2020 Vision:

Progress in Preparing the Engineer of the Future

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Foreword

In 2004, the National Academy of Engineering published *Educating the Engineer of 2020: Visions of Engineering in the New Century* to encourage reform of undergraduate engineering education. That report inspired "The Engineer of 2020" project, two interrelated studies supported by the National Science Foundation. *Prototype to Production: Conditions and Processes for Educating the Engineer of 2020* (NSF-EEC-0550608) sought to benchmark undergraduate engineering education in the U.S. against the attributes the National Academy report believes future engineers will need in order to be effective. *Prototyping the Engineer of 2020: A 360-degree Study of Effective Education* (NSF-DUE-061871) used in-depth case studies to identify curricular, instructional, organizational features that support undergraduate engineering education that is well-aligned with the goals of the *Engineer of 2020*.[1]

This summary of findings from the Engineer of 2020 projects is intended to assist engineering deans, department heads, faculty, associations and professional societies, industry, and public policy makers in their efforts to improve undergraduate engineering education so that graduates are well prepared for careers in engineering. The study findings may also aid in the process of diversifying the engineering student population, and ultimately, the engineering workforce.

Acknowledgements

We are indebted to many individuals[2] and organizations, including the 31 participating institutions (see Appendix A) and their engineering students, faculty members, program chairs, and associate deans for undergraduate education who also shared their time, ideas, experiences, and views with us. We are also deeply grateful to the National Science Foundation, particularly to Sue Kemnitzer, Myles Boylan, and Russ Pimmel for their support throughout the Engineer of 2020 projects, and to Alan Cheville for his encouragement and support to produce this report.

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[1] A brief summary of the studies' samples and methods is given at the end of this report.

[2] See the inside front cover for the names of the many individuals who worked on the E2020 research team.

Report Design by Sneha Reddy

Executive Summary

In 2006, the National Science Foundation funded the *Prototype-to-Production* (P2P) study to assess current levels of alignment between undergraduate engineering program goals, curricula, and instruction and the goals detailed in the National Academy of Engineering's *The Engineer of 2020* (2004). To benchmark progress toward these goals, the P2P study sought to answer two questions:

- To what extent are undergraduate engineering programs providing educational experiences that prepare students to be the "engineers of 2020."

- To what extent do faculty and administrators in undergraduate engineering programs promote the attributes of tomorrow's engineers specified in NAE's report in their courses, programs, and co-curricular activities?

The findings summarized here are derived from surveys of 1,119 faculty members, 115 administrators (29 associate deans for undergraduate engineering and 86 program chairs), 5,249 undergraduate students, and 1,403 alumni in seven engineering fields (Bio-medical or Bio-engineering; Chemical Engineering; Civil Engineering; Electrical Engineering; General Engineering/Engineering Science; Industrial Engineering; and Mechanical Engineering) at 31 U.S. higher education institutions. We first focus on individual findings from the sections of this report and then close with some "big picture" conclusions.

Do Faculty and Administrators Share the National Academy's Vision?

- Faculty, associate deans and program chairs uniformly agreed with a number of the reports' propositions about the engineering workplace and educational goals, including the need to cultivate creativity, awareness of emerging technologies, systems thinking, and consideration of a broad array of relevant factors in solving engineering problems.

- Administrators and faculty members also tended to agree that programs should address ethics in multiple courses, prepare students to work across national and international boundaries, infuse design throughout the engineering curriculum, and encourage interdisciplinary learning (across engineering fields and including disciplines outside engineering). Administrators, however, typically expressed stronger support than faculty for these educational goals.

- Faculty members, however, expressed little support for making sustainability a major curricular focus or for emphasizing intercultural communication. They were less enthusiastic than associate deans about producing engineers who think like entrepreneurs and substantially less likely to see the value of a liberal arts curriculum. Faculty members are also more likely than program chairs to believe programs should leave leadership development to the co-curriculum. These findings identify important obstacles to developing engineers who are aware of global, cultural, and contextual differences that may affect the utility of their design and engineering solutions.

- While virtually all associate deans disagreed or strongly disagreed with the proposition that it is difficult to recruit more women students without sacrificing quality, only 60% of program chairs shared the associate deans' viewpoint, and nearly 20% of the chairs agreed with the proposition. When asked a similar question about recruiting racial/ethnic minority students, nearly three-quarters of the associate deans disagreed – but 70% of program chairs agreed – with the proposition that increasing minority enrollments would necessitate sacrificing academic standards; only 17% of chairs disagreed with it.

- Nearly 60% of the faculty respondents neither agreed nor disagreed with the statement that increasing student diversity (in general) would require sacrificing quality, although the reasons for this uncertainty are unclear. More information and research evidence on engineering student success, as well as more discussion among faculty and administrators about the benefits of diversity and how to achieve them, may be needed.

Progress toward the *Engineer of 2020* Goals

- While the seven engineering fields studied place somewhat different levels of emphasis on the four clusters of curricular emphases we assessed, the overall picture across these fields is substantially the same. These programs give the strongest curricular emphasis to design and professional skills; interdisciplinarity and professional values receive the least attention.

- Of the four clusters of curricular emphases assessed, program chairs reported the lowest emphasis on professional values. This set of survey items assessed curricular attention to the value of gender and racial/ethnic diversity in engineering, ethical issues in engineering practice, examination of one's personal beliefs and how they influence ethical decision making, and the importance of lifelong learning. There was little variation by engineering subfield, with means for each field indicating between slight and moderate emphasis on these topics.

- Graduating seniors corroborate these findings, indicating that their academic programs placed more emphasis on design and professional skills and the least on interdisciplinarity, ethical decision making, and the value of diversity (e.g., professional values). Similarly, the limited emphasis on developing those professional values suggests programs may be overlooking how beliefs and attitudes can affect engineering teams' interpersonal relationships, performance, and ethical decision-making in the workplace.

- Reports from faculty and instructors, as well as graduating seniors, suggest that engineering programs are not capitalizing on knowledge and skills from non-engineering disciplines in their efforts to develop students' design and professional skills. Alumni three years on the job, however, say that understanding and applying knowledge from fields outside engineering is important in their current work.

- Non-tenure track instructors give greater emphasis to the skills the National Academy (2004) says will be important for the 'engineers of 2020' than do their tenured and tenure-eligible colleagues. In their courses, instructors consistently give greater emphasis to design and problem-solving and the professional dimensions of engineering practice than do their tenured and tenure-track colleagues; these differences are not a function of the types of courses taught.

- Despite indications from both program chairs and faculty members that design is at the core of what engineers "do," design courses constitute a small fraction of the undergraduate program. While all the programs studied require a capstone design course, about half required first-year design course. Fewer than half of the programs offer a second-year design course, and less than a quarter require it. About a third do not offer third-year design, although 44% require it.

- According to faculty members' and instructors' reports on their own courses, design courses also carry much of the responsibility for teaching the kinds of non-technical knowledge and skills both ABET and the National Academy identify as critical to effective engineering. These courses emphasize professional skills even as they give students practice in applying foundational and technical knowledge. If design courses are not infused throughout the curriculum, students' development of needed professional skills – communication, teamwork, and project management – may be severely constrained.

- For most students, the design experience has a distinctly disciplinary – rather than multi- or interdisciplinary – focus. This finding suggest a substantial disconnect between some of the skills specified in *The Engineer of 2020* and the experiences that students are having in engineering design courses.

- Judging from the student assessment strategies faculty report using in their courses, faculty members send a strong and consistent message that the knowledge that can be assessed through tests and homework problems is what engineers value most. This message is at odds with that of the *Engineer of 2020* reports, which stress the integration of knowledge and the hands-on use of specific skills in engineering practice.

- Alumni (three years after graduation) rated three professional skills as highly to very highly important in their current work: written and oral communication skills, teamwork, and professional skills (e.g., knowing codes and standards, being on time, meeting deadlines). When looking back at their engineering programs, however, they recalled teamwork was more highly emphasized than were communication and professional skills.

- Alumni also rated leadership and project management skills as highly important in their present positions, but recalled the least emphasis on the development of these skills in their programs. They also tended to report that their current positions required more contextual awareness and ability to apply knowledge from multiple engineering and non-engineering fields than was emphasized in their undergraduate programs.

Promoting Students' Learning in Design Skills, Interdisciplinary Skills, and Contextual Awareness

- The formal curriculum is the surest route to promoting three of the knowledge and skill sets the 'engineer of 2020' needs: design skills, interdisciplinary skills, and contextual awareness (see Appendix B for descriptions of these measures). The instructional approaches used in their courses and students' co-curricular activities were much less influential, although the combinations of curricular, instructional, and co-curricular experiences that best explain differences in students' self-assessments of their learning varied by engineering field.

- A curriculum emphasizing "broad and systems perspectives" (e.g., systems thinking. understanding how non-engineering fields can help solve an engineering problem) had – by far – the strongest relationship with students' design skills, interdisciplinary competence, and contextual awareness across most disciplines.

- With moderate consistency, students enrolled in both first- and senior-year design courses that included students from non-engineering fields reported higher levels of design skills, contextual awareness, interdisciplinary skills, and leadership skills than students enrolled in less heterogeneous courses. Findings from our analyses suggest that engineering faculty may need purposefully to model interdisciplinary thinking and dispositions in courses so that students can understand what these skills are and how to practice them.

- Participation in humanitarian projects and in community service projects were most consistently related to reports of design skill levels, with the strongest relationship found among mechanical engineers.

- Engineering schools have yet to capitalize effectively on the co-curriculum to build "engineer of 2020" competencies. Engineering schools and programs should consider how to leverage co-curricular activities, particularly community service and humanitarian engineering projects, by creating intentional linkages between the formal curriculum (e.g., developing global awareness) and these informal learning experiences (e.g., engineering-related study abroad). Such linkages may be particularly effective in helping develop students' contextual awareness. These experiences, however, should not be a substitute for curricular attention to the role of social, cultural, environmental, and other factors in engineering problem-solving and practice.

Potential Barriers to Realizing the Vision of 2020

- Across the disciplines studied, 70% of engineering faculty members and instructors reported <u>no</u> formal preparation to teach before offering their first course – even when "preparation" is <u>very</u> broadly defined. Without some introduction to the array of teaching practices available to them, new faculty members are likely to emulate their own teachers, thus perpetuating a heavy reliance on lecturing. It is noteworthy, however, that more than 60% of faculty reported making a "significant effort to improve my teaching or one of my courses" during the 12 months preceding the survey.

- Predictably, program chairs and tenure-track faculty at doctoral-granting institutions are much more likely than their colleagues at bachelor's and master's institutions to report that the emphasis on research is greater than that accorded to teaching in both hiring and promotion decisions. Our findings also indicate, however, that only 8% of all faculty surveyed "disagreed" or "disagreed strongly" with the proposition that their engineering programs should reward excellence in teaching commensurate with research; 70% "agreed" or "strongly agreed" with that proposition.

- Program chairs and faculty members in doctoral institutions differ significantly in their assessments of the value placed on teaching and research in the faculty reward system. More discussion and greater transparency regarding what counts in hiring and promotion and tenure decisions may lead to better understandings of how such decisions are made and suggest ways in which a rebalancing of rewards might promote faculty activities and student learning outcomes consistent with the goals of *The Engineer of 2020*.

- The desire for greater attention to disciplinary interconnections has not substantially affected the undergraduate curriculum. Although faculty generally supported the idea of helping students consider multiple perspectives, formal opportunities for students to work with their peers from other engineering disciplines are not common, and design courses that involve students from fields *beyond* engineering are rare. For many engineering faculty, helping students make connections across fields and view the world from multiple perspectives seems to be confined within the boundaries of the engineering disciplines, if at all.

What does it all mean? Integrating the Findings

The *Prototype-to-Production* study found high levels of agreement among faculty and administrators regarding many of the propositions forwarded in the *Engineer of 2020*. Such agreement would presumably support the incorporation of topics such as creativity, ethics, interdisciplinary and systems thinking, cross-cultural competence, and diversity into undergraduate programs of study. Three of these topics received consistently strong endorsements from administrators and faculty alike – design, interdisciplinarity, and ethics, but curricular attention to these topics in practice does not appear to match the pronouncements. In a fourth area – diversity – significant disagreements among faculty members and administrators may underlie the minimal attention currently given to this topic in engineering programs. Combining findings from surveys of administrators, faculty, graduating seniors, and recent graduates leads to five conclusions of importance to the community of engineering educators, undergraduate students, employers, and professional societies and associations.

1. **When it comes to teaching design, practice lags pronouncement.**

   Engineering administrators and faculty strongly support the proposition that engineering programs should introduce hands-on design work in students' first-year and continue it throughout the undergraduate program. While program chairs report that their programs strongly emphasize design skills – including creativity and systems thinking, as well as skills such as defining a problem and developing a product – reports from faculty members on courses they regularly teach suggest that course-level attention to solving problems from real clients and producing a product is less common than claimed. Faculty and instructors report giving these topics "slight" to "moderate" attention, but tenured and tenure-eligible faculty give significantly less attention to these design skills than do fixed-term instructors.

   Graduating seniors corroborate the strong emphasis on defining design problems, generating and evaluating potential solutions, and creativity and innovation, but their opportunities to practice these skills through authentic design experiences appears limited. More than half of engineering programs did not require a first-year design course and 30% did not even offer one. Over half of the programs we studied do not offer a sophomore-level design course, and one-third do not have a third-year design course option. Thus, in many programs, students must wait until their senior year and capstone course before encountering "engineering in the real world." Design skills, of course, are emphasized to some degree outside design courses – faculty and instructors reported placing slight to moderate emphasis on design projects to assess students' learning in their required and elective courses. These elective and required engineering courses, however, rely much more heavily on homework and problem-solving exams to gauge student learning than on more active, hands-on forms of evaluation.

   Finally, it is also worth noting that design courses emphasize professional skills such as teamwork, communication, and project management much more than do required and elective engineering courses. Thus, one might reasonably argue that programs that do not offer design courses before the capstone experience are depriving their students of opportunities to learn about – and practice – critical workplace skills.

2. **Interdisciplinary learning experiences can promote design skills.**

   Analyses of the curricular topics that are most strongly associated with students' confidence in their design skills reveal that an emphasis on "broad and systems perspectives" is most consistently and most strongly related to students' self-reported skill levels. This curricular emphasis stresses systems thinking, understanding how non-engineering fields can help solve an engineering problem, applying knowledge from other fields to solve such problems, and understanding how an engineering solution can be shaped by environmental, cultural, economic, and other considerations. In addition, engineering sophomores and seniors who took their design courses with students from fields outside engineering reported significantly higher levels of contextual competence (understanding how the legal, political, cultural, environmental, and other contextual factors can shape engineering problems and their solutions) than students who took these courses with only students from their own programs or with students from more than one engineering discipline. Our findings suggest that faculty and administrators should assess, and when necessary, redress curricular inattention to interdisciplinary experiences; students who have ample opportunity to learn about non-engineering fields and to apply that knowledge in authentic design projects are likely to develop both greater creativity and stronger engineering design skills.

3. Current undergraduate programs are not capitalizing on engineering-relevant knowledge and skills in fields outside engineering.

Engineering faculty strongly supported the idea that students should be asked to make connections across disciplines, but their reports on their courses, as well as from graduating seniors and alumni, reveal only modest emphasis on cross-disciplinary thinking and connection-making in their courses. Faculty reported they give only slight to moderate emphasis to applying and integrating knowledge from multiple engineering and from non-engineering fields, and graduating seniors agreed with this assessment. Engineering graduates (three years after graduation), however, said systems thinking and applying knowledge from several fields to solve a problem were moderately to highly important in their work, and they noted gaps between their need to understand and apply such knowledge in their current position and their preparation for doing so.

For many engineering faculty, the desire to help students make connections across fields and to see the world from multiple perspectives appears to be narrowly interpreted and confined to the knowledge and topics covered in engineering disciplines. NAE's aspiration for an engineering profession that embraces "crossdisciplinary fertilization" and "openness to interdisciplinary efforts involving non-engineering disciplines" appears to be far from realization (2004, p. 50).

4. Are ethics really marginal to engineering practice?

Few of *The Engineer of 2020*'s propositions received as much strong and consistent support as the statement that engineering programs "should address ethical issues in multiple courses." And yet, when asked if it was their responsibility as a teacher to "encourage students to reflect on their values and how these might influence their work as engineers," engineering faculty were consistently non-committal. This sentiment is reflected in the courses these faculty members teach: tenured and tenure-eligible faculty reported giving "slight" attention to ethical issues in engineering practice while fixed-term instructors' ratings approached a "moderate" level of emphasis. Both groups, however, reported even less attention to asking students to examine their beliefs and how they might influence their ethical decision making. These ratings were the lowest of the more than 20 topic and skill areas assessed.

