application”). Internships, apprenticeships, work-study programs, and other practical interactions between academia and industry can greatly enhance project management skills, but also provide a feedback channel for academia as to what project management skills industry is looking for. Industry would also add content-specific topics and context.

**KSA 14: Teamwork skills and ability to function on multidisciplinary teams (*ability*)**

<b>Responsibility of:</b>	<b>Industry</b>	<b>Academia</b>	<b>Students</b>	<b>Combination of two or more</b>	<b>Total count</b>
Teamwork skills and ability to function on multidisciplinary teams	4%	33%	13%	50%	<b>24</b>

Students have the primary responsibility for learning to work in teams to achieve goals, but academia and industry need to provide the opportunities. Teamwork should be embedded everywhere – as part of authentic design experiences, if possible – and needs to become a meta-skill for every student. Schools and industry need to develop a measure of how well students perform. Academia could offer more teamwork-oriented courses where students depend on their peers. That may require adjustment of the teaching sequence to allow for more complex team activities and projects and rebalancing the lecture-project balance. Group projects involving multiple disciplines (engineers, finance, HR, etc.) are a good practice. It is important to assign students to different roles each time so they can build a diverse skillset and are able to perform not one but all team tasks. Conflict management is an important part of teamwork and should be also taught at universities. Another idea was to identify opportunities for students to create solutions that address problems at the local level (where the university is located), and work with other engineering students, faculty mentors, and POCs in the community to address common issues. Teamwork today means not only face-to-face experience, but online interaction and cooperation as well, across geographical and cultural boundaries. In fact, teamwork is at the core of interactive learning environments and project-based design.

Industry can further cultivate and develop teamwork skills. Opportunities for students jointly provided by academia and industry to build teamwork skills may include participation in school projects, internships, national sponsored competitions, and volunteering in student branches of professional societies.

### KSA 15: Entrepreneurship and intrapreneurship (*ability*)

<b>Responsibility of:</b>	<b>Industry</b>	<b>Academia</b>	<b>Students</b>	<b>Combination of two or more</b>	<b>Other</b>	<b>Total count</b>
Entrepreneurship and intrapreneurship	4%	17%	17%	52%	9%	<b>23</b>

In the words of one participant, this KSA is an aggregated trait of several other KSAs: critical thinking, business/economics acumen, and the ability to take risks. It builds on KSA 8 (economics and business acumen) by expanding on business and economics acumen and enabling students to learn more than economic capitalization, but also the process of starting a business from an idea. According to respondents, students, parents, and academia share the responsibility for developing entrepreneurial and intrapreneurial abilities, whereas industry and government can contribute by offering opportunities and funding for the development of such skills.

Academia can start the process by encouraging engineering students to take courses in business and finance. Incubator companies on campus could provide opportunities for students to engage early and learn about practicing innovation in a business setting. Schools can also facilitate involvement at the community level in support of business initiatives (financing, public-private partnerships, etc.). Colleges of engineering could also collaborate with colleges of business to develop effective business curricula for engineers. Design projects, competition, progressive IP, and incubation infrastructure are all proven techniques of entrepreneurial thinking that could be taught at the university level.

Universities should have centers outside of the curriculum that can cultivate these abilities. That could be done through academia-industry partnerships that foster entrepreneurship skills via internships, apprenticeships, and work-study programs. Representatives of industry and business with real-life knowledge and expertise could be very instrumental in providing tips and pointers on entrepreneurship. Ultimately, although it can be nurtured and supported, entrepreneurial thinking and initiative lies with the students and the individual.

## Section 2: Additional KSAs identified as important for Engineering Education

Table 2 summarizes the distribution of responsibility vis-à-vis each of the additional KSAs, which although not as high of a priority as the first 15 KSAs, were still identified as important for reforming engineering education by survey respondents.

**Table A.2. KSA responsibility across stakeholders, high priority KSAs\***

	Single stakeholder					Combination of two or more stakeholders							
	Students (ST)	Parents (PA)	Academia (AC)	Industry (IN)	Gov't (GO)	ST-PA	ST-AC	ST-IN	PA-AC	AC-IN	IN-GO	PA-AC-IN	AC-IN-GO
Ability to use new technology and modern engineering tools necessary for engineering practice			18%	35%						40%		7%	
Public safety			12%	24%	24%								41%
Informational technology (IT)	6%		39%	28%	11%					17%			
Applied knowledge of engineering core sciences and implementation skills to apply them in the real world	5%		42%	26%						27%			
Data interpretation and visualization			72%		6%					22%			
Security knowledge (cyber, data, etc.)	6%		18%	41%	6%					10%	10%		10%
Leadership	5%	10%	10%	24%						12%		40%	
Creativity	6%		33%						20%	20%		20%	
Emotional intelligence	11%	32%		16%	5%	10%			17%	10%			
Application based research and evaluation skills			56%	25%	6%		12%						

\* percentage totals may not equal 100% due to rounding.

**Table A.2. KSA responsibility across stakeholders, high priority KSAs\*(Cont.)**

	Single stakeholder					Combination of two or more stakeholders							
	Students (ST)	Parents (PA)	Academia (AC)	Industry (IN)	Gov't (GO)	ST-PA	ST-AC	ST-IN	PA-AC	AC-IN	IN-GO	PA-AC-IN	AC-IN-GO
Ability to create a vision	6%	13%	13%	25%	19%				25%				
Good personal and professional judgment	6%	18%		18%	18%	15%				15%			11%
Mentoring skills			12%	47%	12%			9%		10%	10%		
Flexibility and the ability to adapt to rapid change	18%	18%	6%	24%	6%		10%	10%		10%			
Ability to deal with ambiguity and complexity	6%		53%	18%	6%					18%			
Innovation	13%		25%	13%	13%		25%	13%					
Technical intuition/metacognition	24%	6%	24%		6%		30%	11%					
Understanding of design	6%		56%	13%						25%			
Conflict resolution		18%	12%	18%	12%	14%						27%	
Ownership and accountability	6%	18%	12%	18%						20%		27%	

\* percentage totals may not equal 100% due to rounding.

**KSA 16: Ability to use new technology and modern engineering tools necessary for engineering practice (skill)**

Responsibility of:	Industry	Academia	Combination of two or more	Total count
Ability to use new technology and modern engineering tools necessary for engineering practice	35%	18%	47%	17

Staying abreast of new technology and the ability to utilize modern engineering tools is largely seen as a responsibility of both academia and industry, often in unison. Academia should stay cognizant of trends and expose students to more design experience, tools in class, modeling, simulation, computing, CAD and CAM, etc. Engineering schools also must integrate the use of technology in their curricula and practice and provide tools, training, and projects for students to use the equipment. For instance, mechanics of materials design projects in civil engineering should be done using AutoCAD; use of datasheets in systems-building portions and how it applies to the system being built should be

demonstrated in all classes. Decontextualizing this into separate courses only reduces its significance and loses value.

Due to the large number of proprietary tools, industry remains best suited to take these skills to the next level and continue to develop them during an engineer’s career. Technology remains industry specific and individual companies know best how to prioritize the skills and technology their employees need. In addition, modern engineering tools evolve so quickly that it is difficult for academia to keep up. This process of continuous training and education for engineers should start at the university but run through internships and into jobs in industry.

### KSA 17: Public safety (*knowledge*)

Responsibility of:	Industry	Academia	G'ment	Combination of two or more	Total count
Public safety	24%	12%	24%	41%	17

Respondents reported that public safety is best taught and demonstrated through experience and professional development in industry. Industry has the responsibility for what they knowingly do to people, and therefore must introduce young engineers to safety standards and familiarize them with the consequences of not adhering to those standards. An effective way to do that is through case studies, which will vary from industry to industry because safety standards are very industry specific. A focus on safety also instills professional ethics and critical thinking. At the same time, government should set guidelines and standards to keep people safe and limit negligence. Early on, academia will have the responsibility to introduce government-mandated public safety standards into courses and to enforce real-world safety standards at the educational level, too (not just ISO qualification, but FCC regulations, etc.). Industry can provide schools with meaningful case studies that help to articulate the key issues.

### KSA 18: Informational technology – IT (*knowledge*)

Responsibility of:	Industry	Academia	Students	Combination of two or more	Other	Total count
Informational technology (IT)	28%	39%	6%	17%	11%	18

This was one of the few KSAs that were not viewed as joint responsibilities, but respondents were divided on whether the burden should fall on academia or industry. Several respondents thought that basic IT skills and coding should be taught by academia to all engineers as foundational courses. Those who believed that the responsibility lies with industry pointed to the ever-changing nature and the context sensitivity of the IT discipline across industries.

The few respondents who believed that IT acumen was a joint responsibility argued that IT education should begin in academia and continue throughout an engineer’s career in industry. Industry should share their IT requirements with academia in order for faculty to include current best practices and technologies in their courses, not just theory. Industry should help schools keep up with trends by regularly communicating what IT skills are in demand in their field at any given moment. Ultimately, most institutions are capable of teaching the core IT skills as long as they are mindful of current trends and needs of industry.

**KSA 19: Applied knowledge of engineering core sciences and implementation skills to apply them in the real world (*skill*)**

<b>Responsibility of:</b>	<b>Industry</b>	<b>Academia</b>	<b>Students</b>	<b>Combination of two or more</b>	<b>Total count</b>
Applied knowledge of engineering core sciences and implementation skills to apply them in the real world	26%	42%	5%	26%	<b>19</b>

This KSA ties into KSA 2 – the core engineering sciences. Respondents suggested that in order to address the practical application of science, academia needs more integration of practice and design experiences in the curriculum from the beginning, and opportunities for applied engineering such as trans-disciplinary activities, lab work, internships, co-ops, group projects, national competitions, industry-sponsored capstone projects, and guest speakers from industry. Industry possesses the necessary insights to take the lead in defining what the core skills and concepts are. What is more, industries have their own perspective on what “the real world” means, so it’s best for them to guide the application of science in practice.

Both academia and industry could encourage students to seek practical problems to solve -- fix their car, automate their dorm room, program software or an application, set up a server, or try to solve a computer problem, for instance. This would be a great opportunity for students to put theory into practice and would further stimulate their interest in engineering.

**KSA 20: Data interpretation and visualization (*skill*)**

<b>Responsibility of:</b>	<b>Academia</b>	<b>Combination of two or more</b>	<b>Other</b>	<b>Total count</b>
Data interpretation and visualization	72%	22%	6%	<b>18</b>

Data skills are a fundamental core KSA for engineering. Learning must begin at university and be incorporated into all applicable courses, rather than being taught as stand-alone courses such as a basic statistics class. Universities and companies should partner to ensure real world relevancy and accuracy. Development of data skills should continue throughout an engineer’s career.

Participants also provided one book as a useful reference for students and the academic curriculum - Edward Tufte’s *The Visual Display of Quantitative Information*.

**KSA 21: Security knowledge: cyber, data, etc. (*knowledge*)**

<b>Responsibility of:</b>	<b>Industry</b>	<b>Academia</b>	<b>Students</b>	<b>Combination of two or more</b>	<b>Other</b>	<b>Total count</b>
Security knowledge (cyber, data, etc.)	41%	18%	6%	29%	6%	<b>17</b>

Academia should give students the basic awareness of cyber security as it relates to their computer and mobile device and personal usage practices. A class or seminar that shows how to protect basic personal information, email and social media, as well as how to prevent e-mail phishing and malicious links, would be a good starting point for students. Although academia can teach basic security concepts, industry and perhaps even government will likely have to take the lead on case studies and priorities so that the concepts are practical and relevant to the real world and do not place too much emphasis on abstract technical concepts like encryption. Moreover, security changes by the day and so do the details pertaining to each company's security practices. Industry's updated input is much needed in order to modify the curriculum on a semester-to-semester basis and incorporate new security strategies or technologies.

One respondent noted that the question of security is extremely sensitive and the line between awareness and potentially incriminating knowledge is unclear. Cyber security should be approached with caution by both academia and industry and students must be imbued with a sense of ethics and responsibility in addition to knowledge and expertise.

#### KSA 22: Leadership (*skill*)

Responsibility of:	Industry	Academia	Students	Parents	Combination of two or more	Total count
Leadership	24%	10%	5%	10%	52%	21

Because leadership is cultivated and not taught, it is a more challenging skill to develop and it is difficult to determine exactly what it is and how it would be measured. Not everyone can be an effective leader and this requires established leaders to properly identify and mentor potential future leaders. The majority of respondents agreed that leadership is a joint responsibility cultivated by students, parents, academia, and industry. It is a trait that has to be developed through mentorship and practice. Encouraging students to be involved in organizations and team activities (student branches of professional societies, teamwork projects, national competitions of engineering nature, etc.) is one way to help cultivate leadership. Leadership is also a skill that is more relevant to the actual engineering profession than to academia. Therefore, industry should focus on further developing those skills through practice and training geared towards specific industry needs and by providing appropriate model behaviors and examples. Students, on the other hand, also bear some of the responsibility to identify examples of leadership that are relevant to their field and interests and learn from them.

#### KSA 23: Creativity (*ability*)

Responsibility of:	Academia	Students	Combination of two or more	Total count
Creativity	33%	6%	61%	18

The majority of respondents agreed creativity as an ability is a shared responsibility. While based in part on a student's personality, it can be strengthened with help from parents, K-12, and academic and industry experiences. Students should be encouraged to think out of the box, develop interests and hobbies outside of engineering, frequently venture out of their comfort zone, take risks, and not be afraid of failing. Parents can support that but also try to involve their children in creative engineering projects early on. K-12 and academia can also help by stressing innovation within existing courses, and by initiating creative projects just for fun. Creativity is related to the development of multiple solutions to open-ended problems and should be taught in the context of design: It's common to hear that there is a creative solution to that complex problem but one never hears that there is a creative solution to the equation  $F=ma$ , for example. Academia should provide problems and experiments that foster creativity. Industry has to recognize that creativity can easily be crushed through standardization and status quo thinking, and needs to make an attempt to minimize such limiting factors.

#### KSA 24: Systems thinking (*skill*)

Responsibility of:	Industry	Academia	Combination of two or more	Other	Total count
Systems thinking	17%	22%	56%	6%	18

According to respondents, all problems are generally system problems. Therefore, systems thinking skills are critical for engineering. Colleges can help students develop these skills by teaching basic concepts and providing experience with real projects. Having an understanding of how engineering disciplines work with each other to accomplish one goal is important. Academia could implement courses that cover big-picture topics (e.g. "Developing this block of code using this textbook topic will do this-and-this for a program") and make students build systems more often. Industry can then continue to build on that foundation at the workplace.

#### KSA 25: Emotional intelligence (*ability*)

Responsibility of:	Industry	Students	Parents	Combination of two or more	Other	Total count
Emotional intelligence	16%	11%	32%	37%	5%	19

Respondents consider this a core human quality that is important for the engineering professional. The greatest influence on developing emotional intelligence and social skills is the home, and parents are mostly responsible for cultivating it from an early age – alongside schools. Academia can be helpful as well, but if a student enters college emotionally unready, he or she needs first to recognize a lack of maturity and then begin to develop it. Students will naturally mimic and they could greatly benefit from any feedback from academia on how different behavior could help them achieve better results.

One respondent pointed out that, like leadership, emotional intelligence is a "soft ability" that is hard to define or operationalize. Its development would take time, so it should be addressed as an integral part of communication skills that both academia and industry seek to foster.

### KSA 26: Application-based research and evaluation skills (*skill*)

Responsibility of:	Industry	Academia	Combination of two or more	Other	Total count
Application based research and evaluation skills	25%	56%	13%	6%	16

In the view of most participants, responsibility for developing these skills falls on academia. Most technical concepts can be recast from a research perspective. It comes down to the willingness of institutions to review and modify their curricula and to engage more students in research activities. Academia needs to create projects where teachers define the end application and students develop the execution. As an example, one person suggested that students could be assigned to find a programmable voltage regulator within a certain set of parameters, justify why they picked it, and discuss with the class several examples and the pros and cons of each possible choice. Then students could run test to see if the chosen item works as they anticipate. The same should be possible for many materials, fuels, and chemicals.

### KSA 27: Ability to create a vision (*skill*)

Responsibility of:	Industry	Academia	Students	Parents	Combination of two or more	Other	Total count
Ability to create a vision	25%	13%	6%	13%	25%	19%	16

Several respondents expressed reservations about whether the ability to create a vision could be taught. They suggested instead that, like leadership, it should be cultivated through mentorship and an enabling environment. The process could begin with parents encouraging children to think big, imagine, and not just fulfill requirements. For instance, if children dream of being an astronaut, expose them to informal education environments, such as a visit to NASA, or space focused museums, and watch relevant documentaries and movies. The role of academia is to show students how to start with a definition of what they want to achieve, frame the scope and break everything down into general and specific steps of how to get there. One suggestion was that this could be taught as part of systems engineering in academia. Industry can also contribute to shaping a vision by providing real-life project experience.