Graduating seniors' ratings largely mirror those of their faculty members. Students reported a moderate emphasis on ethical issues but less on examining their values and their potential impact on their decision making. Alumni three years on the job reported the importance of ethical issues in practice was "high" and the need to examine their beliefs and their impacts on decision making "moderate" to "high" in their current positions. They also reported substantial gaps between the emphasis on ethical issues in their jobs and that given to these issues in their undergraduate programs.

5. Diversity is a forgotten workplace reality and professional value.

Despite consistent concerns about the needs to diversify the engineering workforce and thoughtful discussions about the benefits of diversity to engineering learning, creativity, and productivity, many engineers hesitate because they believe that recruiting a diverse student population will require a trade-off between diversity and academic and engineering excellence. Associate deans are least inclined to hold this view, but a majority of program chairs assume that diversifying the engineering student population will require compromising on academic quality. Faculty members appear uncertain about the question.

These findings suggest the need for more, and more concerted, efforts to address questions about what it takes to recruit and retain a more diverse group of students. Research evidence challenges the widespread belief about the existence of a strong relationship between standardized admissions test scores and secondary school performance and subsequent collegiate academic success. This evidence also challenges the belief that recruiting a diverse student population will require a trade-off between diversity and excellence.

Greater attention to diversity in the undergraduate curriculum is also needed. Engineering alumni report that working with people who are different from them in terms of gender, race/ethnicity, or cultural backgrounds is moderately to highly important. They also report that their undergraduate programs, however, gave only moderate attention at best to such skills. Faculty and graduating seniors agreed that their programs placed very little emphasis on diversity as a professional value. These findings suggest that programs may be overlooking the need to help students understand how their beliefs and attitudes about others can affect their interpersonal relationships with their classmates today and with their colleagues tomorrow, as well as the evidence that diversity can enhance team performance and produce more effective solutions to complex problems.

Introduction

In 2004, the National Academy of Engineering published the first of two reports that sought to identify the knowledge, skills, and abilities that would be needed for engineers to succeed in the workplace of the year 2020. The initial report, entitled *Educating the Engineer of 2020: Visions of Engineering in the New Century* (2004), envisioned the workplace of the near future as global, diverse, and technologically fluid. To be successful, engineers would need the strong analytical skills that are the bedrock of engineering practice , but also a number of other attributes, including creativity; skills in communication, management, and leadership; high ethical standards and professionalism; agility, resilience, and flexibility; and an understanding of the complex societal, global, and professional contexts in which engineering is practiced. Accordingly, the engineer of 2020 would need a new kind of engineering education to develop this diverse set of interdisciplinary knowledge and skills.

In two studies that took the "Engineer of 2020" vision as a starting point, we sought to understand and assess the current capacity of undergraduate engineering programs to prepare engineers for this future. In the first study, Prototyping the Engineer of 2020, we collected information through national surveys from engineering students, recent graduates, faculty members, program chairs, and associate deans for undergraduate engineering at 31 institutions. Given the need to improve the recruitment and retention of undergraduate engineers, particularly from populations that have been underrepresented in engineering schools and the workforce, the study design had to provide information on the educational experiences of women, members of underserved minority groups, and community college transfer students entering four-year engineering programs. A summary of study findings and implications related to community college engineering students are discussed in a report entitled *America's Overlooked Engineers: Community Colleges and Diversity in Engineering Education.*

A second study, *Prototyping the Engineer of 2020* (P360), explored the organizational, cultural, curricular, and instructional features of engineering programs at six institutions, empirically identified as outperforming their peers in educating engineers who resembled in some ways the engineer of 2020. These detailed case studies relied primarily on interviews with engineering administrators, faculty members, and undergraduates to understand how their engineering programs promoted undergraduate students' development of design and problem-solving skills, interdisciplinary competence, and contextual competence. Like the P2P study, P360 also sought to understand how to improve the recruitment and retention of women and underrepresented minority students by identifying conditions, policies, and practices that appeared to support the achievement of these objectives. An overview of the research methods for both studies is included in Appendix A to this report. (More detailed information can be found at http://deepblue.lib.umich.edu/handle/2027.42/107462; survey instruments at http://deepblue.lib.umich.edu/handle/2027.42/107459.) This report is divided into four parts that summarize key findings from the P2P studies and highlight selected findings from the P360 case studies:

Part 1: Do Faculty and Administrators Share the Vision of the Engineer of 2020?

Part 2: Progress toward the Engineer of 2020 Goals

Part 3: Promoting Students' Design Skills, Interdisciplinary Competence, and Contextual Competence

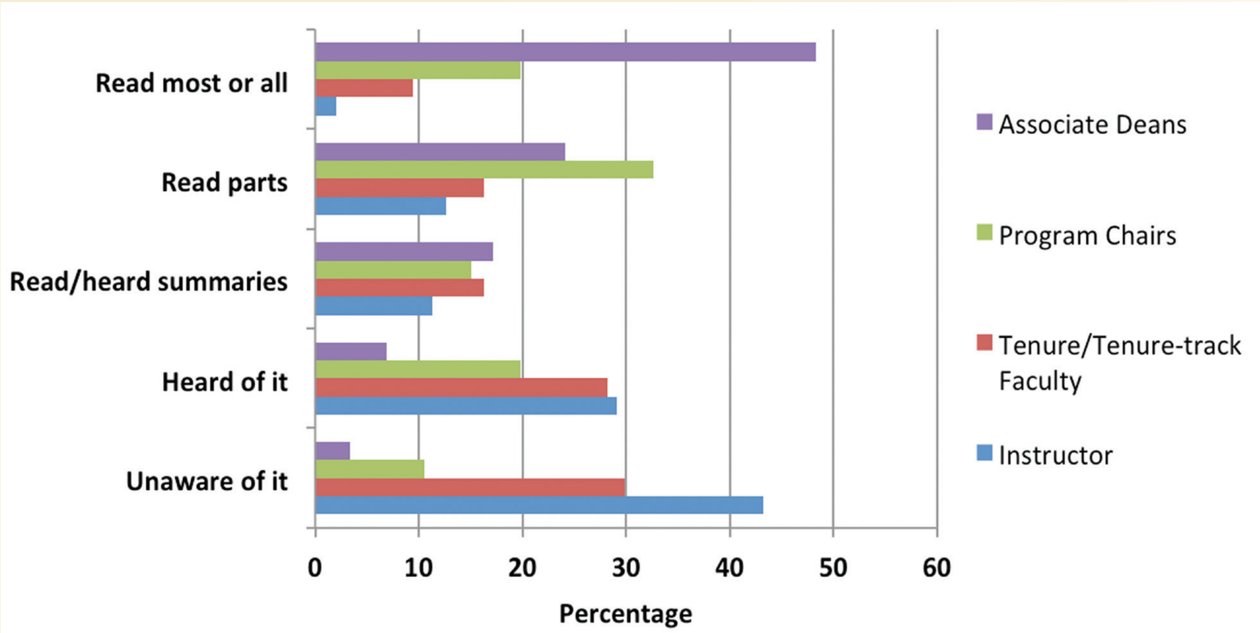
Part 4: Potential Barriers to Realizing the Vision of the Engineer of 2020

Part 1. Do Faculty and Administrators Share the Vision of *The Engineer of 2020?*

Part 1 of this report lays the foundation for later sections. It responds to the question "To what extent do engineering faculty and administrators buy into the educational propositions associated with NAE's vision of the "engineer of 2020?" Because program chairs and associate deans of undergraduate engineering education help shape decisions about instructional resources, curricula, and educational effectiveness, we consider their views of the vision of the "engineer of 2020" along with those of their faculty colleagues.

Figure 1.1 compares the levels of familiarity with *The Engineer of 2020* among four groups of engineering educators (associate deans, program chairs, tenure-eligible/tenured faculty, and non-tenure line instructors).

Figure 1.1: Familiarity with *The Engineer of 2020*



- More than 70% of associate deans and more than half of program chairs had read "part" or "most or all" of *The Engineer of 2020*.
- While nearly half of associate deans read "most or all" of the first *Engineer of 2020* report, less than a fifth of the program chairs did so.
- About 50% of tenured/tenure-track faculty and instructors were "unaware of" the report or had only "heard of it.

Although academic administrators appear to be knowledgeable about the NAE's report, awareness is considerably lower among faculty members and instructors.

Do Administrators' and Faculty Buy In to the Engineer of 2020 Vision?

Next we take a closer look at the extent to which the views of administrators and faculty align with the vision of *The Engineer of 2020*, regardless of their levels of familiarity with the report itself. Each group of educators responded to a set of survey questions based on propositions advocated in *The Engineer of 2020* (and, often, in other educational reform reports). Responses were provided using a 5-point scale (where 1 = Strongly Disagree, 3 = Neither Agree nor Disagree, and 5 = Strongly Agree).

We found high levels of agreement across the board (all group means = 4.0 or greater) regarding each of the following five propositions:

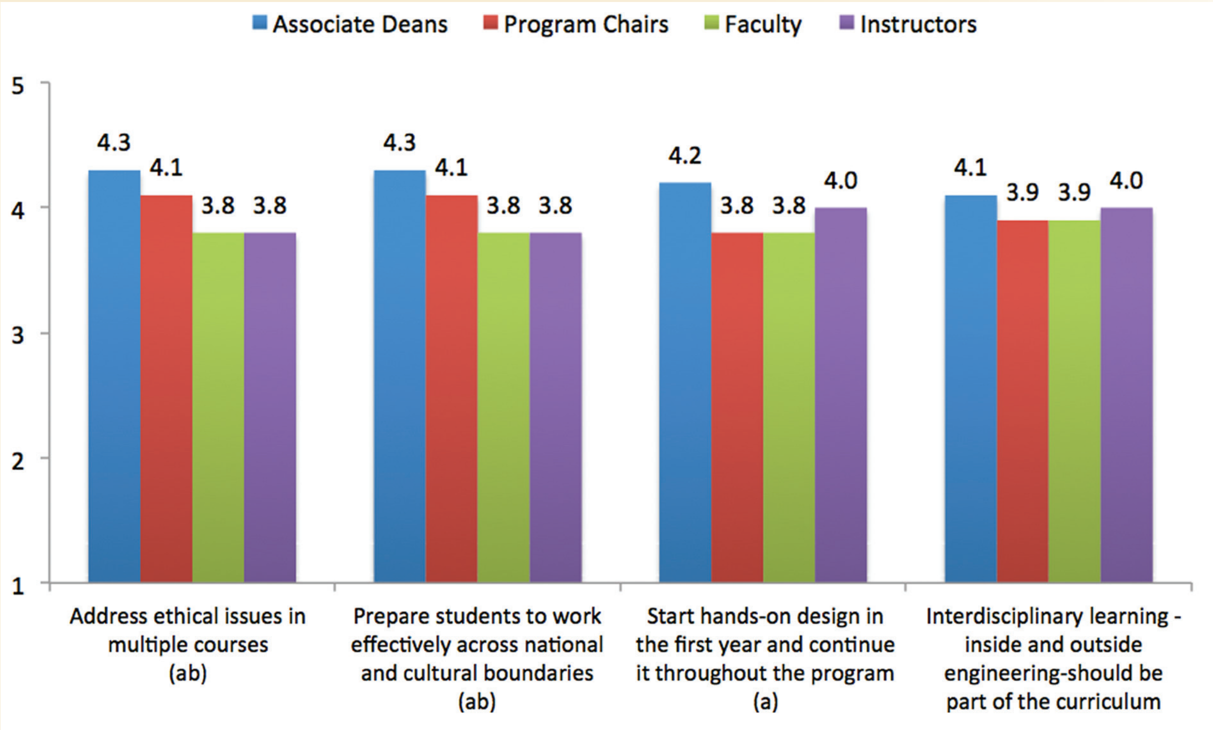
- The engineering workplace requires systems thinking.
- Engineering programs should periodically update the curriculum to ensure awareness of emerging technologies.

- Engineering programs should cultivate student creativity.
- Programs should teach learning strategies to help ensure students' academic success.
- Programs should teach students to consider all relevant factors in solving engineering problems.

High levels of agreement with these propositions presumably would lead to conditions conducive to curricular and instructional strategies to support these goals. In Part 4 of this report we look for such alignments in the undergraduate curriculum. As will be seen, beliefs and actions do not always align themselves.

Figures 1.2 and 1.3 reveal those educational propositions that received less support from administrators and faculty; group means ranged from 3.2 to 4.3 — roughly from "neither agree nor disagree" to "agree." Any statistically significant — and potentially meaningful for practice — differences in means between tenured/tenure-track faculty and program chairs and/or associate deans are noted.

Figure 1.2: Propositions with the Highest Levels of Agreement among Administrators and Faculty



Response scale: 1=Strongly disagree, 2=Disagree, 3=Neither agree nor disagree, 4=Agree, 5=Strongly agree

[a] Indicates statistically significant difference between Tenure-Track Faculty and Associate Deans

[b] Indicates statistically significant difference between Tenure-Track Faculty and Program Chairs

Four propositions (Figure 1.2) had group means above or close to 4 ("agree"):

- Ethical issues should be addressed in multiple engineering courses.
- Programs should prepare students to work across national and cultural boundaries.
- The engineering curriculum should engage students in hands-on design learning throughout the curriculum.
- Interdisciplinary learning - inside and outside engineering - should be part of the engineering curriculum.

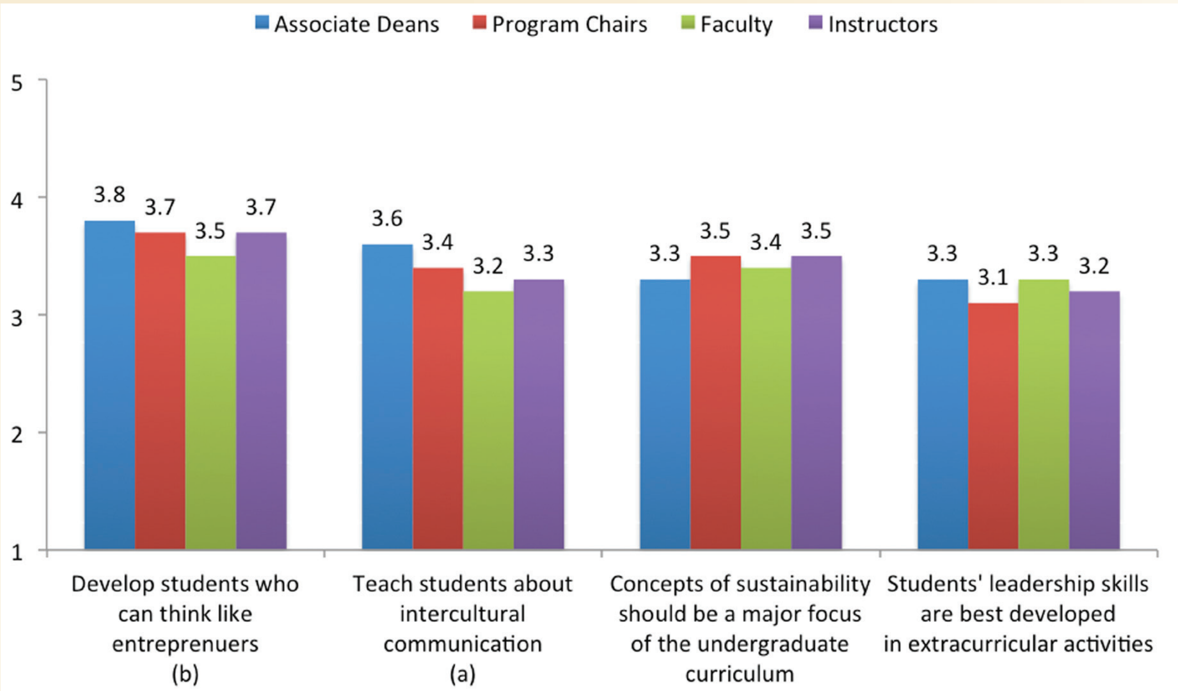
Notable differences are apparent between administrators and faculty for three of the four items (because we did not find signficant differences between instructors and faculty, we simplify results by making comparisons using tenured/tenure-track faculty only). To identify meaningful differences, we calculated effect sizes, which estimate the magnitude of the relationship between two means after adjusting for differences in group sizes and the variability of scores. Effect sizes are expressed in standard deviation units, using the pooled standard deviation between the two groups. We considered an effect size of .3 or more to be potentially meaningful for practice.[3] Using this criterion, the following differences between tenured/tenure-eligible faculty and one or both groups of administrators deserve attention. Despite chairs and faculty means being the same, the smaller number of chairs reduces the power in estimating faculty vs. chairs effect sizes.