### KSA 28: Good personal and professional judgment (*ability*)

Responsibility of:	Industry	Students	Parents	Combination of two or more	Other	Total count
Good personal and professional judgment	18%	6%	18%	41%	18%	17

According to respondents, good personal and professional judgment abilities are another example of core life skills that are hard to teach and develop over a lifetime. That process is a shared responsibility of parents, academia, and industry, and is related to critical thinking and leadership. Parents should enable children to work for things – volunteer in the community, for instance, or get a job to pay for a car. Professional judgment requires posing and solving open-ended problems, something that academia needs more of in many courses. Therefore schools should teach the philosophy of science,

business, and security as part of science classes. Both academia and industry need to understand that “how” is not “why.”

### KSA 29: Mentoring skills (*skill*)

Responsibility of:	Industry	Academia	Combination of two or more	Other	Total count
Mentoring skills	47%	12%	29%	12%	17

Respondents reported that peer facilitation and mentorship at the student level as well as in industry has been shown to be highly effective for both mentor and mentee. It’s recommended that students get several mentors during their matriculation process inside and outside of academia through credit-based or volunteer mentoring and tutoring programs, as well as mentors in the business world. In industry particularly, mentoring needs to be reinforced as a necessity for success and competent, sustainable engineering. Industry needs to stop allowing their wise old engineers to retire without passing along the benefit of their experience to younger engineers. Furthermore, if students receive good mentoring, they will become better mentors themselves. In partnership with academia, industry should also provide real-world counseling to all students who request it, not just top-tier students.

### KSA 30: Flexibility and the ability to adapt to rapid change (*ability*)

Responsibility of:	Industry	Academia	Students	Parents	Combination of two or more	Other	Total count
Flexibility and the ability to adapt to rapid change	24%	6%	18%	18%	29%	6%	17

Respondents saw this as an ability that can be fostered by students, parents, academia, and industry together. Parents should help children be adaptable. One way is through participation in a variety of activities, such as sports and music. Several respondents made the observation that by definition, academic institutions are more stable and change-averse. Generally, students who are flexible and can easily adapt to change tend to succeed, but academia does not make enough effort to teach these skills. Internships and project work opportunities with industry will likely offer the best exposure to the hectic pace of the real world. Oftentimes industry, and large businesses in particular, lacks the ability to adapt to rapid change and large businesses are generally slower to adapt. Industry and academia should work together to develop projects that have technical twists and force students to change approaches. Career counselors and business managers and leaders in particular could also play a role, especially when it comes to adapting to change.

### KSA 31: Ability to deal with ambiguity and complexity (*skill*)

Responsibility of:	Industry	Academia	Students	Combination of two or more	Other	Total count
Ability to deal with ambiguity and complexity	18%	53%	6%	18%	6%	17

Respondents noted that the ability to deal with ambiguity and complexity ties in with several other KSAs – communication skills, good judgment, critical thinking, and technical intuition. Most people placed the responsibility for this KSA on academia. The undergraduate curriculum should repeatedly expose students to problems with complexity and ambiguity. The groundwork should be laid in the classroom with teachers presenting open-ended problems that don't lend themselves to a single right answer. Teachers should prompt students to engage in discussions and show they have pondered the problem. Academia should use complex and ambiguous questions to enhance communication and creativity. One participant suggested holding troubleshooting seminars, addressing ambiguity and complexity. A few respondents also thought that this is a skill honed in industry, where there are no tests or quizzes and grading is necessarily more subjective.

### KSA 32: Innovation (*ability*)

Responsibility of:	Industry	Academia	Students	Combination of two or more	Other	Total count
Innovation	13%	25%	13%	38%	13%	16

Innovation was put in the same category as creativity by respondents and was seen as a shared responsibility of students, academia, and industry. This and similar skills can be addressed by academia through modifications to the undergraduate curriculum that repeatedly expose students to open-ended design problems. Instead of one-command, one-action instructions, academia should start asking questions along the lines of “How would you solve this problem?” One respondent noted that innovation differs from creativity in that it has a more tangible and practical end result. Academic institutions can develop more open-ended exercises in which students are assessed on how they meet functional goals using unique or inspired techniques. In addition, schools could provide more electives for students to explore things that interest them, even if they are not related to a degree. On the other hand, students need to realize that you innovate any time you find a solution that is simpler than the last, works better, and can save money. This is a shared responsibility of students and industry: Students must be self-motivated, and industry needs a policy of encouraging workers and providing enough time for them to innovate.

### KSA 33: Technical intuition/metacognition (*ability*)

Responsibility of:	Academia	Students	Parents	Combination of two or more	Other	Total count
Technical intuition (metacognition)	24%	24%	6%	41%	6%	17

These were seen as the responsibility of students, parents, academia and industry alike. Parents should expose children to opportunities to think about how things work, even allowing them to take things apart, such as an old VCR. Academia could then further develop technical intuition by having students validate others' work, conducting calculator-free exams, and offering practical opportunities to work on projects. Intuition comes from experience finding real solutions to real problems, not fictitious problems from textbooks. It takes practice. Therefore, industry could be the most instrumental player by providing exposure and experience.

Metacognition (self-awareness of how one learns) is not the same as technical intuition, one respondent noted. The latter comes from experience and cannot be taught in the traditional sense.

#### KSA 34: Understanding of design (*knowledge*)

Responsibility of:	Industry	Academia	Students	Combination of two or more	Total count
Understanding of design	13%	56%	6%	25%	16

Most respondents considered design to be solely the responsibility of academia. Repeated authentic design experiences should be integrated through all four years of the curriculum and include engineering drawing courses. Single-solution problems do not teach design. Students should study current designs with an eye for simplicity, effectiveness, and the thought that goes into the seemingly inane. Students should ponder such questions as “What is there to the shape of a bar of soap?”, or “Why does a Bic lighter cost only \$2.50 but yet works more reliably than many other economy lighters?” Even if the answer is not immediately known, thinking through such questions may kickstart the wheels of design.

A few respondents agreed that design is another debatably ambiguous concept and will require the combined efforts of industry and academia to realize something meaningful and practical from a teaching perspective. Also, design can mean a lot of different things depending on the industry. Therefore industry's input in the teaching of design is important. One suggestion for partnership and cooperation was for industry and academia to hold high-level design review meetings.

#### KSA 35: Conflict resolution (*knowledge*)

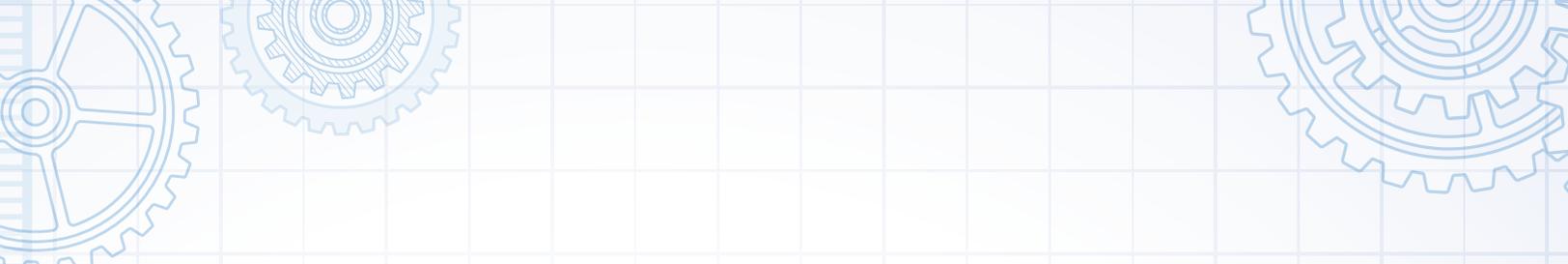
Responsibility of:	Industry	Academia	Parents	Combination of two or more	Other	Total count
Conflict resolution	18%	12%	18%	41%	12%	17

Respondents viewed conflict resolution as related to team building and communication and a shared responsibility of parents, academia and industry. It is very much a core human value that starts at home. Parents should help children develop good social skills and to try to understand multiple points of view. That effort should be supported in parallel by K12 education. Academia can help students realize that, within a team, conflict can actually be a positive building block in reaching a consensus. Academia needs to provide conflict scenarios in group projects for students to resolve and build a positive emotional reaction to having disagreement, where finding an elegant solution that you can be proud of becomes more important than winning an argument. Industry can further develop conflict resolution abilities through team work and group projects.