Faculty expressed less agreement than administrators on the following propositions:

- Faculty agreed less than program chairs (effect size =.35) and associate deans (effect size = .58) that ethics should be taught in multiple courses.
- Faculty agreed less than program chairs (effect size = .48) and associate deans (effect size = .71) that programs should prepare students to work across national and cultural borders.
- Associate deans agreed more than faculty (effect size = .39) that design learning should be infused throughout the curriculum.

Figure 1.3 includes a set of four propositions about the undergraduate curriculum that received less support from administrators and faculty than the statements just listed; all group means were below 4.0 (“agree”).

Figure 1.3: Propositions for Which Levels of Agreement Are Lowest among Administrators and Faculty



Response scale: 1=Strongly disagree, 2=Disagree, 3=Neither agree nor disagree, 4=Agree, 5=Strongly agree

[a] Indicates statistically significant difference between Tenure-Track Faculty and Associate Deans

[b] Indicates statistically significant difference between Tenure-Track Faculty and Program Chairs

In general, faculty and administrators’ responses to these propositions were between “neither agree nor disagree” and “agree,” but some notable findings and differences among the groups emerged.

- Faculty agreed significantly less than associate deans that programs should teach students to think like entrepreneurs (effect size = .34).
- Faculty agreed more than program chairs that students’ leadership skills are best cultivated outside of class (effect size = .33).

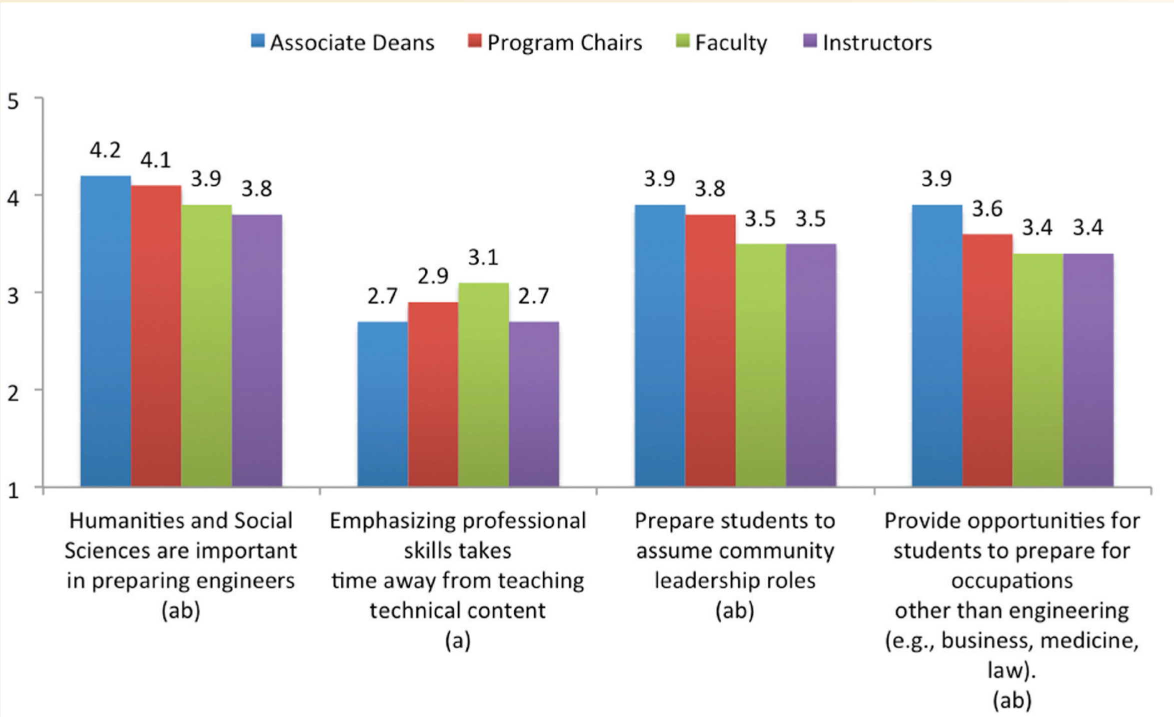
In addition to responding to NAE’s vision of the engineering workplace of the near future, entrepreneurship, sustainability, and working across national and cultural boundaries are increasingly emphasized by federal agencies such as the National Science Foundation. The nature of the opinions expressed by our survey respondents signals the need for sustained dialogue about the desirability of these educational proposals if reforms are expected.

[3] Cohen (1988) has given a widely (but not universally) accepted set of characterizations, where an effect size of 0.2 to 0.3 is considered “small,” 0.5 is “medium,” and 0.8 to infinity is a “large” effect.

Potential Barriers to Greater Curricular Diversity

The Engineer of 2020 argues for a broader view of engineering education. In this section we examine several potential barriers to achieving this vision. The first is the perception that non-engineering courses do not contribute to the preparation of engineers. When asked about the importance of humanities and social science courses in engineering education, administrators agreed significantly more than faculty that such courses are important (Figure 1.4). While the significant difference between faculty and program chairs is too small to be meaningful, the difference between the views of faculty and associate deans is substantial (effect size = .8). Positive views might become more prevalent if the value of general education courses in developing the knowledge and skill sets needed for the contemporary workplace could be demonstrated. Support from engineering faculty, and others, may grow if assessment evidence reveals that relevant learning outcomes are achieved in such courses.

Figure 1.4: Administrator and Faculty Views Posing Potential Barriers to Educational Propositions



Response scale: 1=Strongly disagree, 2=Disagree, 3=Neither agree nor disagree, 4=Agree, 5=Strongly agree
[a] Indicates statistically significant difference between Tenure-Track Faculty and Associate Deans
[b] Indicates statistically significant difference between Tenure-Track Faculty and Program Chairs

Another possible impediment to a broader curriculum is the belief that emphasizing professional skills reduces the time that can be spent teaching students essential technical skills. When ABET introduced the EC2000 accreditation criteria in the late 1990s, with its mandate to increase curricular attention to professional skills, many expressed concern that teaching such skills would diminish attention to (and students' development of) technical knowledge. Nearly a third (30%) of tenured and tenure-line faculty in this study agreed or strongly agreed with the statement that emphasizing professional skills takes time away from teaching technical content (graphic not shown). Some evidence suggests, however, that curricular emphasis on professional skills does not lead to reductions in fundamental math, science, and engineering sciences knowledge; scientific and technical foundations can be laid at the same time that instructors promote students' development of their communication, group, problem-solving, and contextual skills (Lattuca, Terenzini, and Volkwein, 2006). Engineering programs may be responding to accreditation requirements but some faculty still appear to question the wisdom of the accreditation criteria and recent reports that stress the need for greater emphasis to professionalism and practice (e.g., Sheppard, Macatangay, Colby, & Sullivan, 2008).

In addition to its assertion that a broad array of knowledge and skills are needed to understand and solve complex engineering problems, the *Engineer of 2020* report argues that engineering programs should prepare engineers who view themselves as global citizens and who are prepared to be leaders not only in business but in public service. It also envisions a future in which an engineering degree **is a valued path to success in jobs beyond engineering.** We framed two propositions to assess the popularity of these views.

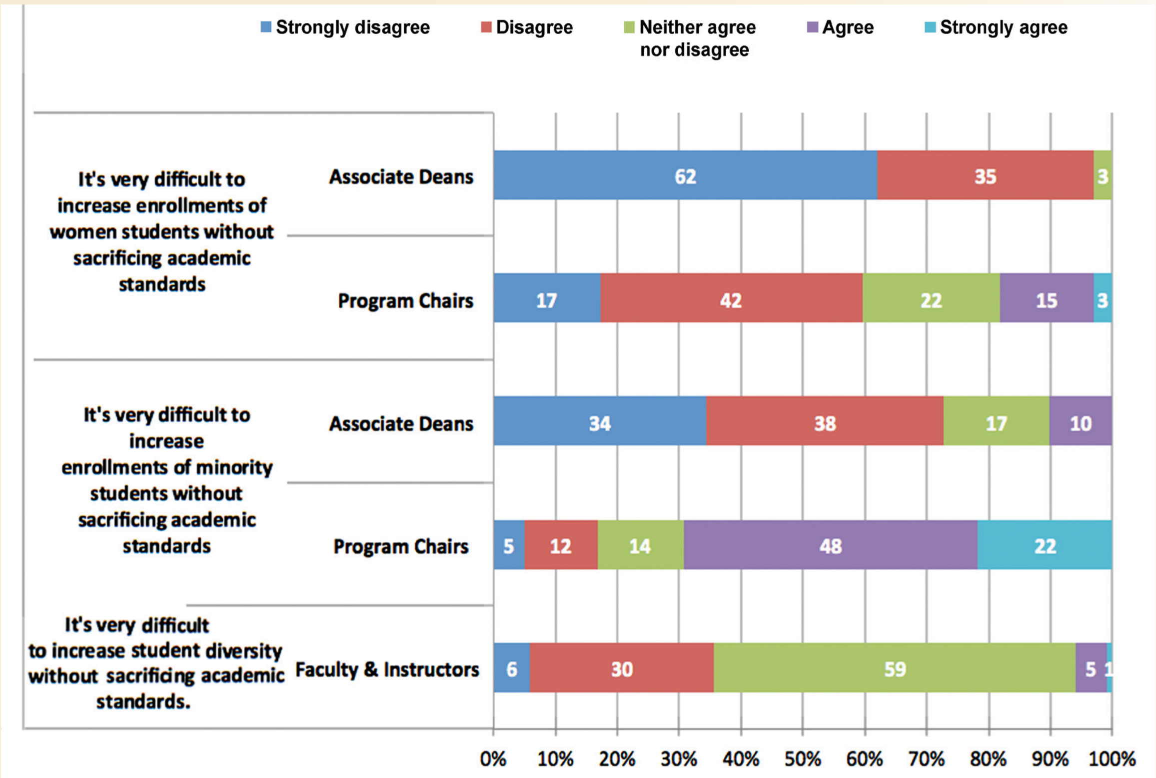
- We found modest levels of support among administrators for the proposition that engineering programs should prepare students to assume leadership roles in their communities (mean for associate deans = 3.9; program chairs = 3.8); faculty were significantly and substantially less likely to agree that programs should prepare students to assume leadership roles in their communities, compared to associate deans (effect size = .40) or program chairs (effect size = .31).

- Associate deans tended to agree that engineering programs should provide opportunities for students to prepare for careers outside engineering, such as law or medicine. Tenured and tenure-track faculty members, however, agreed significantly and substantially less with this proposition than associate deans (effect size = .55).

Potential Barriers to Greater Student Diversity

Finally, because recent reports have emphasized the need to diversify the engineering workforce, we asked administrators and faculty to respond to questions about the perceived trade-off between diversity and academic quality (Figure 1.5).

Figure 1.5: Faculty and Administrators' Perceptions of Goals of Increasing Student Diversity



Response scale: 1=Strongly disagree, 2=Disagree, 3=Neither agree nor disagree, 4=Agree, 5=Strongly agree

- Nearly all associate deans (97%) disagreed or strongly disagreed with the proposition that it is difficult to recruit more women students without sacrificing quality.

- Nearly 60% of program chairs also disagreed or strongly disagreed with this statement; about one-fifth neither agreed nor disagreed while 18% agreed.

When asked a similar question about the recruitment of minority students, we found much more variation among administrators.

- Nearly three-quarters of associate deans disagreed that there would be a trade-off between academic standards and higher enrollment of minority students, and only 10% agreed.

- In contrast, 70% of program chairs' agreed that increasing minority enrollments would necessitate sacrificing academic standards; only 17% disagreed and 14% neither agreed nor disagreed.

Faculty responded to a different statement regarding the difficulty of increasing student diversity (in general) without sacrificing academic standards. Because faculty and instructors gave very similar responses, these are combined in Figure 1.5, which indicates that:

- Nearly 60% of faculty members neither agreed nor disagreed with this statement. This finding might reflect the lack of specificity about what increased diversity entailed, or it might reveal their lack of information and knowledge about the impact of diversifying the engineering student population.

- Just over a third of faculty disagreed or strongly disagreed that greater student diversity would require a reduction in standards.

These differing views of the impact of greater student diversity suggest the need for more information-sharing and discussion among faculty and administrators. Analyses of an institution's admissions and registrar's databases can provide information on the qualifications of an institution's applicant and admitted student pools, as well as the academic achievement of its engineering undergraduates. Such discussion should include attention to the limited power of measures such as SAT/ACT scores for predicting student learning outcomes. A critical examination of admissions standards is also warranted in light of growing evidence that students' academic profiles upon entrance to college are not necessarily predictive of their learning outcomes. Certain educational experiences (such active learning strategies and studying with peers) enhance learning among all students, but are especially beneficial for first-generation and historically underrepresented students (Pascarella, Pierson, Wolniak, & Terenzini, 2004; Terenzini, Springer, Pascarella, & Nora, 1995). There is also evidence that students who enter college scoring below average on measures of cognitive ability and learning orientation experience higher gains on these measures than students with more traditional profiles (Cruce, Wolniak, Seifert, & Pascarella, 2006; Kuh, Cruce, Shoup, Kinzie, & Gonyea, 2008).

Finally, more than self-esteem is at risk when women and students of color in engineering programs sense that some faculty and program chairs lack confidence in their abilities. A substantial body of research demonstrates that awareness of negative beliefs about one's own identity group can depress the academic performance of women and minority students. Such an experience is particularly damaging to students who are the most academically capable (for example, see Aronson, Fried & Good, 2002; Sekaquaptewa, Waldman, & Thompson, 2007; Steele, 1997; Murphy, Steele, & Gross, 2007).

* * * * *

In this part of our report, we assessed administrators' and faculty members' espoused levels of support for the ideas advocated in reports like *The Engineer of 2020* to reveal potential alignments and possible hurdles to achieving this vision. When combined, these findings suggest that some administrators, and more faculty members, hold to traditional views of undergraduate engineering education and who and what makes a good engineer. Most faculty and administrators agreed that programs should cultivate student creativity, teach about emerging technologies, encourage students to consider all relevant factors when solving engineering problems, and support students' efforts by teaching learning strategies. They did not, however, express much support for making sustainability a major curricular focus, teaching students to work across national and international boundaries, stressing intercultural communication, or teaching ethics in multiple courses. Finally, while the great majority of associate deans disagreed that increasing student diversity would reduce educational quality, the majority of program chairs perceived greater trade-offs and faculty appeared largely uncertain. Efforts to expand the undergraduate curriculum and diversify the student population must recognize and address these variations in views if they are to prepare students for the workplace of 2020 while simultaneously ensuring that all students' have positive, equitable, and effective educational experiences.

In the next section of this report, information about program and course emphases, faculty engagement in professional development, and perceptions of the reward system provide additional information about the state of engineering education that can catalyze dialogues about the future of engineering education.

Part 2: Progress toward *The Engineer of 2020* Goals

In the previous section, we examined engineering administrators' and faculty members' levels of agreement with the educational propositions advocated in the *Engineer of 2020* reports. Here we look for manifestations of that support in the form of alignment between the educational propositions of *The Engineer of 2020* and the current practices of engineering programs.

We first assess alignments between the educational practices called for in educational reforms and the content and instructional methods found in engineering courses and programs. We next examine levels of engineering faculty members' preparation for teaching before coming to academia and participation in professional development activities that might help engineering faculty meet the demands for curricular and instructional change to better prepare students for the engineering workplace. Finally, we consider perceptions of the faculty reward system that might present a support or barrier to achieving educational reforms.

Are Programs Educating the "Engineer of 2020"? Alignment between the Vision and the Curriculum

The *Engineer of 2020* reports recommended major shifts in thinking about engineering education and identified new knowledge and skills that students need for work in a dynamic, technologically fluid, team-intensive, and global workplace. In Part 1, we reported on faculty members' and administrators' buy-in to the vision of the "engineer of 2020," finding strong support for some ideas, but more mixed support for others. Here, to benchmark progress toward the educational vision of *The Engineer of 2020*, we report on what is actually emphasized in engineering courses (based on survey responses collected in 2009), clustering curriculum topics into four knowledge and skills sets: Design Skills, Interdisciplinary Competence, Contextual Competence, and Professional Skills.