### KSA 36: Ownership and accountability (*ability*)

<b>Responsibility of:</b>	<b>Industry</b>	<b>Academia</b>	<b>Students</b>	<b>Parents</b>	<b>Combination of two or more</b>	<b>Total count</b>
Ownership and accountability	18%	12%	6%	18%	47%	<b>17</b>

Ownership and accountability was perceived by respondents as both an ability and a value, one cultivated with help from parents, the community, teachers, academia, and eventually industry. The earlier such cultivation begins, the better the effects will be for the individual later in the professional world. Parents should get children used to being held accountable for their actions and provide proper reinforcement (positive or negative). The institution must enforce clear guidelines on the obligations of the student. In the end, it will come down to how rigorous the institution is in assessing the student's work. Students working in groups often can coast if they are not interested, while another student shoulders more of the work to get a better grade. Instructors often let teams sort this problem out themselves, thinking it will help develop leadership skills. That is of little help to the student trying to do all the work. Academia needs to provide guidance, benchmarks, and a clear expectation of individual performance in each group. It is absolutely crucial for parents, academia, and industry to not only teach and cultivate ownership and responsibility, but also to raise awareness of all possible consequences of students' actions.



## Appendix B. Pre-Workshop Survey Results

This appendix provides a summary of responses (n=33) to a pre-meeting survey designed to delve into workshop participants' mindset regarding Knowledge, Skills and Abilities (KSAs) that the 21st century engineering education should provide, and how industry can help catalyze a transformation of undergraduate engineering education in that direction.

KSAs on which survey items were based were derived from a literature review of current publications addressing the skillset that engineers need in the 21st Century workforce. The sources that contained the most comprehensive listing of KSAs included two conference papers presented at the American Society for Engineering Education annual conferences, the ABET 2013-2014 engineering schools accreditation criteria, and a National Academy of Engineering publication on the engineer of 2020. References are listed below.

### References:

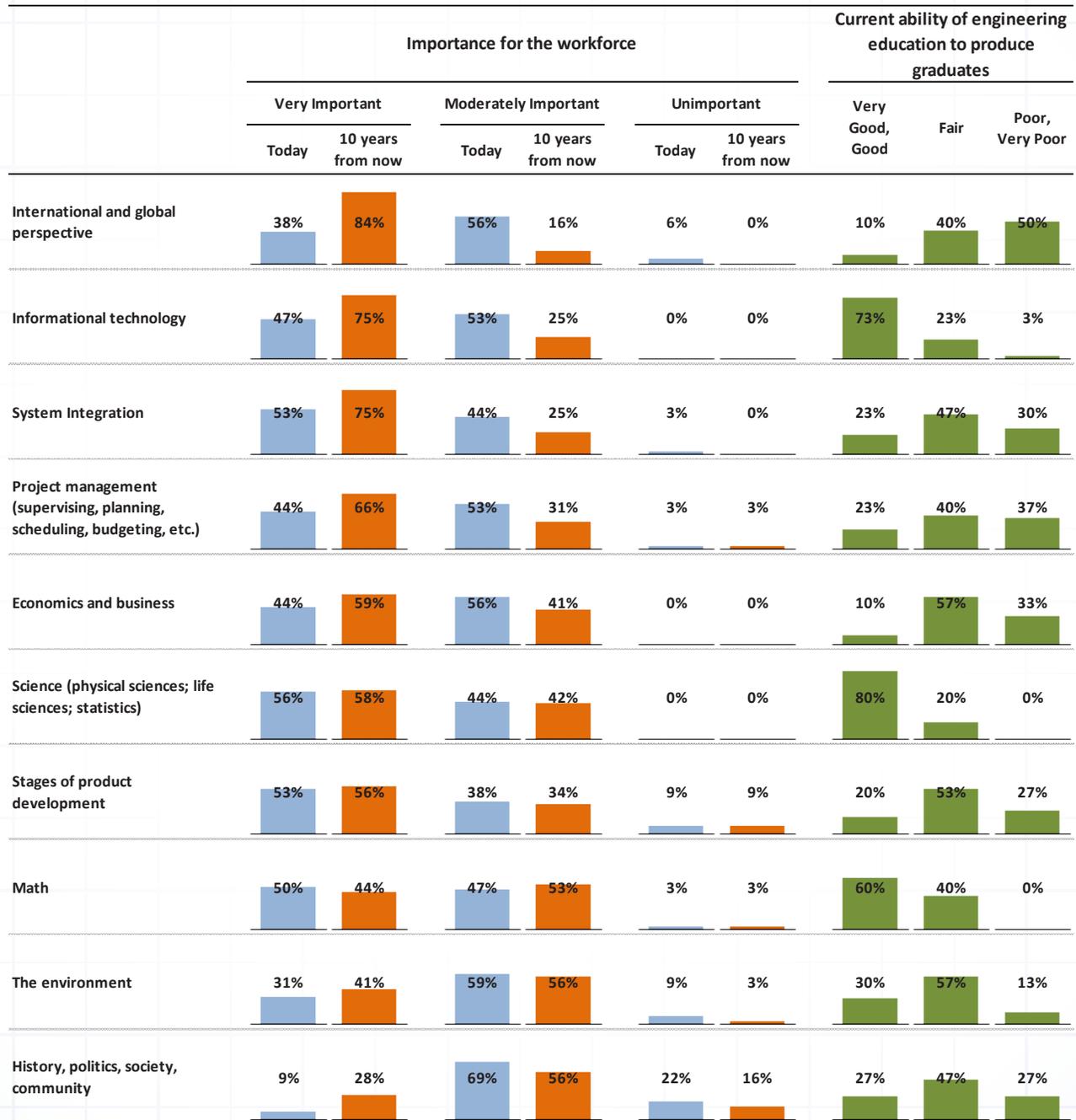
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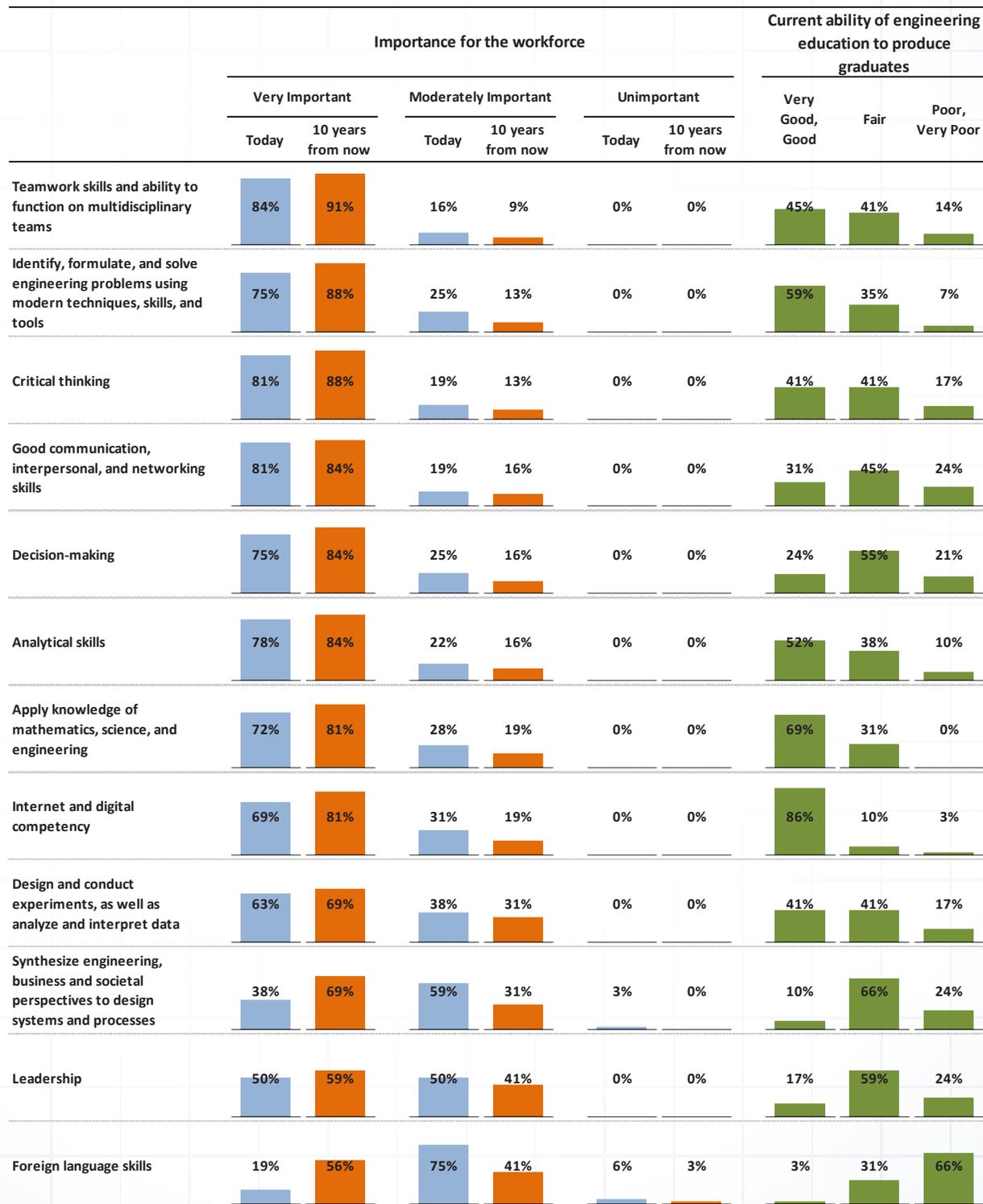
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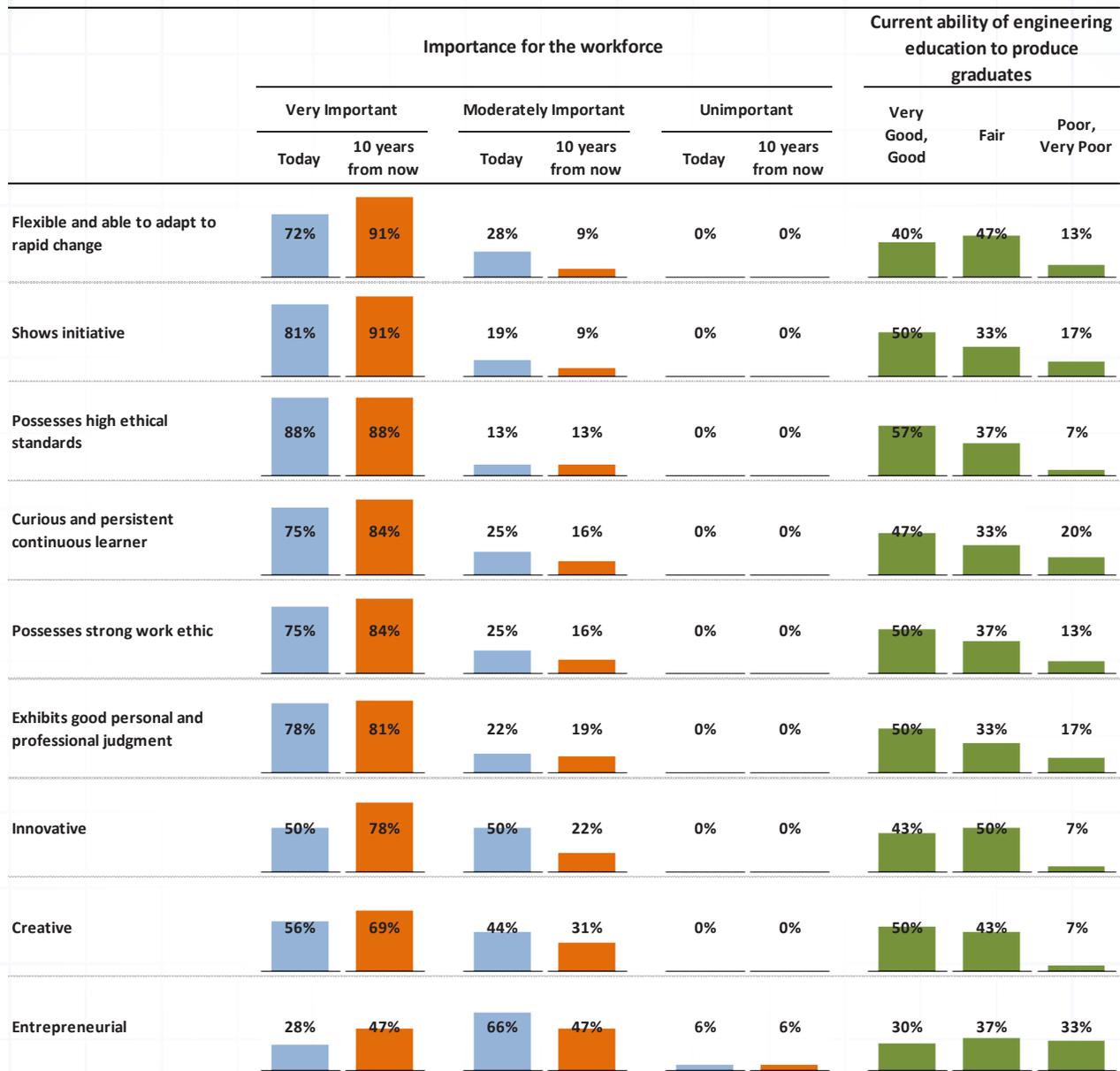
**Table B.1. Workshop participant responses to the quality of engineering education in the following KNOWLEDGE areas, as well as their importance for the engineering workforce today and 10 years from now.**