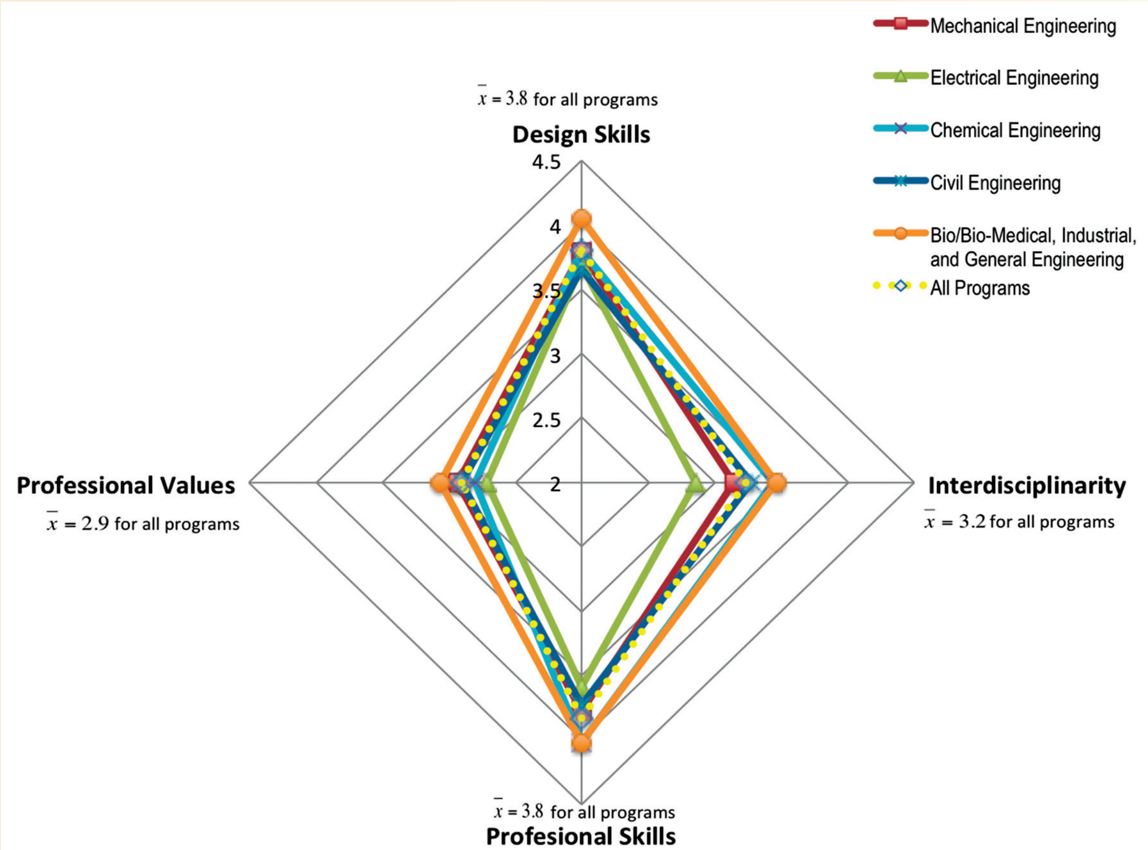
- We begin with the reports of engineering program chairs to provide a picture of engineering curricula as a whole.
- Next, reports from engineering faculty and instructors regarding the topics that they emphasize in their undergraduate courses provide information on the degree to which faculty teach the knowledge and skills sets associated with E2020.
- Finally, we examine the undergraduate curriculum from the students' perspective, arraying the topics that senior-year students perceived as most – and least – emphasized in their engineering programs.

Curricular Emphases at the Program Level: Reports from Program Chairs

Engineering program chairs responded to a set of survey items asking them to characterize their engineering programs as a whole, focusing in particular on topics associated with the knowledge and skill sets that figure prominently in *The Engineer of 2020* and in similar calls for engineering education reform. Chairs responded to these questions using a 5-point scale where 1=Little/No emphasis, 2=Slight, 3=Moderate, 4=Strong, and 5=Very strong emphasis. To simplify our presentation, we rely on empirically derived scale scores for survey items that are statistically and conceptually related. These scales represent the following four curricular emphases: Design and Problem Solving, Interdisciplinarity, Professional Values, and Professional Skills. (See Appendix B for the survey items comprising each scale and the scale reliabilities.). Because we had small samples of program chairs in the fields of industrial, biomedical/bioengineering, and general engineering, we combined the program chairs' responses for these fields, which are linked by an emphasis on interdisciplinarity. Industrial engineering chairs comprise 60% of respondents in this group.

Figure 2.1 depicts the relative emphases placed on each of these four knowledge and skill sets for the engineering disciplines we studied and for all of these disciplines combined (the dotted yellow line). The most notable finding here is that while there are some differences in the emphasis that a particular discipline places on a given knowledge and skill set, the overall picture across the fields is one of substantial similarity. This correspondence may reflect the influence of program accreditation, which requires that all engineering programs teach the same set of competencies (although programs may choose to emphasize particular competencies in line with their educational missions and objectives).

Figure 2.1: Program Chairs' Reports of Program Emphases by Field and for All Fields Combined



Scale: 1=Little/No emphasis, 2=Slight, 3=Moderate, 4-Strong, and 5=Very strong emphasis

As Figure 2.1 shows, program chairs reported that their programs give the strongest curricular emphasis to Design and Professional Skills.

- The **Design Skills** scale (mean for all fields = 3.8) includes measures of curricular emphasis on creativity and innovation, systems thinking, and emerging engineering technologies, as well as on the development of skills such as defining design problems, generating and evaluating a variety of ideas about potential problem solutions, solving problems for real clients, and developing a product. Engineering subfield means ranged from 3.7 to 4.0, suggesting considerable uniformity across fields.

- The **Professional Skills** scale (mean for all fields = 3.8) measured curricular attention to teamwork, oral and written communication, leadership, and project management. Of these, teamwork and communication skills are most strongly emphasized (not shown in graphic); this circumstance likely reflects the emphasis on these competencies in the EC2000 accreditation criteria. Means ranged from 3.6 to 4.0 for the engineering subfields.

- The combined fields of biomedical/bioengineering, Industrial and general engineering appear to place greater emphasis on **Design** and **Professional Skills**, but the small number of programs in our sample suggests some caution in interpretation of these findings.

According to program chairs, interdisciplinarity and professional values receive less emphasis in the curriculum than design and professional skills.

- Overall, program chairs reported a moderate emphasis on **Interdisciplinarity**, although electrical engineering stands out as the only field with a mean less than 3.0. The **Interdisciplinarity** scale is composed of items assessing the extent to which a program stresses understanding how multiple engineering disciplines contribute to a problem solution, as well as integrating and applying knowledge from various engineering disciplines to solve an engineering problem. The scale also measures curricular emphasis on understanding how fields *outside* engineering might contribute to engineering problem-solving and making explicit connections to knowledge and skills from fields other than engineering.

- A closer look at the individual items comprising this scale (graphic not shown) reveals that programs place only a slight to moderate emphasis on the contributions of non-engineering fields and a slightly higher, but still moderate, emphasis on making explicit connections to non-engineering fields. Interdisciplinarity in undergraduate engineering programs appears to be focused on linkages among engineering subfields rather than expanding the range of disciplines that can be engaged when solving engineering problems.

- Of the four clusters of curricular emphases assessed, program chairs reported the least emphasis on **Professional Values**. These survey items assess curricular attention to the value of gender and racial/ethnic diversity in engineering, ethical issues in engineering practice, examination of one's personal beliefs and how they influence ethical decision making, and the importance of lifelong learning. There was also little variation by subfield, as means ranged from 2.7 to 2.9.

- A review of the items comprising the **Professional Values** scale reveals that the mean for all programs for curricular emphasis on "the value of gender and racial/ethnic diversity in engineering" is 2.8 (graphic not shown). The only item with a lower mean (2.6) is "examining beliefs and values and how they influence ethical decision making." These findings suggest that programs are stressing professional skills, such as communication and teamwork, but perhaps overlooking beliefs and attitudes that can affect team interpersonal relationships, performance, and ethical decision making in the workplace.

Curricular Emphases at the Course-Level: Reports from Engineering Faculty and Instructors

More than 1,100 engineering faculty members and instructors responded to our surveys, providing information on the curricular topics and skills that they emphasize in their courses (using the same 5-point scale as program chairs). The focus of this section is, again, on the competencies of design and problem-solving, professional skills, interdisciplinarity, and professional values, but each is examined in greater detail. Findings are also reported for two faculty groups: 1) tenured/tenure-track faculty (n=987), and 2) full-time, fixed-term instructors (n=132). For discussion purposes, any statistically significant — and potentially meaningful for practice — differences in means between tenured/tenure-track faculty and instructors are noted as effect sizes.[4]

Figure 2.2 shows a fairly consistent pattern of course-level emphasis on **Design Skills** by tenured/tenure-line faculty and instructors. This consistency suggests faculty members and instructors are tending to emphasize the same skills as elements of the design process. Moreover, the level of emphasis is consistent with the overall level of emphasis at the program-level reported by the chairs (Figure 2.1).

- Instructors and faculty members report moderate to strong levels of attention (in a course they regularly teach) on creativity and innovation, defining design problems, systems thinking and emerging technologies.

- While tenured and tenure-line faculty appear to report less emphasis on the latter stages of the design process than do instructors, only one of the differences in means appeared both statistically and practically important: instructors report significantly more emphasis on solving design problems from real clients than do tenured/tenure-line faculty.

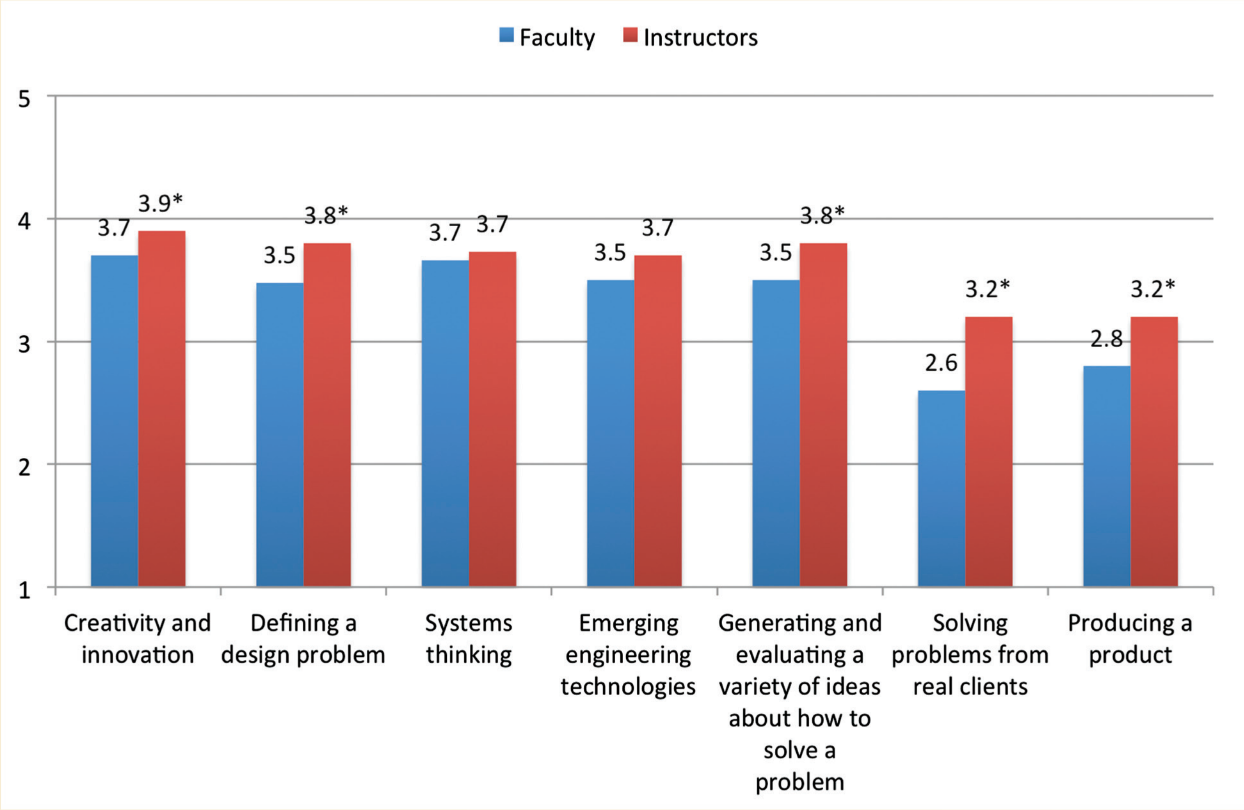
Faculty and instructors reported a moderate to strong emphasis on **Professional Skills** in their courses (Figure 2.3). (These reports align with those of program chairs who report similar levels of attention to Professional Skills in their undergraduate programs as a whole.) There are, however, statistically significant and practically meaningful differences between the levels of attention faculty and non-tenure line instructors give to all but one of these skills in their courses.

- In all cases, instructors report significantly more attention to these skills than tenured/tenure-line faculty. The only trivial difference between these groups is in their emphasis on written and oral communication skills.

- Instructors report giving noticeably more attention to developing students' leadership skills (effect size = .58), professional skills (e.g., knowing codes and standards, being on time, meeting deadlines; effect size = .50), project management skills (effect size =.45), and working effectively in team (effect size = .45).

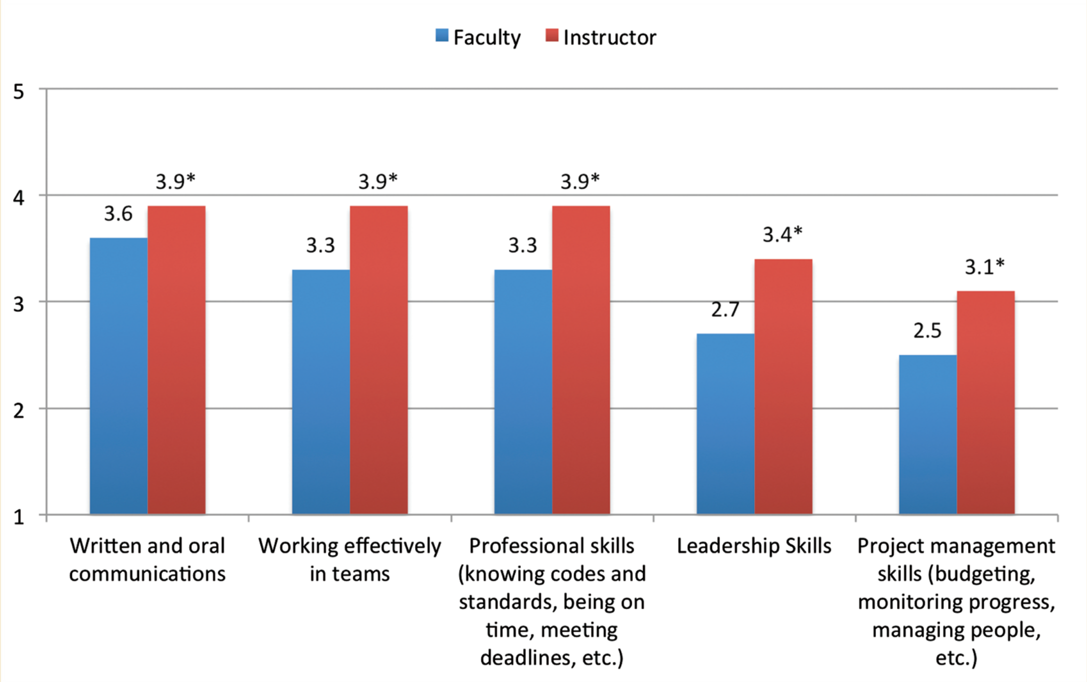
4 To identify practical differences in mean scores between faculty and instructors' means, we calculated effect sizes, which estimate the magnitude of the relationship between two means after adjusting for differences in group sizes and the variability of scores within groups. Effect sizes are expressed in standard deviation units. Throughout this report, an effect size of .3 or more is considered to be practically meaningful.

Figure 2.2: Faculty Members' and Instructors' Reports (Means) of Course Emphasis on Design Skills



Scale: 1=Little/No emphasis, 2=Slight, 3=Moderate, 4-Strong, and 5=Very strong emphasis
p < .05

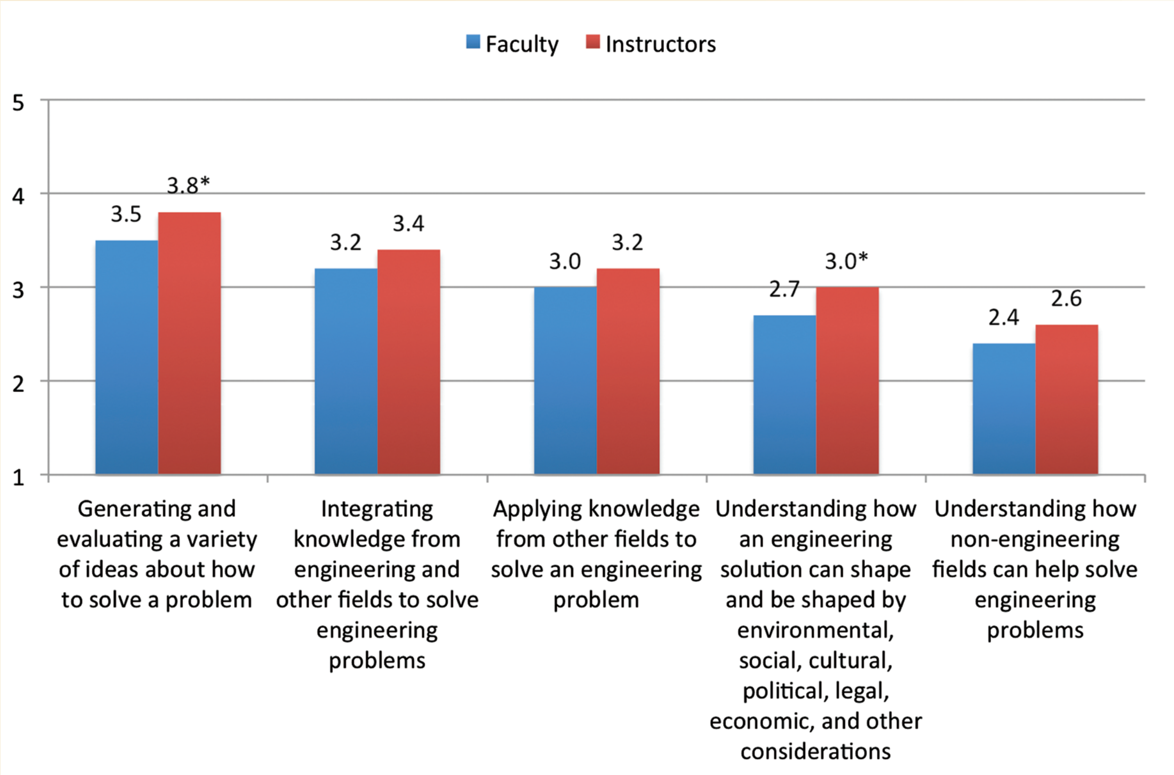
Figure 2.3: Faculty Members' and Instructors' Reports (Means) of Course Emphasis on Professional Skills



Scale: 1=Little/No emphasis, 2=Slight, 3=Moderate, 4-Strong, and 5=Very strong emphasis
p < .05

It appears that instructors are significantly and substantially more likely to emphasize the professional dimensions of engineering practice in their courses than their tenured and tenure-line colleagues, and our analyses (not shown) indicate that these differences are not due to differences in the types of courses taught.

Figure 2.4: Faculty Members' and Instructors' Reports (Means) of Course Emphasis on Interdisciplinarity



Scale: 1=Little/No emphasis, 2=Slight, 3=Moderate, 4-Strong, and 5=Very strong emphasis
$p < .05$

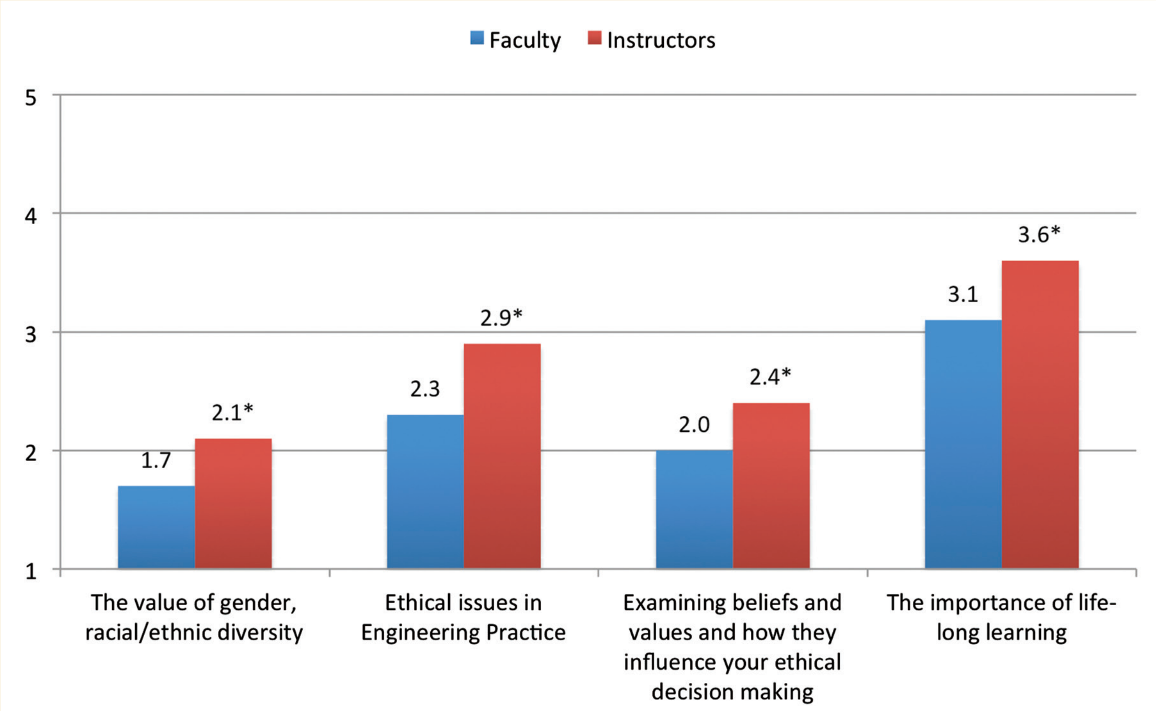
Figure 2.4, relative to earlier figures, indicates that there is less emphasis on interdisciplinarity in engineering courses than on design and professional skills, and these reports of a generally moderate level of emphasis align closely with reports from engineering program chairs (Figure 2.1). While there are statistically significant differences for two of the course emphases, neither is meaningful in practice.

- Faculty and instructors report moderate levels of emphasis on integrating knowledge from engineering and other fields to solve engineering problems, and on applying knowledge from other fields to solve engineering problems.
- Both groups report slight to moderate levels of emphasis on understanding how engineering solutions can be shaped by environmental, political, social and cultural contexts or considerations, and on how non-engineering fields can contribute to the solutions of engineering problems.

Given these reports of somewhat less emphasis on non-engineering fields and contextual factors, it appears that engineering courses are giving greater attention to integrating knowledge from multiple *engineering* fields, which is consistent with reports from program chairs. This finding supports the claim that undergraduate engineering programs tend to define "interdisciplinarity" as connecting the knowledge and skills associated with the different engineering subfields rather than as incorporating what might be learned from other fields in the sciences, social sciences, and humanities.

Faculty and instructors emphasize **Professional Values** the least (Figure 2.5), and this finding is consistent with the overall characterization of engineering programs provided by program chairs (Figure. 2.1). We again found statistically significant and practically meaningful differences between the faculty and instructors for all the course topics assessed.

Figure 2.5: Faculty Members' and Instructors' Reports (Means) of Course Emphasis on Professional Values



Scale: 1=Little/No emphasis, 2=Slight, 3=Moderate, 4-Strong, and 5=Very strong
p < .05

- As shown in Figure 2.5, faculty and instructors placed moderate to strong emphasis in their courses on "the importance of life-long learning." Instructors, however, were notably more likely to stress this ABET competency in their courses (effect size = .41).

- Both faculty and instructors gave the least emphasis to teaching about the value of gender and racial/ethnic diversity in engineering. Instructors reported placing slight emphasis on this topic, but reports from tenured and tenure-line faculty did not even reach this level of emphasis. The effect size for this difference (.40) is noteworthy, approaching as it does a half standard deviation.

- Instructors gave significantly more attention to "ethical issues in engineering practice" than tenured/tenure line faculty, although the level of emphasis for both groups can be characterized as between slight and moderate. The effect size for this difference can is substantial (.52).

- Faculty and instructors reported even less emphasis on examining how values and beliefs influence ethical decision-making (effect size = .35). In Part 1, we saw that nearly three-quarters of faculty agreed or strongly agreed that engineering education should address ethical issues in multiple courses (Figure 1.2). Our surveys, however, reveal that the attention paid in courses to ethical concerns barely reaches a "moderate" level.

It is noteworthy that – without exception – instructors report giving greater emphasis than their tenured or tenure-track colleagues to the engineering skills the National Academy says will be important for engineers of the future.

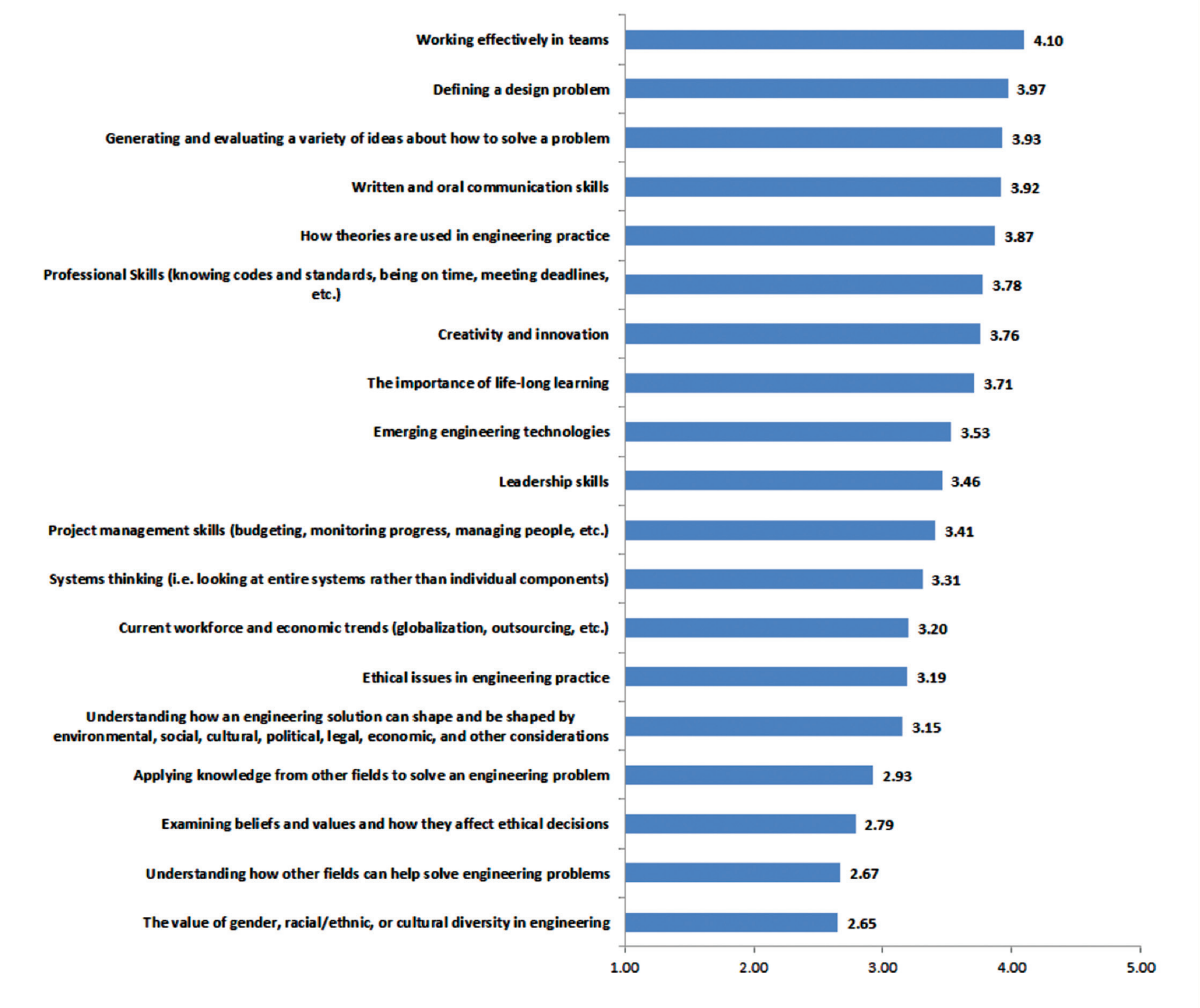
The Student Perspective: Curricular Emphases in My Engineering Program

Educators often distinguish the "intended" curriculum from the "received" curriculum as it appears to students; Figure 2.6 depicts the latter. Discrepancies between what students' perceive and what faculty intend should *not* be interpreted as challenges to the veracity of the reports from either group; rather, educators can use different reports to both cross-check findings and to assess whether the level of emphasis on important knowledge and skills is picked up by students.

In Figure 2.6, the bars above the midpoint of the scale (3.0) identify the curricular topics that senior students reported to be moderately to strongly emphasized in their engineering programs. Note that with the exception of the second and third bars, which focus on design, the remaining bars represent workforce knowledge and skills. From the students' perspective, engineering programs are giving substantial attention to many of the topics and skills advocated by employers and reformers who call for increased preparation for engineering practice.

The bars below the midpoint of 3.0 in Figure 2.6 identify engineering topics and skills that students report are being emphasized slightly to moderately in their major programs. All the topics and skills associated with interdisciplinary and contextual competence lie here. Engineering seniors reported slight to moderate emphasis in their programs on applying knowledge from different fields to solve an engineering problem; examining personal values and how these might affect one's ethical decisions; understanding how other fields can help solve an engineering problem; and the value of race/ethnicity, gender, and cultural diversity in engineering.

Figure 2.6: Senior Engineering Students' Reports (Means) of Curricular Emphases in Their Engineering Program



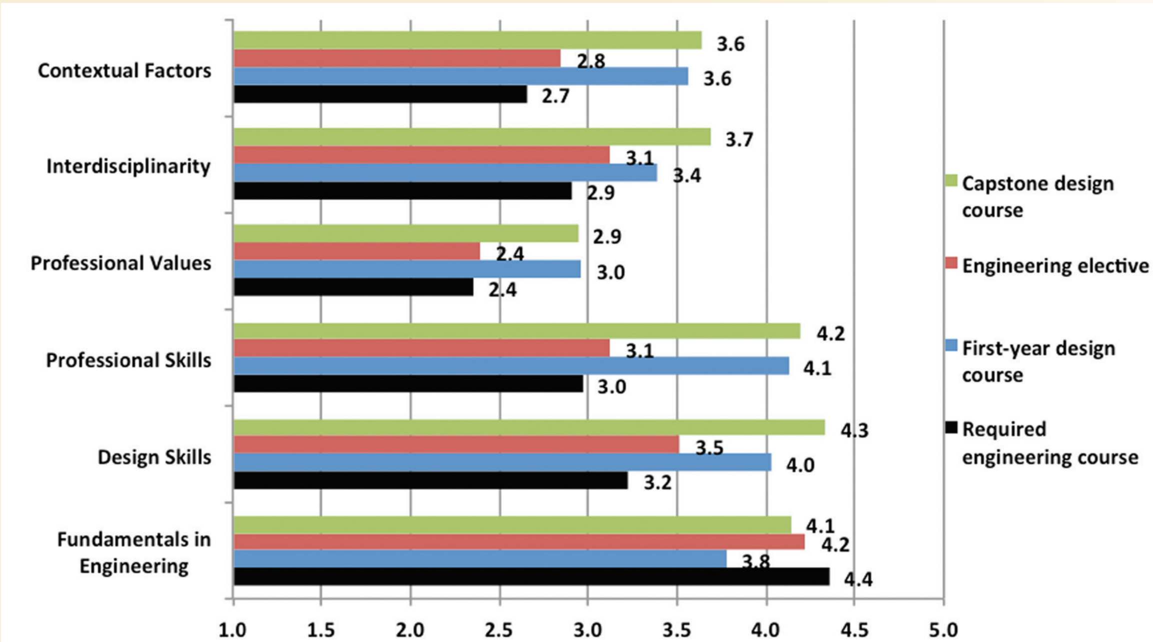
Scale: 1=Little/No emphasis, 2=Slight, 3=Moderate, 4-Strong, and 5=Very strong

Curricular Emphases across the Undergraduate Curriculum: Variations across Course Types

Our presentation thus far may lead one to ask whether curricular emphases vary according to the type of course on which a faculty member or instructor reported. They do. In this section, we focus on how curricular topics and assessment strategies vary among design courses, required engineering courses, and elective engineering courses. The question for engineering educators is whether the findings reveal their view of the optimal curriculum design.

Figure 2.7 displays faculty members' reports of the topics and skills they emphasize in the type of course on which they reported for this study (a first-year design, capstone design, elective, or required engineering course). We added two additional variables to the four curricular emphases scales used in the analyses presented in the previous section. The Fundamentals in Engineering scale is a two-item measure that taps the curricular emphasis on 1) the application of math and science to engineering programs, and 2) how theories are used in engineering practice. The Contextual Factors variable is a single survey item that assessed the emphasis on understanding how an engineering solution can shape and be shaped by environmental, social, cultural, political, legal, economic and other considerations. In these analyses, we combined tenured/tenure-line and non-tenure track instructors to simplify the presentation of findings.