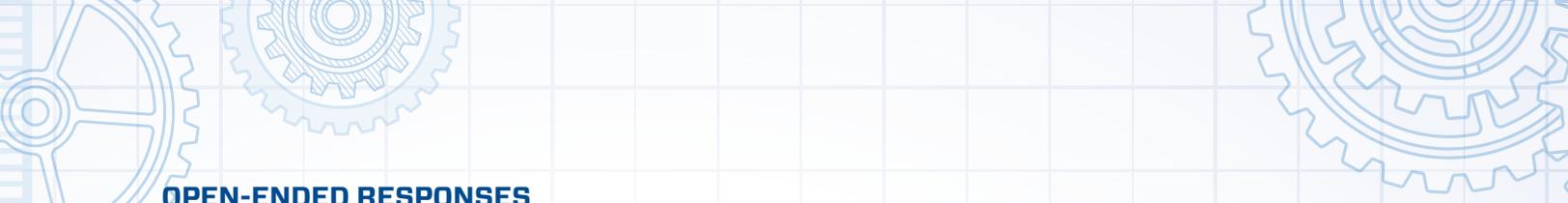


**Table B.2. Workshop participant responses to the quality of engineering education in the following KNOWLEDGE areas, as well as their importance for the engineering workforce today and 10 years from now.**



**Table B.3. Workshop participant responses to the quality of engineering education in the following KNOWLEDGE areas, as well as their importance for the engineering workforce today and 10 years from now.**

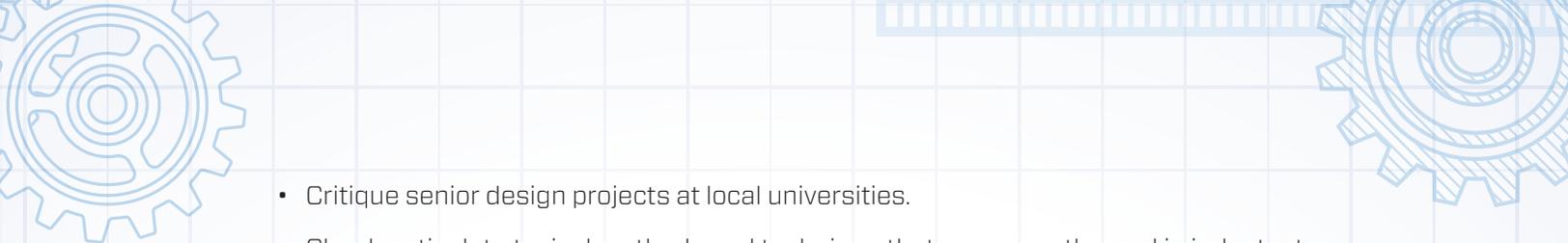




## OPEN-ENDED RESPONSES

*How might industry usefully provide guidance to academe in preparing graduates to exhibit the differing skills sets desired among employees at different career levels?*