Figure 2.7: Faculty and Instructors' Reports (Means) of Curricular Topics Emphasized in Four Types of Undergraduate Engineering Courses



Scale: 1=Little/No emphasis, 2=Slight, 3=Moderate, 4-Strong, and 5=Very strong.
Note: Respondents could indicate a topic was "not applicable" for the course on which they reported. "Not applicable" responses were removed from the analysis.

Figure 2.7 indicates that faculty and instructors teaching first-year and capstone design courses are emphasizing many different kinds of knowledge and skills, and compared to those reporting on required and elective engineering courses, they gave more emphasis to:

- **Professional Skills**: Whereas those teaching design courses reported strongly emphasizing skills such as project management, teamwork, and communication, those teaching required engineering courses and elective engineering course gave moderate levels of attention to these professional skills.

- **Contextual Factors:** Faculty and instructors teaching first-year and capstone design courses placed moderate to strong emphasis on understanding how environmental, social, cultural, political, legal, economic, and other considerations shape engineering solutions – and vice versa. Those teaching required and elective engineering courses reported slight to moderate emphasis.

- At the same time, faculty and instructors reporting on capstone design courses appear to stress the application of fundamental skills almost as strongly as faculty and instructors reporting on required and elective engineering courses.

In programs where students are required to take only capstone design (and may not even have the option of taking a design course(s) earlier in their academic program), this late-stage, one-year emphasis on professional skills and contextual factors may disappoint students and employers alike. One study of more than 1,600 engineering employers revealed that supervisors rated effective communication, use of engineering tools, teamwork, and professional ethics – along with fundamental and engineering problem-solving skills – as the most important engineering skills they look for in job applicants (Lattuca et al., 2006). Similarly, in-depth case studies of six engineering firms by Anderson, Courter, McGlamery, Nathans-Kelly, and Nicometo (2010) found that even though their workplace cultures differed, engineers tended to view their work as problem solving done in formal teams or through informal collaborations. They cited clear communication as the most important workplace skill and budgets and time limitations as the most significant constraints on their work.

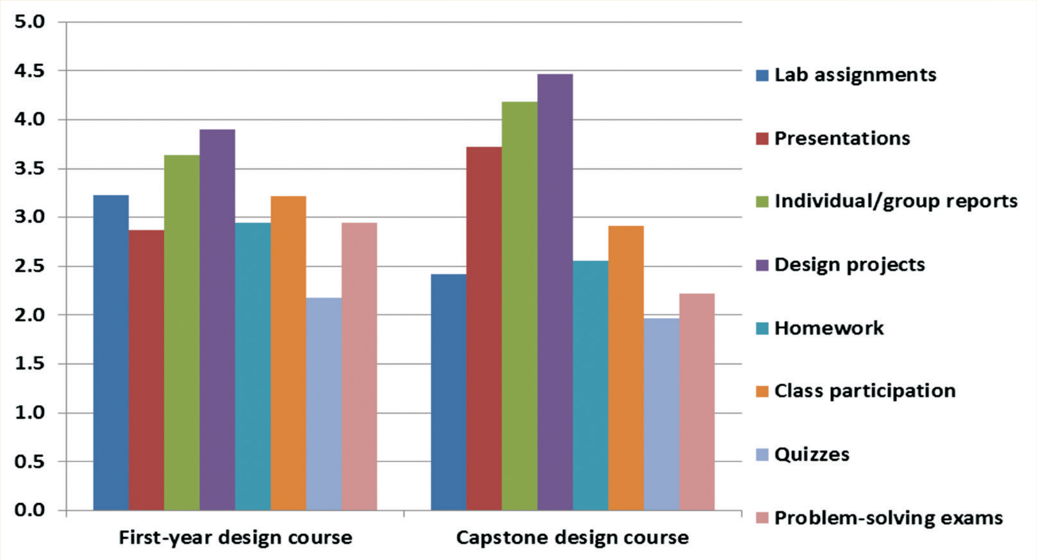
Assessment of Student Learning: Variations by Course Type

Students learn early to pay attention to what their teachers assess, asking frequently, "Will this be on the test?" Thus, what faculty and instructors assess matters not only because it contributes to students' course grades, but because it sends a message to students about what is valued in their courses, programs, and the engineering workplace. In this section, we look at the assessment strategies used in different kinds of engineering courses. Faculty and instructors responded to a survey question asking how important different assessment strategies were in determining students' grades in a course they regularly teach. Respondents used a five-point scale, where 1= Not at all important, 2 = Slightly, 3 = Moderately, 4 = Very, and 5 = Extremely important.

As shown in Figure 2.8, grading in design courses, and particularly in capstone design courses, gives more weight to assignments that are well suited for evaluating students' professional skills.

- **First-year design course** instructors indicated that they relied on a variety of strategies to assess student learning. They cited design projects, individual and group reports, lab assignments, and class participation as moderately to very important in determining students' grades. Other kinds of assessments, including presentations, homework, and problem-solving exams, however, also contribute to the determination of students' grades in first-year design courses.
- Assessment strategies are noticeably different for **capstone design courses**, where faculty and instructors rely more on design projects, individual and groups reports, and presentations than in first-year design courses. Capstone instructors still rely (although at a lower level), however, on the more traditional forms, such as class participation, quizzes, homework, labs, and exams. Overall, the practices in use suggest considerable variation in the pedagogical and assessment practices used in capstone courses.

Figure 2.8: Faculty and Instructors' Reports of Types of Assessment They Use in First-Year and Capstone Design Courses



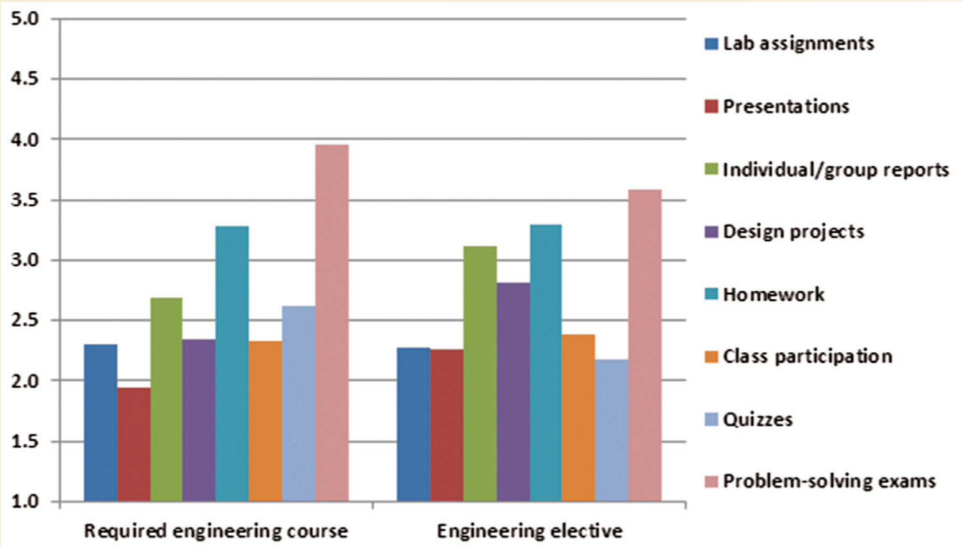
Scale: 1= Not at all, 2 = Slightly, 3 = Moderately, 4 = Very, and 5 = Extremely

Note: Respondents could indicate a topic was "not applicable" for the course on which they reported. "Not applicable" responses were removed from the analysis.

This set of findings on assessment practices in design courses contrasts with the picture that faculty and instructors provided for their required and elective engineering courses (Figure 2.9).

- In both **required engineering courses** and **elective engineering courses**, problem-solving exams are reportedly very important, with homework also moderately important in assessing student work.
- In **required engineering courses**, faculty and instructors also reported relying, although somewhat less so, on the remaining assessment strategies: quizzes, individual and group reports, class participation, design projects, and lab assignments and presentations.
- The pattern is similar for **elective engineering courses**. Faculty and instructors reported that problem-solving exams, homework and individual/group reports were moderately to very important in grading, and they rated the remaining assessment strategies as slightly to moderately important.

Figure 2.9: Faculty and Instructors' Reports of Types of Assessment Used in Required and Elective (Non-Design) Courses They Teach



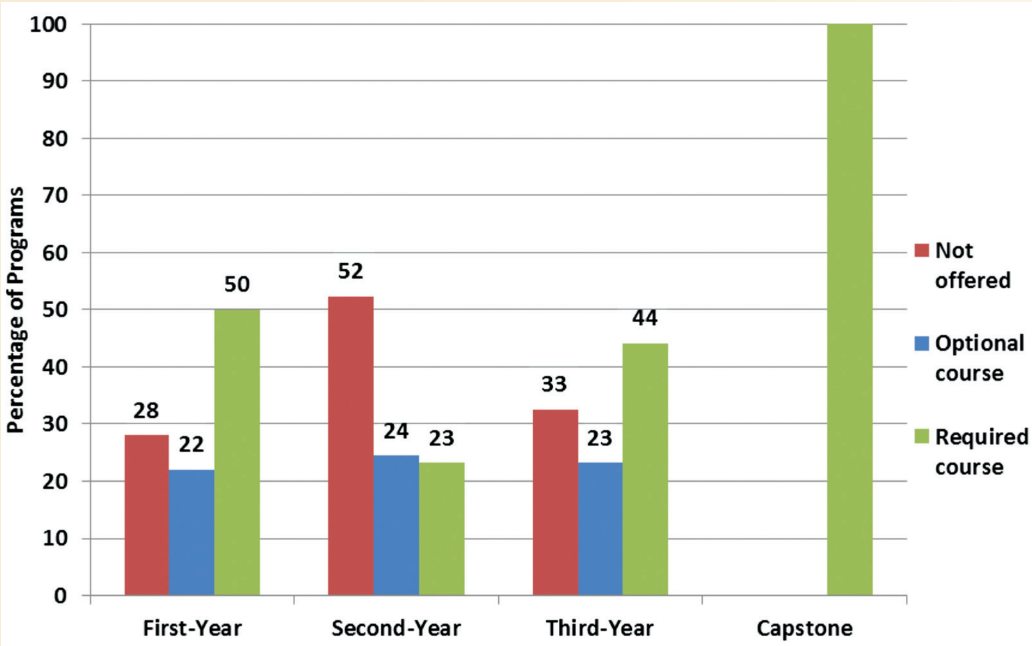
Scale: 1= Not at all, 2 = Slightly, 3 = Moderately, 4 = Very, and 5 = Extremely

In Part 1 we reported high levels of agreement among administrators and faculty that the engineering curriculum should engage students in hands-on design learning throughout the curriculum (see Figure 1.2). The analyses in this section show, however, that most students will take a very few design courses as part of their undergraduate program, and will enroll in far more required courses and technical electives. Moreover, when it comes to professional knowledge and skills, first-year and capstone design courses appear to be carrying most of the load for professional skill development. The problem is compounded when one considers that many programs do not require (or, in many programs, even offer) a design course until students' senior year of study. Finally, if students attend most to what is assessed, our findings regarding the use of assessment in engineering courses suggest that faculty are sending a strong and consistent message that the knowledge that can be assessed through tests and homework problems is what engineers value most. This message is at odds with that of National Academy's *Engineer of 2020* reports, which stress the integration of knowledge and the hands-on use of specific skills in engineering practice.

Design Course Requirements in Undergraduate Programs

Calls for greater emphasis on engineering practice in undergraduate programs often focus on increasing students' opportunities to engage in design education, and faculty seem to support a strong focus on design in the undergraduate curriculum. Nearly 70% of the engineering faculty we surveyed agreed or strongly agreed that engineering programs should introduce engineering design in the first year and continue design education throughout the curriculum. There is a notable discrepancy, however, between aspiration and reality. As Figure 2.10 shows, although every program reported a required capstone design course, the emphasis on design throughout the curriculum varies significantly.

Figure 2.10: Program Chairs' Reports of Design Course Offerings by Class Year



- Only half of the programs we surveyed require first-year design, 22% offer it as an elective, and more than a quarter do not offer it at all.

- About half offer either an elective or required sophomore design course.

- In the third-year curriculum, 44% of programs offer a required design course; another 23% offer design as an elective. A third do not offer a design course option.

What kind of learning experiences do students have in these design courses? For most students, the experience has a distinctly disciplinary – rather than multi- or interdisciplinary – focus. Table 2.1 shows that students are most likely to have a multidisciplinary experience (with students from other engineering fields) in their first year. Many of these first-year courses reported as "multidisciplinary" probably enroll students before they declare a specific academic major.

Table 2.1: Program Chairs' Reports of Types of Engineering Students Enrolling in Design Courses by Year

	Students only from major program	Students from different engineering fields	Students from non-engineering fields
First Year Design	24%	28%	6%
Second Year Design	23%	12%	0%
Third Year Design	48%	10%	0%
Fourth Year Design	71%	22%	4%

Only a few programs in our sample (7%) offered an interdisciplinary experience that engages students from outside engineering in first-year design courses. Multi- and interdisciplinary design experiences are even less common after the first year of study, although nearly a quarter of the engineering programs surveyed offered a multidisciplinary capstone experience, defined as a course that enrolls students from different engineering majors. Despite ABET's emphasis on multidisciplinary teamwork and the National Academy's calls for more interdisciplinary learning experiences, major changes to the design curriculum were not yet apparent at the time these data were collected in 2009.

The analyses in this and the preceding sections suggest that, despite indications from both program chairs and faculty members that "design" is at the core of what engineers "do," design courses represent a small fraction of an undergraduate engineering program. Moreover, they are the workhorses that carry much of the responsibility for teaching non-technical knowledge and skills specified by both ABET and the National Academy as critical to effective engineering, even as they give students practice in applying foundational and technical knowledge. When design is not infused throughout the curriculum, students' development of needed professional skills – communication, teamwork, and project management – may be severely constrained.

How much of a concern are such limitations? We can turn to engineering graduates, three years on the job, whom we asked for some insight into what they need to know and do.

What do I need on the job? Reports from Engineering Alumni

Engineering graduates can tell us something about how well they were prepared for their current jobs by reflecting on the differences between what they recall was emphasized in their engineering programs and what is important to them in their current jobs. Our sample of 1,380 alumni comes from the same 31 institutions and 86 engineering programs as the associate deans, program chairs, faculty, and students surveyed in the P2P project. These graduates of the Class of 2006 were surveyed three years after earning their undergraduate engineering degrees. Nearly 80% of the responding graduates are male. Just over half are Caucasian, just under 25% are members of historically underrepresented minority groups, and about 6% are foreign nationals. About 70% graduated with a degree in electrical, mechanical or civil engineering; the remaining 30% represent the other four engineering disciplines targeted for the study. (See Appendix C for an extended profile of the alumni respondents.)

About 70% of all surveyed graduates are working in a technical capacity (e.g., in research, development or testing or as research, professional or technical positions). About 5% are in non-technical roles (e.g., marketing/sales, human resources), and the remainder are roughly evenly split between supervisory and consulting roles. We found no gender- or race/ethnicity-related differences in the graduates' primary job functions. Unsurprisingly, alumni who reported that their primary job function is non-technical are the most likely to say their work is unrelated to their engineering degree (47%). Almost a third of alumni in supervisory roles (32%), however, also report their work is not related to engineering.

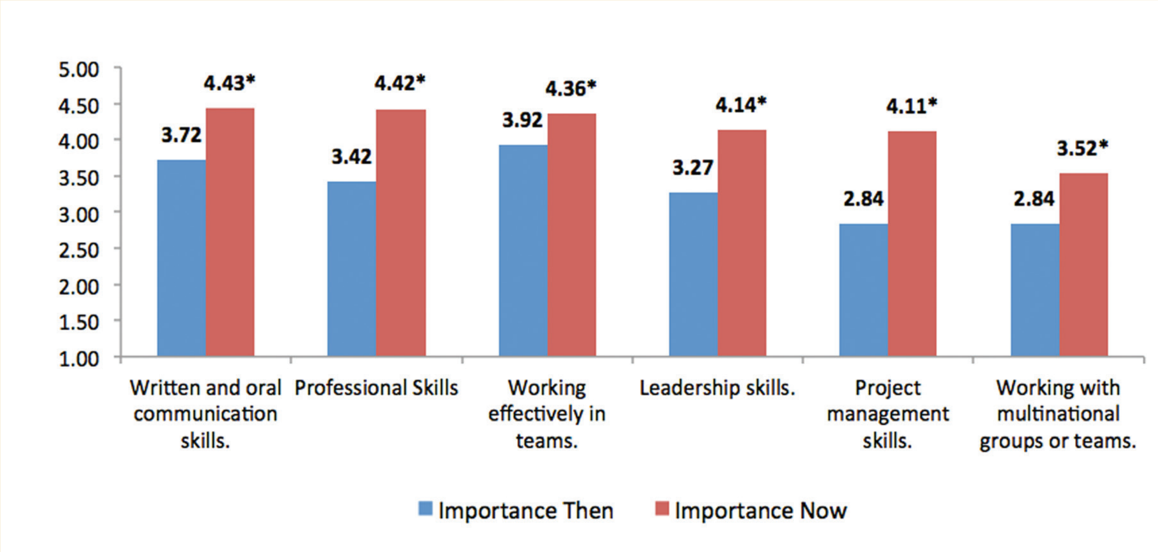
We asked young alumni how much the courses in their undergraduate engineering program emphasized 19 different engineering topics and how important those same topics and skills were in their current work. Respondents answered using a five-point scale where 1=Little/none, 2=Slight, 3=Moderate, 4=High, and 5=Very high importance. Figures 4.11 to 4.13 summarize their responses.