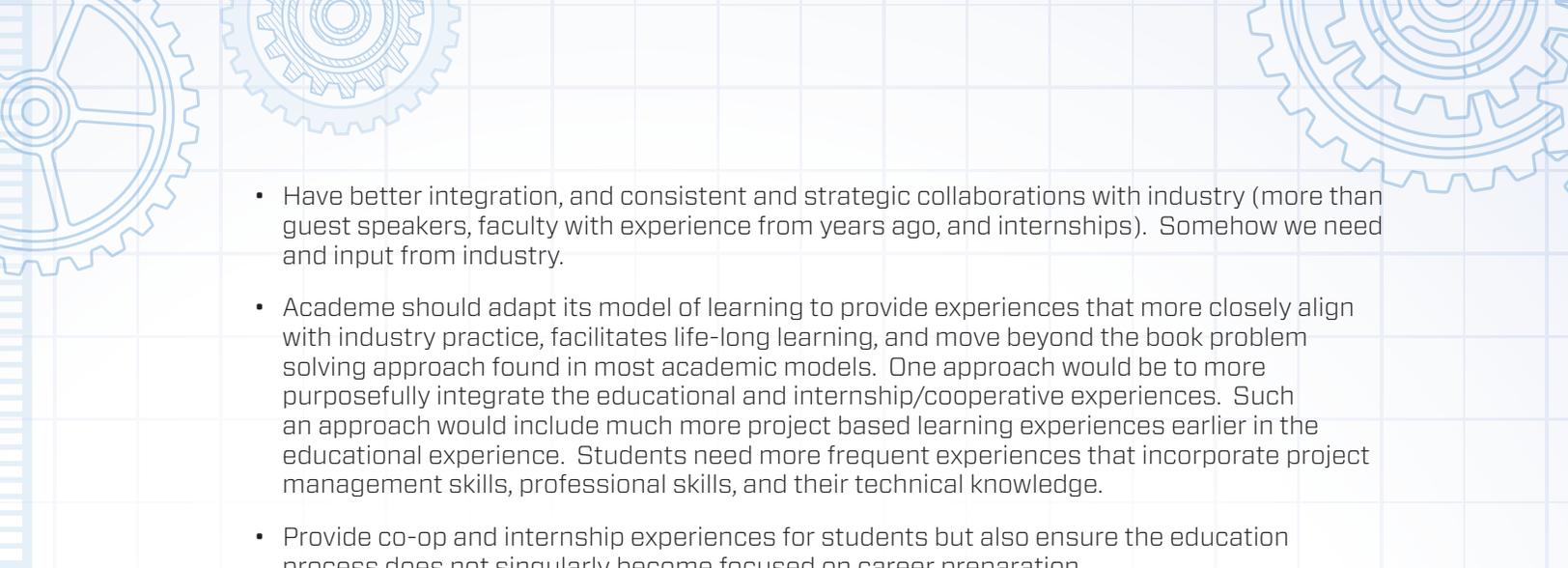
- Actively participate in advisory boards both at the college and department level.
- Become involved in engineering professional societies — these organizations are a conduit for driving change in engineering education.
- Industries should respond thoroughly to employers' survey sent by department chairs and deans, and should have a continual relationship with the deans and chairs of engineering schools.
- Provide the perspective of industry professionals (through surveys, interviews, observations of practice), instead of asking management only
- Provide examples of how engineers contribute to various industry sectors today and in the future, and also, know how engineers grow within and across organizations.
- Help develop a set of prioritized educational outcomes and graduate attributes to guide engineering education programs.
- Recognize what abilities and skills engineers need to have and point at the right courses or curriculum.
- Offer to develop simulations of “real world” type engineering work to be woven into the curricula.
- Provide more co-placement and internship opportunities, job shadowing programs, and extracurricular activities that provide useful industry experience (sponsoring hands-on projects that coincide with class lessons).
- Having faculty from industries and the real world (or professors that understand industries).
- Getting involved with reviewing accreditation and have industry representatives on ABET review teams.
- Right now, industries communicate with professors on a one to one basis - it would be useful to have forum to bring together deans and industries.
- Provide industry feedback on strengths and weaknesses found during interviewing and training processes and sharing of job descriptions that include clear requirements and expectations.
- Guide academia in technology used in industries (and expected of new graduates and entry-level professionals) to be taught and mastered in school first (e.g. STAAD.Pro; CAD).
- Provide technology & strategy roadmap exchanges.
- Share and discuss competency models.
- Assist with career development guides.
- Engage industry leaders to provide input to curriculum objectives and establish mentoring relationships between industry employees and university instructors (TAs and professors) to “translate” how curriculum content applies to the business world.
- Provide university/industry partnerships to foster innovation and engage students early (first year)

- 
- Critique senior design projects at local universities.
  - Clearly articulate typical methods and technique that are currently used in industry to university in order to evolve curriculum for the modern context, and also provide case studies that can help professors establish context for courses and concepts

***What might constitute a single integrated set of lifelong core knowledge, skills, and attributes among engineers in industry?***

- Problem-solving skills and being innovative.
- Communication and inter-personal skills.
- Multidisciplinary knowledge and ability to understand core concepts across disciplines (e.g. other branches of engineering, design, production, management, research, data, statistics etc.).
- Be organized and efficient with time.
- Staying abreast with trends in engineering while at the same time building on experience. It is increasingly unclear what the ideal partnership is on continuous learning between the individual and his/her organization.
- A solid math, physics, sciences, and programming background.
- Strong values and integrity and a high level of accountability and responsibility.
- Competency - being willing to put the time in and just think and mull over problems and issues to understand them in detail.
- Deep understanding of the related process and the real world beyond science and academia.
- Analytical skills.
- Leadership.
- Desire for continued learning (self development).
- Teamwork - all engineers work in project teams.
- Attention to detail.
- Entrepreneurship.
- Program Management.
- Systems engineering and system thinking – dealing with complexities.
- Social acumen (develop an awareness of the socio-technical ecosystem to understand stakeholder needs and motivations).
- Financial acumen - understand what adds value to a company's bottom line to grow profits (this understanding is essential to promote ideas).

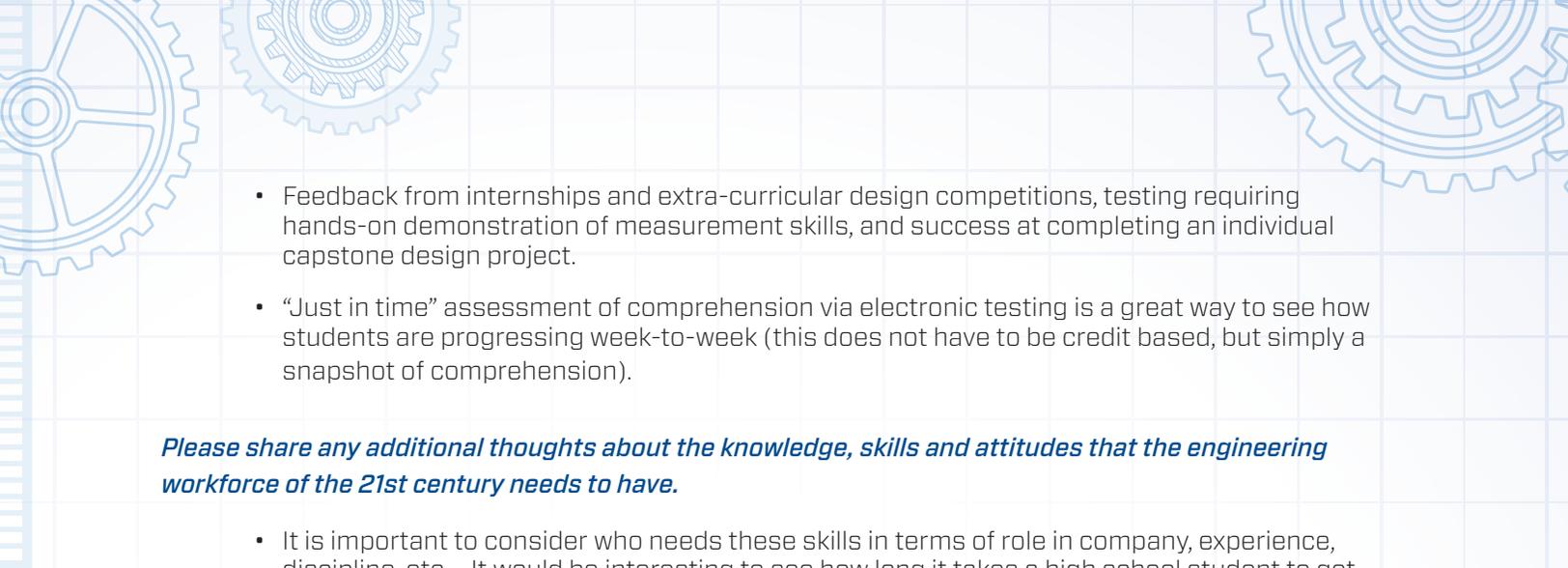
***How might academe provide appropriate deep preparation for industrial employment through instruction, tailored learning experiences, and internships/coop/etc?***

- 
- Have better integration, and consistent and strategic collaborations with industry (more than guest speakers, faculty with experience from years ago, and internships). Somehow we need and input from industry.
  - Academe should adapt its model of learning to provide experiences that more closely align with industry practice, facilitates life-long learning, and move beyond the book problem solving approach found in most academic models. One approach would be to more purposefully integrate the educational and internship/cooperative experiences. Such an approach would include much more project based learning experiences earlier in the educational experience. Students need more frequent experiences that incorporate project management skills, professional skills, and their technical knowledge.
  - Provide co-op and internship experiences for students but also ensure the education process does not singularly become focused on career preparation.
  - Emphasize on how to use the course material to solve problems related to industry.
  - Have workshops on state of the art technology.
  - Provide rewards and scholarships.
  - Students should be required to take a communications class to learn how to write and speak in the business environment.
  - Include lab courses that focus on different aspects of industry, including maintenance of equipment, learning different types of equipment, reading P&IDs, process safety management etc.
  - Establish centers on campuses focused on relevant research for students to work on (especially during summers).
  - Upper year students in engineering could give presentations about what they worked on during their internships and how they worked (how a real world project gets completed).
  - Have team projects.
  - Encourage students to affiliate with professional associations (IEEE, ASME, AICH, University Alumni associations).
  - Academia should actively inquire with industry to see what tools they are using in their day to day activities. The students should be exposed to these tools through labs and workshops (e.g., computer modeling software, CAD, etc.).
  - University teachers need to be trained and developed to ensure they are on top of the subjects that they are teaching, especially in new technology areas. These teachers would preferably have some industry experience or ties to industry.
  - Universities need to stop thinking of industry as “other” or as “vendors” but more as a potential partner.
  - Develop partnerships with surrounding municipalities and not-for-profits and task students to develop solutions to real problems in the communities surrounding the universities.
  - Tie projects and science concepts with sufficient complexity to more realistic applications to show which concepts typically apply in practice. This will help institutions make choices in selecting topics and establish applied framework for courses. They can still retain the rigorous traditions to offer even deeper knowledge than typical industrial applications but it would still maintain context.



### *What forms of assessment might provide greater confidence in student acquisition of specified skills?*

- Licensure exams (FE).
- Internship confidential evaluations.
- Having more integrated (judging multiple skills at once) and flexible (tolerant of various skill levels) assessment.
- E-portfolio - these collections not only give an institution some insights into their students' learning, but also add to the students' learning.
- Moving away from just graded courses as an indicator that students have obtained these desired skills and competencies and incorporating outcome based assessments focused on student demonstration of the skills and competencies needed for industry.
- An informal performance evaluation similar to those made in industry to provide feedback on student strengths, discussions with students on how they learn best, and pointers to improve skills.
- Industry, faculty, and student meetings where all parties attend and discuss successes, short comings, and future topics (similar to a stakeholder's meeting).
- Timed hands-on testing, similar to timed writings for SAT.
- Field applicable, real-world problems to be solved and graded (could be as team effort as well).
- Gauging how well students can evaluate the scope of a problem to issue resolution.
- Having students perform a Process Hazards Analysis, might be a great way to see if they understand PSM. Other ways maybe a class in an actual production area (working with industry) to see if they understand the process, etc.
- Immediate assessment and feedback would be ideal for students to quickly be able to assess their performance while acquiring new skills. Rather than place all (or the majority) of assessing the student at the end of the term/course, it would be more encouraging and valuable to the student to receive feedback early and often.
- Everyone looks at resumes. Not every resume represents the student accurately. Even additional screening questions in our applicant tracking system for students applying to positions can portray their potential inaccurately. Having in person, interactive and targeted activities are the best. This is beyond interviews. Maybe it includes competitions, team building activities, or even social events.
- Having students perform presentations of their work to faculty, or local volunteers of nearby industry or associations.
- Evaluation of the participation on national competitions (solar cars, web page creation, etc.) not in the performance of the resulting output but rather how students organize and divide their tasks, accountability for completion of tasks, how they seek the needed info to design or complete the task, etc.
- Internships are extremely effective and could count for course credit.
- On-the-job, apprenticeships and experiential learning
- One-on-one project coaching.

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- Feedback from internships and extra-curricular design competitions, testing requiring hands-on demonstration of measurement skills, and success at completing an individual capstone design project.
  - “Just in time” assessment of comprehension via electronic testing is a great way to see how students are progressing week-to-week (this does not have to be credit based, but simply a snapshot of comprehension).

***Please share any additional thoughts about the knowledge, skills and attitudes that the engineering workforce of the 21st century needs to have.***

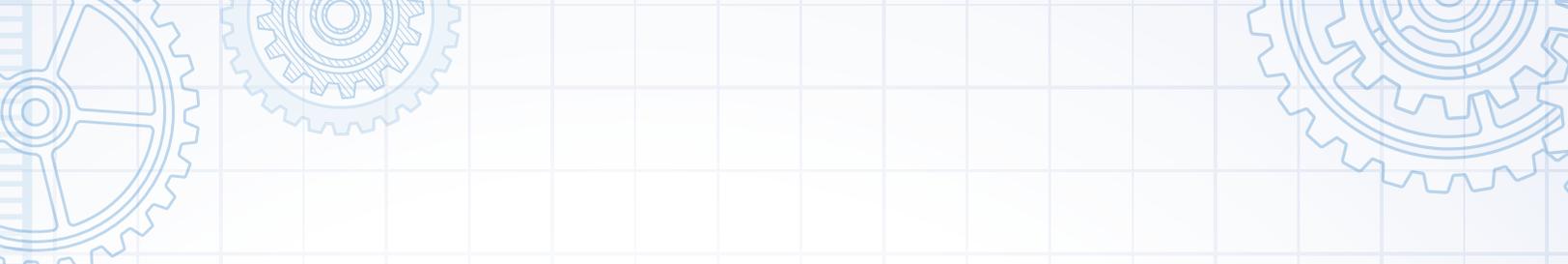
- It is important to consider who needs these skills in terms of role in company, experience, discipline, etc... It would be interesting to see how long it takes a high school student to get up to speed in an engineering firm compared to a college graduate.
- I think the up and coming workforce need to have the drive and ambition to actually work and want to accomplish things. In recent years I feel there is a sense of entitlement that comes from young workers. Young engineers should have the drive and passion to work and learn and understand. I come into contact with fewer and fewer graduates who are exposed to working on their own appliances, cars or other equipment.
- There needs to be a balance with this generation between the ability to be thinking innovatively and being very ambitious, with having an entitled attitude. We are seeing a good level of knowledge and skills new graduate hires. However, we have a conservative culture that surprises some and they get impatient or have misaligned expectations of how quick they can progress. I continue to give guidance regarding the desire to want to cross train and rotate around with the time it takes to gain knowledge, experience and in-depth skills. They want breadth and have this idea that depth comes rapidly. This is difficult for engineering schools to address and more associated with the generational culture of today.
- Now and in the future, the engineering curricula has to avoid stereotypes in teaching its disciplines and be more collaborative with other disciplines, creating linkages where practical, and preparing an engineering workforce with a broader background and perspective that goes beyond the engineering curriculum.

# Appendix C. Meeting Agenda

Thursday, May 9, 2013

Identification of Desired KSAs (Knowledge, Skills and Abilities)

8:00 AM - 8:30 AM	<b>Breakfast</b>	Ballroom C Foyer
8:30 AM - 9:00 AM	<p><b>Welcome</b> <i>Norman L. Fortenberry, Executive Director, ASEE</i></p> <p><b>Charge</b> <i>Don L. Millard, Program Director, DUE, NSF</i></p> <p><b>Pre-workshop Survey Results</b> <i>Brian Yoder, Director of Assessment Evaluation and Institutional Research, ASEE</i></p>	Ballroom C
9:00 AM - 10:00 AM	<b>Breakout Session I</b> Technical KSAs	Ballroom C, Crystal V, Crystal VI
10:00 AM - 10:15 AM	<b>Break</b>	Ballroom C Foyer
10:15 AM - 11:15 AM	<b>Breakout Session II</b> Professional/social KSAs	Ballroom C, Crystal V, Crystal VI
11:15 AM - 12:00 PM	<b>Reports from Breakout Groups</b>	Ballroom C
12:00 PM - 12:45 PM	<b>Lunch</b> <i>Donna Riley, Program Director, DUE, NSF</i>	Ballroom C
12:45 PM - 1:15 PM	<p><b>Reactions to Listed KSAs</b> (academics)</p> <p><b>Industry Representatives Break</b></p>	Crystal V
1:15 PM - 2:00 PM	<b>Academics-led Discussion</b>	Ballroom C
2:00 PM - 3:30 PM	<b>Breakout Session III</b> Jigsaw - Integration of Perspectives	Ballroom C, Crystal V, Crystal VI
3:30 PM - 3:45 PM	<b>Break</b>	Ballroom C Foyer
3:45 PM - 4:45 PM	<b>Synthesis Session I</b> Final List of Desirable KSAs	Ballroom C
4:45 PM - 5:00 PM	<b>Recap and Plans for Day 2</b>	Ballroom C
5:30 PM - 7:30 PM	<b>Dinner</b>	Ballroom C