All of the differences in Figures 2.11 to 2.13 are statistically significant, and all are greater than .30, our threshold for a practically meaningful difference in a given comparison. In a number of cases, the effect sizes are notably large.

As shown in Figure 2.11, new graduates rated a number of **professional skills** as highly to very highly important in their current work. For most of the professional skills, substantial discrepancies are apparent between those that alumni report are important on the job and what was emphasized in their engineering programs. Teamwork is the one exception.

- Alumni rated three professional skills has highly to very highly important in their work now: **written and oral communication skills**, **teamwork,** and **professional skills** (e.g., knowing codes and standards, being on time, meeting deadlines). When looking back at their engineering programs, however, they perceived teamwork to be more highly emphasized than communication skills and professional skills. The effect size for the differences between "then" and "now" for professional skills is among the largest we identified in this set of questions (effect size = 1.09), and the difference between communication then and now is also large (.81). The difference for teamwork is considered a medium-sized effect (.50).
- In addition, alumni rated **leadership** and **project management** skills as highly important in their present positions, but recalled the emphasis on the development of these skills in their engineering programs as moderate in the case of leadership skills and only slight to moderate for project management skills. The effect sizes for both these differences are large: project management = 1.15; leadership =.92.
- **Working with multinational groups or teams** is moderately to highly important in their work, but alumni recalled only slight to moderate emphasis on this skill in their programs. The effect size (.53) can be characterized as medium sized.

Figure 2.11: Alumni Reports of the Importance of Professional Skills in their Engineering Programs (Then) and in Their Work (Now)



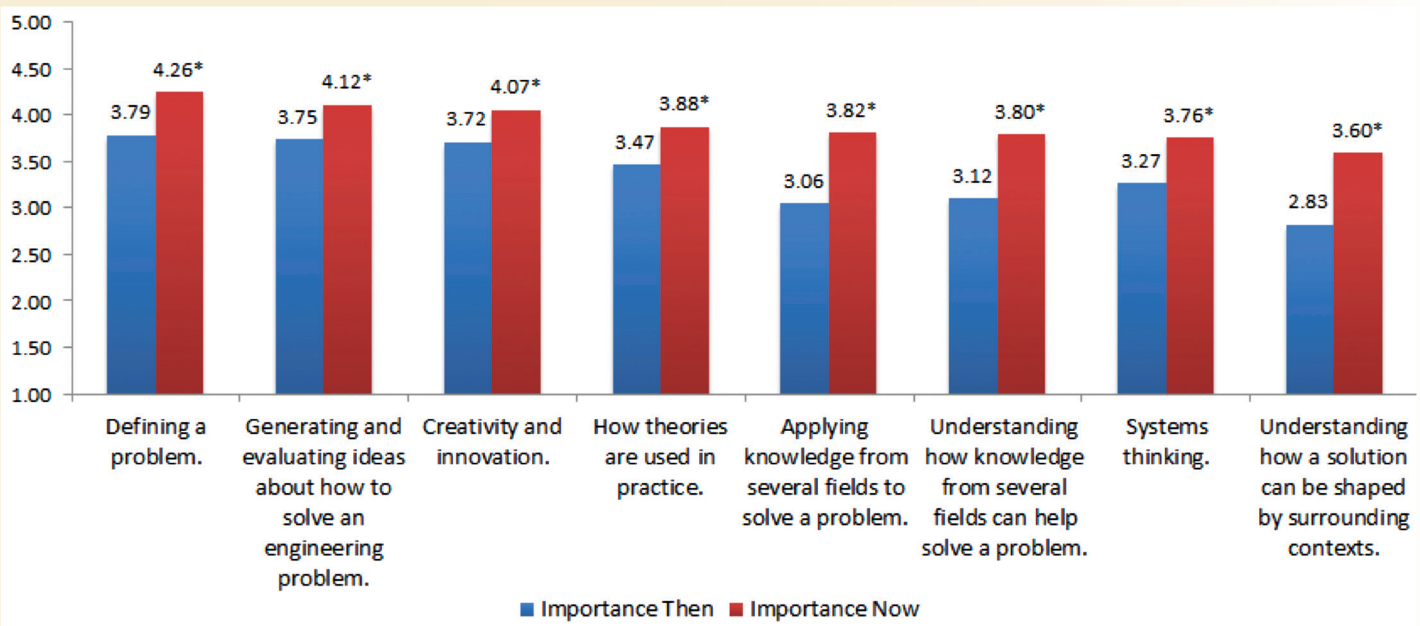
Scale: 1=Little/none, 2=Slight, 3=Moderate, 4=High, and 5=Very high

$p < .001$

Many studies of engineering practice and employer-needs acknowledge that problem-solving is central to engineering practice (e.g., Anderson et al, 2010; Lattuca, Strauss, & Volkwein, 2006; Sheppard, Macatangay, Colby, & Sullivan, 2008). Our engineering graduates' ratings of the importance of a number of problem-solving and design skills is consistent with this body of evidence (Figure 2.12).

- Alumni rated **defining a problem, generating and evaluating ideas about how to solve an engineering problem**, and **creativity and innovation** as highly to very highly important in their current work. They perceived the emphasis in on these problem-solving skills in their undergraduate programs, however, as moderate to high. All of the effect sizes for these differences between then and now are meaningful for practice, creativity and innovation (.33); defining a problem (.52); and generating and evaluating potential engineering solutions (.35).

Figure 2.12: Alumni Reports of the Importance of Design and Problem-Solving Skills in their Engineering Programs (Then) and in Their Work (Now)



Scale: 1=Little/none, 2=Slight, 3=Moderate, 4=High, and 5=Very high

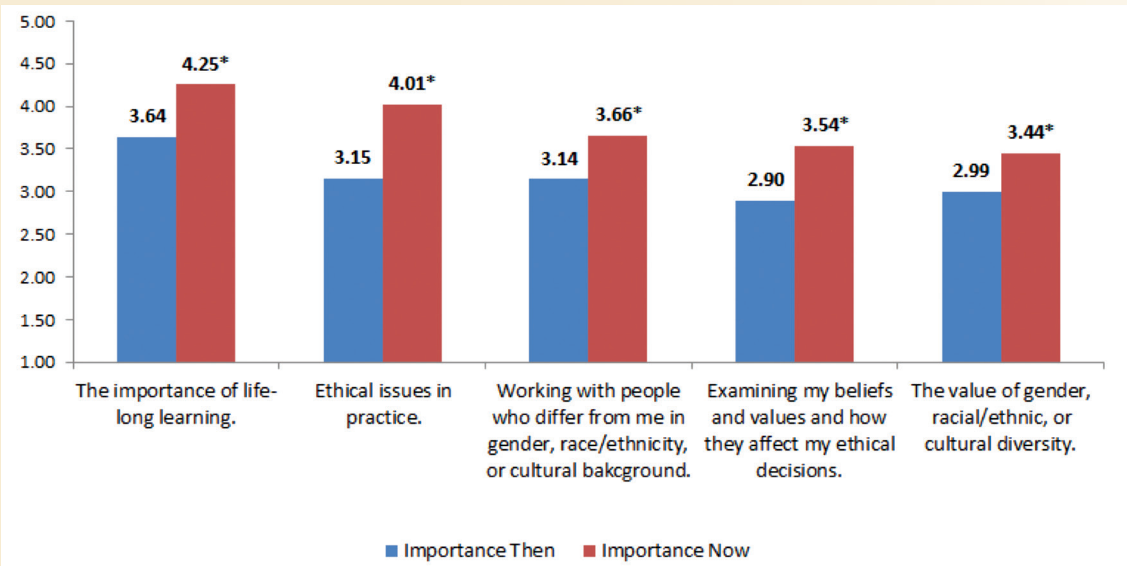
$p < .001$

- The remaining problem-solving and design skills were rated less highly, but still in the high-moderate to highly important range: how theories are used in practice, applying knowledge from several fields to solve a problem, understanding how knowledge from several fields can help solve a problem, systems thinking, and understanding how a solution can be shaped by surrounding contexts. The effect sizes for the differences between the use of theory in practice then and now (.40) and systems thinking then and now (.44) are both in the medium-size range. The remaining discrepancies are more pronounced, with graduates indicating that these skills were emphasized slightly to moderately in their programs. The effect sizes for the following differences are large: understanding how knowledge from different fields can be used in engineering problems (.71); applying knowledge from different fields (.77), and understanding the influence of contextual factors on engineering solutions (.76).

We also asked alumni to tell us how much ethics- and diversity-related topics were emphasized in their undergraduate programs and how important these issues are in the current work. Figure 2.13 shows that two of these knowledge and skill sets are highly important to alumni in their work.

- Graduates indicated that **life-long learning** is highly to very highly important in their work, and indicated that it was moderately to highly emphasized in their programs. The effect size for this difference is approaching the threshold for a large effect at .65.
- They also rated **ethical issues** as highly important in their work, but noted that their programs emphasized ethics only moderately. The effect size of .79 is large.

Figure 2.13: Alumni Reports of the Importance of Ethics and Diversity Knowledge and Skills in their Engineering Programs (Then) and in Their Work (Now)



Scale: 1=Little/none, 2=Slight, 3=Moderate, 4=High, and 5=Very high
$p < .001$

The remaining knowledge and skills sets, focusing on ethics and diversity issues, were rated as somewhat less important than the others in graduates' work now, and there is a greater discrepancy between what graduates say they need now and what their programs emphasized (Figure 2.13).

- Alumni viewed the **examination of their values and how they affect their ethical decisions** as somewhat less important in their work, but their ratings indicate that it is still moderately to highly important. In their undergraduate programs, however, the emphasized they perceived on ethical reflection was moderate at best. The effect size for the difference "then" and "now" (.79) is large.
- Alumni reported that **working with people of different genders, ethnicities, and cultural backgrounds** is moderately to highly important in the workplace, but they thought it was moderately emphasized in their programs. The effect size here (.43) is medium-sized.

- Similarly, alumni perceived moderate to high emphasis on the **value of diversity** in their workplaces and somewhat less emphasis in their undergraduate programs. The effect size (.37) is medium in size.

In every instance, the skills and knowledge that are important to engineering graduates in their current positions were given less emphasis in their programs. These knowledge and skill sets are also those that are emphasized in the *Engineer of 2020* reports.

* * * * *

The seven engineering fields we studied place somewhat different levels of emphasis on different engineering knowledge and skill sets, but the overall picture across these fields is substantially the same. Program chairs reported that their programs placed the strongest curricular emphasis to design and professional skills and relatively less on interdisciplinarity and professional values (e.g., the value of diversity, ethical decision making). Faculty reports on their courses, as well as graduating seniors' reports on their program curricula as a whole, corroborate this finding.

Design courses appear to carry much of the responsibility for teaching professional knowledge and skills, even as they give students practice in applying foundational and technical knowledge. Design courses, however, constitute a small fraction of the undergraduate program: about half of responding programs required a first-year design course, and options for design courses in sophomore and junior years are limited, although all programs reported requiring a capstone design course. For most students, these design courses offer a disciplinary design experience that involves students from their own major program. Engineering programs do not appear to be capitalizing on knowledge and skills from non-engineering disciplines in their efforts to develop students' design and professional skills.

The relative lack of emphasis on the knowledge and skills needed in engineering practice is important because engineering alumni (three years after graduation) rated professional skills as highly to very highly important in their current work but often noted gaps between this need and the level of emphasis given to skills like leadership and project management in their present positions. Alumni also tended to report that their current positions required more contextual awareness and ability to apply knowledge from multiple engineering and non-engineering fields than was emphasized in their undergraduate programs.

Finally, it is worth noting that non-tenure track instructors reported that they give greater emphasis to the design and professional skills the National Academy argues will be need by the "engineers of 2020" than did tenured and tenure-eligible faculty members. In the next part of this report, we examine how curricular emphases and instruction affect students' confidence in three of the knowledge and skill set stressed in the NAE's vision: design and problem-solving skills, interdisciplinary competence, and contextual competence.

Part 3: Promoting Students' Learning in Design Skills, Interdisciplinary Skills, and Contextual Competence

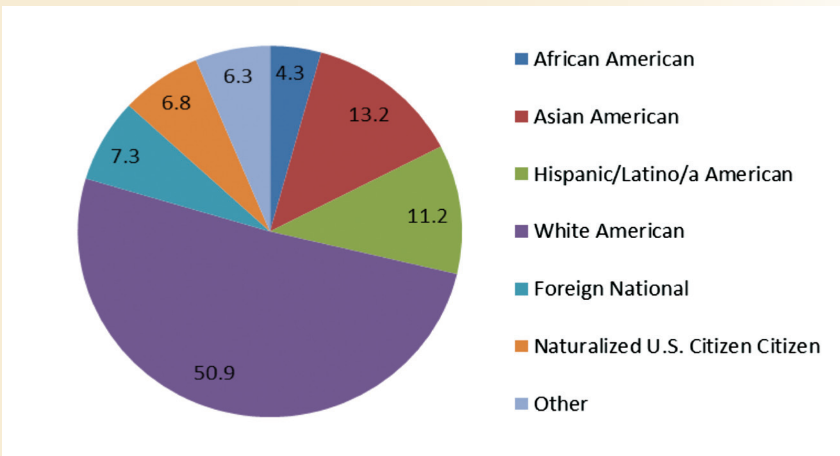
As concerns about the preparation of engineering graduates for the world of practice have increased, so have the efforts of the engineering education community to improve undergraduate programs. Reforms such as ABET's EC2000 focused attention on the knowledge and skills that graduates need to succeed in the engineering workforce, and reports such as ASEE's (2010) report *Systematic innovation in engineering education* recommend new instructional approaches that actively engage students in applying their burgeoning knowledge and skills before entry into the workforce. Recently, attention has also been paid to what students do outside of their courses to understand how engineering programs might leverage the co-curriculum to complement and build upon what undergraduates learn in classes.

In this part of the report, we first present a profile of the undergraduate engineering students who participated in the study and then a series of analyses that identify the curricular, instructional, and co-curricular experiences that promoted these students' development of three knowledge and skill sets critical to the "engineer of 2020" – design and problem-solving, interdisciplinary competence, and contextual competence. We also highlight, in the boxes throughout this section, findings from the case studies conducted through the companion P360 study to identify approaches and environments that support the development of these skills sets.

A Profile of the Participating Engineering Students

Mirroring the U.S. population of engineering students, the students who participated in this study are predominantly male (81% male; 19% female). As shown in Figure 3.1, just over half identify as White Americans and just over 7% are foreign nationals. Approximately 10% are members of historically underrepresented minority groups in engineering (African American and Hispanic/Latino/a Americans); another 13% are Asian Americans. Students who selected the "Other" category tended to identify as multiracial or Middle Eastern. Because Native Americans constituted less than one percent of our sample, they are included in the "Other" category. Just over 87% of respondents reported that English is their native language. Most respondents are traditional college students (77%), but 16% transferred from a community college and 7% transferred from another four-year college. (For more information on the community college as a pathway to college, please see our report, *America's Overlooked Engineers: Community Colleges and Diversity in Engineering Education*, at http://deepblue.lib.umich.edu/handle/2027.42/107460.)

Figure 3.1: Racial/Ethnic Characteristics of Four-Year Student Respondents



Most undergraduates in this study come from families with at least some college experience. Nearly 30% indicate that their mother or father earned a bachelor's degree; 20% report that, between their parents, the highest degree earned is a master's. Almost 10% of the sample reported that their mother had earned a doctoral degree (compared to less than 5% of fathers). At the other end of the spectrum, about 5% of the responding students come from families where neither parent finished high school, and another 10% come from families where a high school diploma is the highest level of parental educational attainment. Research indicates that first-generation college students often require assistance in navigating their colleges and universities and making informed choices about curricula and careers (Pascarella, Pierson, Wolniak & Terenzini, 2004; Pike & Kuh, 2005).