## Friday, May 10, 2013

### Opportunities and Challenges for Implementation

7:30 AM - 8:00 AM	<b>Breakfast</b>	Ballroom C Foyer
8:00 AM - 8:15 AM	<b>Recap from Day 1 and Overview of Day 2</b>	Ballroom C
8:15 AM - 9:45 AM	<b>Breakout Session IV</b> How Industry can Collaborate with Academia?	Ballroom C, Crystal V, Crystal VI
9:45 AM - 10:00 AM	<b>Break</b>	Ballroom C Foyer
10:00 AM -10:45 AM	<b>Report from Breakouts</b>	Ballroom C
10:45 AM - 11:45 AM	<b>Synthesis Session II</b> Opportunities and Challenges	Ballroom C
11:45 AM - 12:00 PM	<b>Closing Remarks</b> <i>Don L. Millard, Program Director, DUE, NSF</i>	Ballroom C

# Appendix D. List of Participants

**Jayaprakash Balakrishnan**

Infosys

**Andy Bell**

National Instruments

**Brian Beneda**

Hewlett-Packard

**Dana Berkheimer**

Center for Energy Workforce Development (CEWD)

**Stephanie Bernheisel**

DuPont

**Molly Bigness**

IBM

**Shane Brown**

Washington State University

**Ann Carbonell**

National Geospatial-Intelligence Agency

**Alexey Castrodad**

National Geospatial-Intelligence Agency

**Wayne Chen**

Northrop Grumman Corporation

**Bruce Collins**

National Geospatial-Intelligence Agency

**Jared Corgan**

Emerson

**Lorraine Fleming**

Howard University

**Cameron Fulford**

Quanser

**Kenneth Galloway**

Vanderbilt University

**Luke Hartwig**

Lockheed Martin

**Christopher Higa**

Northrop Grumman Corporation

**Bart Johnson**

Itasca Community College

**Karsten Keller**

DuPont

**Fayez Khan**

Quanser

**Nathan Klingbeil**

Wright State University

**Ashley Ater Kranov**

Washington State University

**Tom Lee**

Quanser

**Luis Lopez**

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**Brian F. Majerowicz**

Baltimore Gas and Electric Company

**Nancy Martin**

General Electric

**Rick McMaster**

IBM

**Michael McQuade**

DuPont

**Michael Milligan**

ABET

**Zachary Nelson**

National Instruments

**Adedamola Omotosho**

Intel

**Chris Orlowski**

Northrop Grumman Corporation

**MaryBeth Oyer**

Lockheed Martin

**Riddhi Parmar**

Infosys

**Lance Perez**

University of Nebraska

**Lenora Peters-Gant**

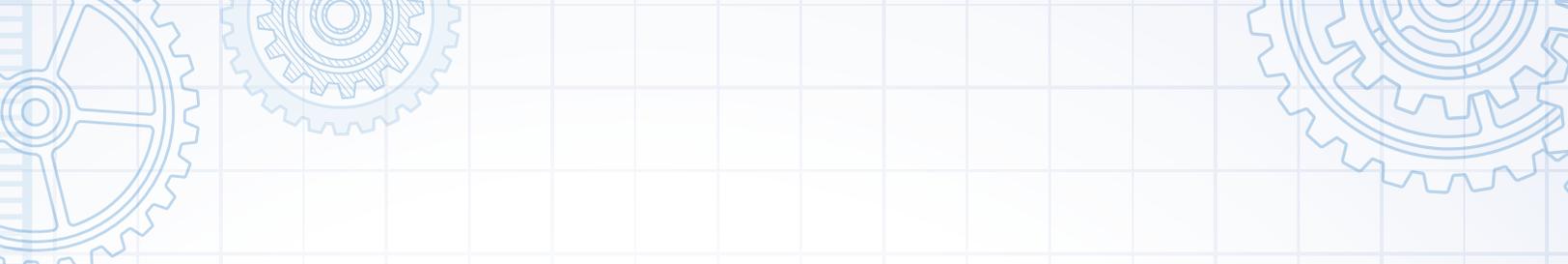
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**Michael Richey**

Boeing

**Gabriel Rodriguez**

Hewlett-Packard



**Jose Santiago**

Baltimore Gas and Electric Company

**Kimberly Sills**

Intel

**Jacob D. Terkelsen**

IBM

**Todd Walls**

Emerson

**Marilyn Watkins**

Infosys

**James Wei**

Lockheed Martin

**Dave Wilson**

National Instruments

**JoAnn Winson**

IBM

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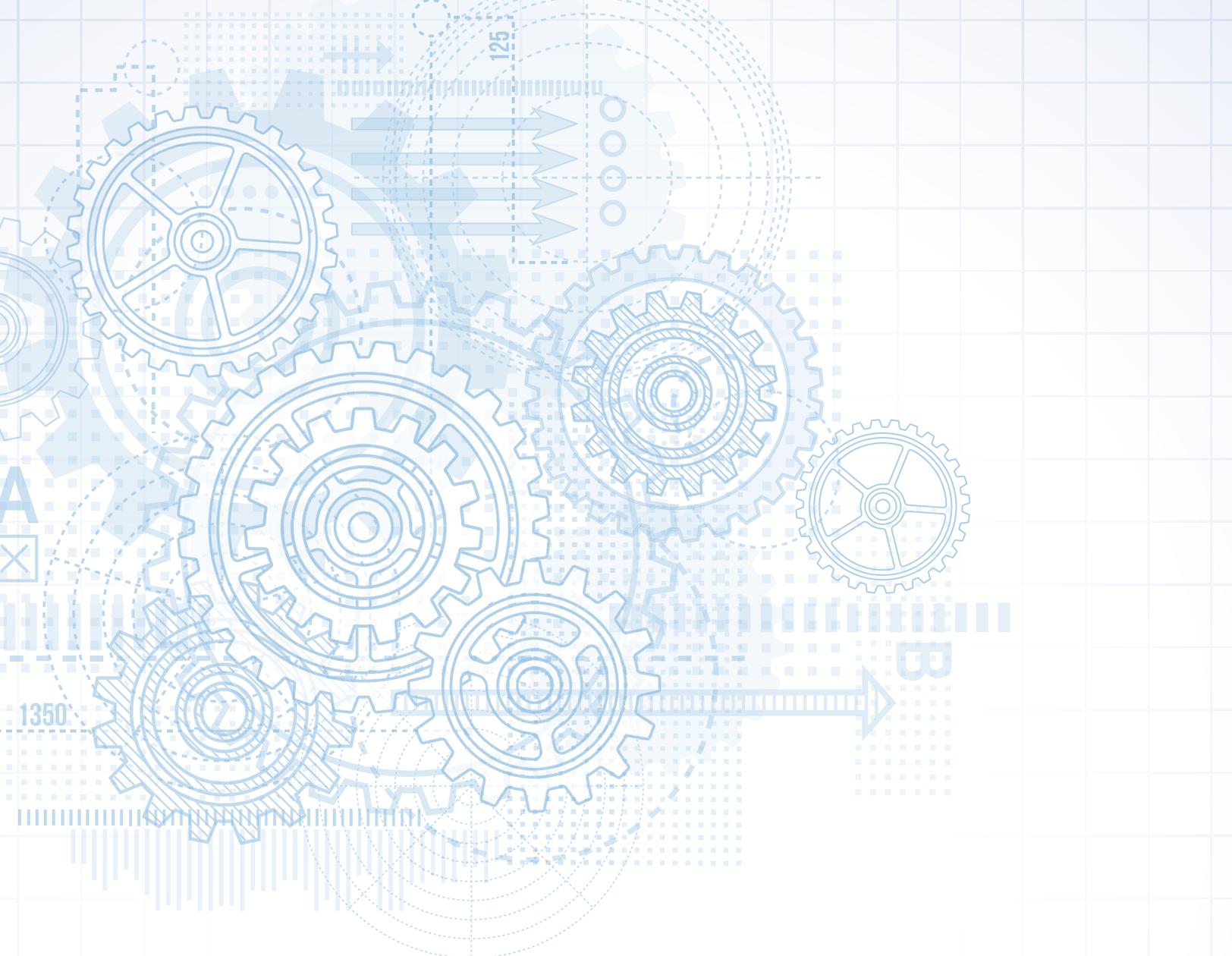
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