The educational profile of four-year undergraduate students reflects the diversity of their educational experiences prior to college. Given the critical role that mathematics preparation plays in engineering success, we asked students to tell us about their first college math course. Four out of five students arrived in college having completed a calculus or another math course higher than calculus. For more than 15%, however, their first math course after high school was at a level below calculus, and a small percentage started with a remedial mathematics course at the level of algebra or below.

Relative to their male peers, female students reported significantly higher math, critical reading, and writing SAT scores. It's worth noting that there is a strong correlation between self-reported and actual test scores (Cole & Gonyea, 2010; Mayer, Stull, Campbell, Almeroth, Bimber, Chun et al., 2007). White respondents reported higher SAT scores in math, reading, and writing than all other American ethnic groups, but all American-born students reported math SAT scores higher than 620 (of 800). Differences in preparation are most notable for African American students, who reported the lowest average SAT scores in reading, writing, and mathematics. (Note: For these analyses, we converted ACT scores to SAT-equivalent scores.)

Engineering Seniors' Learning Outcomes

The following analyses examined the influence of three sets of variables on the learning outcomes of fourth- and fifth-year senior engineering students:

- **Curricular Emphases**: students' reports of the emphasis placed on four types of engineering content in their engineering program (e.g., professional skills, engineering fundamentals)
- **Instructional Methods**: students' reports of the extent to which they experienced different instructional techniques, such as active learning or lectures, in their engineering program
- **Co-curricular Involvement**: the out-of-class activities in which students participated (e.g., engineering clubs, study abroad) and students' levels of engagement in those activities.

In each analysis, we statistically controlled for an array of students' characteristics (gender, race/ethnicity, parents' educational level, and standardized test scores); as a result, the group differences in findings regarding the influence of curricular, instructional and co-curricular factors cannot be attributed to any of these student characteristics. Of course, findings may be influenced by students' characteristics and experiences that we did not measure and were thus not able to control (e.g., student motivation).

The plots in this section show how much of the variability in students' learning is explained by curricular emphases, instructional methods and students' co-curricular involvement for each of the engineering disciplines we studied.[5] (See Part 1 for additional discussion of curricular topics assessed in this study.) Because inferential analyses require large group sizes, we are unable to report separate findings for three of the seven fields we studied: Biomedical/Bioengineering, Industrial, and General Engineering. We thus combined students' responses for these fields – which are arguably linked by a greater emphasis on interdisciplinary thinking – in the interest of providing information about student learning outcomes in these fields. Biomedical and Bioengineering majors, however, represent half of the students in this group, so results should be cautiously interpreted for General and Industrial Engineering majors.[6]

Design and Problem-Solving Skills

In most engineering fields, design is considered a critical skill that builds on a strong foundation of technical knowledge and problem-solving skills, but that also requires strong professional skills that contribute to the engineer's ability to work with clients and customers and to design products, processes, and systems that address complex commercial and public problems. We recognize that a design solution must also take into account the specific contexts in which it will be used, attending to the relevant social, cultural, economic, political and/or environmental contexts in which it is designed and will be put to use. In the P2P study, we called this capacity "contextual competence" and assessed it separately from design. Findings related to contextual competence begin on page 37.

Our analyses clearly show that engineering subdisciplines matter in terms of students' learning: the variables that best explain differences in students' self-assessments of their design and problem-solving learning vary by engineering field. Figure 3.2 summarizes our findings for four individual engineering fields (Chemical, Civil, Electrical, and Mechanical Engineering) as well as for the combined set of engineering fields that tend to be more interdisciplinary in focus (Biomedical/Bioengineering, General, and Industrial Engineering).

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[5] The survey items that comprise each of the scale variables used in these analyses are given in Appendix B.

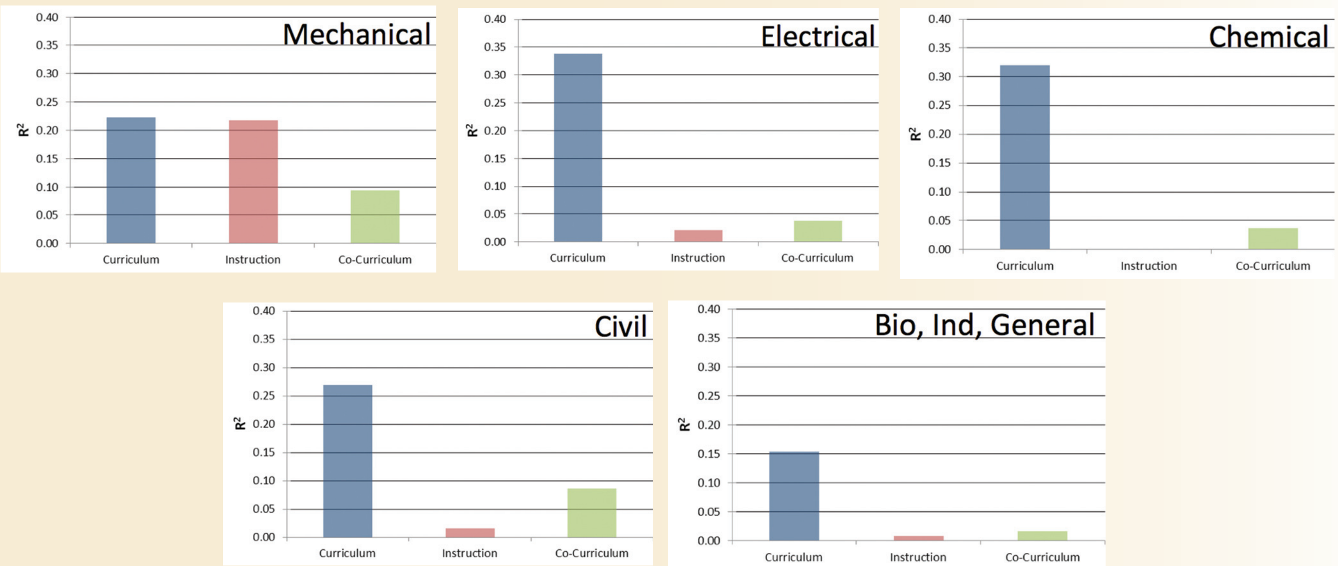
[6] Of 2,422 seniors (4th and 5th year) included in these analyses, 410 (or 17%) are members of the composite group. Of these 410 students, 209 (51%) identified as bio/biomedical engineering majors, 90 (22%) as general engineering majors, and 111 (27%) as industrial engineering majors.

In most of the engineering fields we studied, the topical emphases in the program curriculum that students reported were more strongly related to their reports of their design and problem-solving skills than were the instructional strategies used in engineering courses or students' involvement in an array of 10 co-curricular activities. In Figure 3.2, R^2 indicates the unique proportion of variability in students' reported design skills that is attributable to each of the three sets of college experiences.[7] (Note: the absence of a bar indicates that the variable did not have a statistically significant effect on learning.)

- In every field but Mechanical Engineering, the curriculum has a substantially stronger effect on students' design and problem-solving skills than instructional strategies or co-curricular participation.
- In Mechanical Engineering, instructional strategies are as important as curricular emphases in shaping students' reports of their design learning.
- Co-curricular activities appear to have a greater impact on Mechanical and Civil engineers' learning outcomes than they do in other fields.

See Box 3.A for curricular approaches to promoting design skills from the P360 case study institutions.

Figure 3.2: Relative Influence[a] of Curricular Emphases, Instructional Methods, and Co-Curricular Participation on Students' Self-Reported Design and Problem-Solving Skills



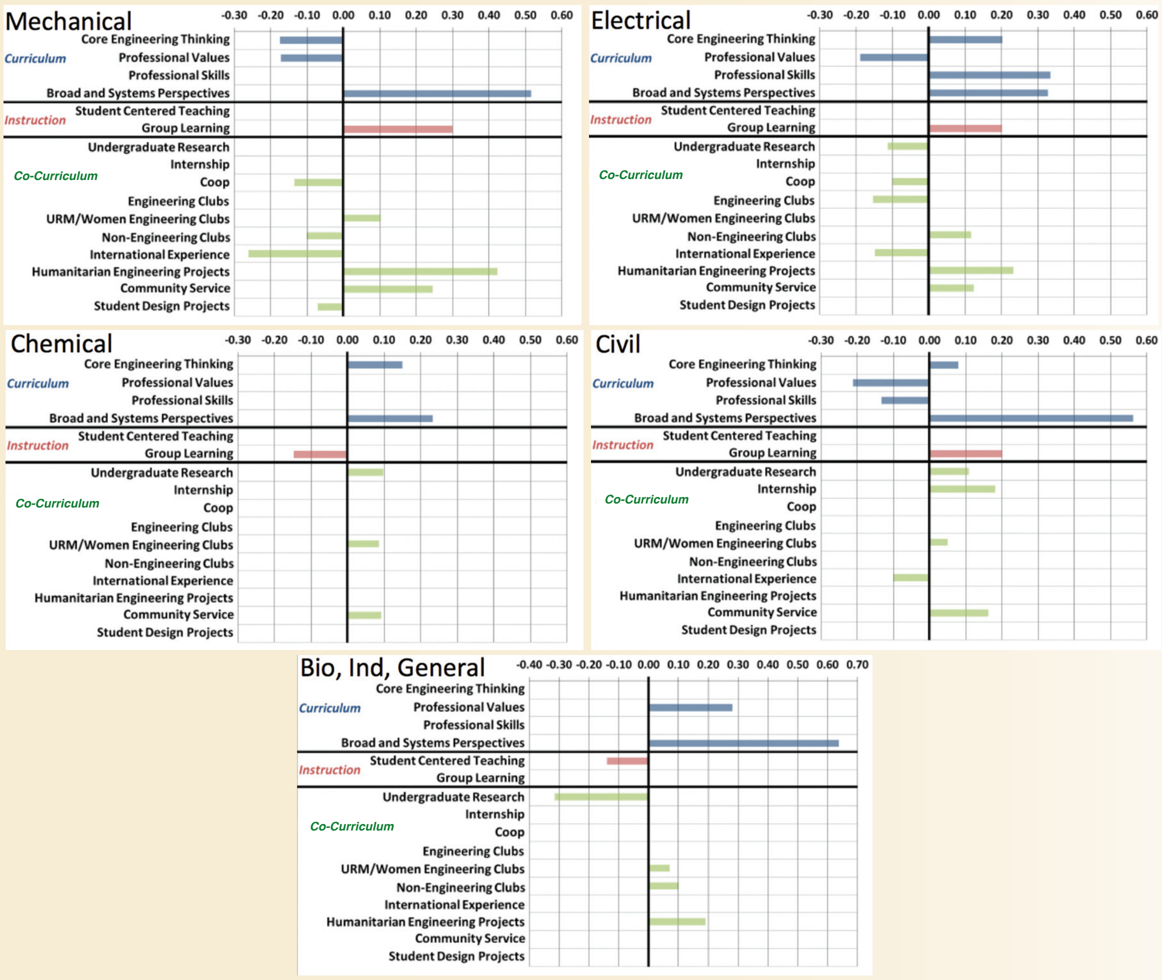
[a] R^2 indicates the proportion of variance in reported design skills that is attributable to three sets of college experiences

Influences of the Engineering Curriculum on Design Skills

Given the strong overall influence the undergraduate curriculum on the design and problem-solving skills reported by students in several engineering fields, we examined the curricular effects in greater detail to identify which aspects of the curriculum were the major contributors. Specifically, we examined how differences in students' perceptions of the topics their program curriculum emphasized and the instructional methods used affected students' development of design and problem-solving skills (Figure 3.3). The analysis for each engineering field includes all the variables noted on page 30. In this section, we report only on the findings for the curriculum and instruction variables, reserving our discussion of co-curricular activities for the following section. The numbers reported at the top of each discipline figure are standardized regression coefficients (i.e., beta weights); beta weights reflect the relative importance of each variable in predicting an outcome while controlling for all other variables in the model. Only statistically significant findings are shown, and furthermore we discuss only what appear to be the most influential findings (coefficients equal to or greater than .3 without regard to sign).

[7] Indicates the unique R^2 value for each set of variables, independent of the contributions of the other two sets.

Figure 3.3: Relative Contributions[a] of Students' Curricular, Instructional, and Co-Curricular Experiences on Their Self-Reported Design and Problem-solving Skills by Engineering Field



[a] The numbers at the top of each figure are standardized regression coefficients (beta weights) that reflect the relative importance of a variable while controlling for all other variables in the model. Only statistically significant beta weights are shown.

As noted, students' perceptions of curricular emphases in their programs were more consistently and more strongly related to their development of design and problem-solving skills than were the instructional methods they experienced (Figure 3.3). In particularly, our analyses show that:

- Especially noteworthy is the very strong and consistently positive association between **Broad and Systems Perspectives** (i.e., systems thinking; understanding how non-engineering fields can help solve an engineering problem) and design learning.

- This effect is particularly strong in Mechanical and Civil Engineering, and moderate in Electrical and the combined fields of Biomedical/Bioengineering, Industrial, and General Engineering.

- Notably, the relationship between a curricular emphasis on **Professional Values** – which includes topics such as ethics, lifelong learning, and diversity – and design skills varies by engineering subfield.

    - In the combined interdisciplinary fields of Biomedical/Bioengineering, Industrial, and General Engineering, an emphasis on **Professional Values** is associated with higher levels of self-reported design and problem-solving skills.

    - In other fields, however, the greater the perceived emphasis on Professional Values, the lower students' self-ratings of their design and problem-solving abilities. This finding should *not* be interpreted as indicating that students reporting a greater emphasis on **Professional Values** in their undergraduate programs are not learning design skills. Rather, these findings may suggest that a focus on ethics, lifelong learning, and diversity is insufficient for building students' confidence in their design and problem-solving abilities in some fields.

- The use of **Group Learning** had a moderate influence on students' reports of design skills in Mechanical Engineering, but students in Electrical and Civil Engineering also seem to reap some benefit from teaching strategies that stress hands-on and group learning activities.

BOX 3.A: Practices that Build Design Skills

*The emphasis on the development of design skills throughout the curriculum distinguished the general engineering programs at Harvey Mudd College and the Polytechnic Campus at Arizona State. At **Harvey Mudd**, the College's integrated curriculum maintains a clear focus on systems thinking, design, and professional practice throughout the students' educational program. Design learning begins with in their first year of study with a simple reverse-engineering project, and hands-on approaches are used throughout the curriculum. At **ASU-Polytechnic**, the project-based curriculum attracts – and prepares – students who want to head directly to industry. The emphasis at each institution is both vertical – across years – and horizontal – in terms of its inclusion across courses in the same year.*

*Several case study institutions – **Harvey Mudd**, **Virginia Tech**, and most programs at **Arizona State** – require a two-semester senior-year capstone design experience that engages students in industry-sponsored projects. At **Harvey Mudd**, students preparing for their capstone project observe a Clinic project in their junior year.*

Co-Curricular Influences on Design and Problem-Solving Skills

We also analyzed the influence of the amount of time students spent in 10 different co-curricular activities on their design and problem-solving skills. The activities included, for example, undergraduate research experiences, internships, participation in engineering clubs, humanitarian engineering projects, and out-of-class design competitions, and students were asked to report on their participation "in the past year." In Figure 3.3 (above), co-curricular experiences are represented by the green bars.

Two findings stand out.

- Associations between participation in **humanitarian projects** and **community service** were most consistently related to reports of design skills, with the strongest relationship found for Mechanical engineers.

- Surprisingly, significant relationships between participation in design competitions and design skills for the engineering majors studied are almost completely absent from Figure 3.3. Once our analyses controlled for students' pre-college characteristics, significant relationships disappeared for all but the Mechanical Engineering majors (and this relationship, although significant, is quite weak). This may, in part, be due to the fact that less than half of the responding seniors reported participating in a design competition "in the past year" (as the survey question directed). It may, however, also suggest that students who are already confident in their designs skills self-select into these activities and thus perceive little additional benefit to their design and problem-solving skills. Design competitions, of course, may yield other kinds of benefits that we did not examine in this study.

The absence of strong associations among time spent in co-curricular activities and design skills suggests that the formal curriculum is more likely to influence students' confidence in their design skills than participation in clubs, organizations, and other out-of-class activities. To achieve the maximum benefit from co-curricular activities, engineering schools and programs may want to leverage co-curricular activities, particularly community service and humanitarian engineering projects, by creating intentional linkages between the formal curriculum and these types of informal curricula (see Box 3.B).

BOX 3.B: Leveraging the Co-Curriculum to Promote Design Skills

*Two of the P360 institutions recognized – and leveraged – co-curricular activities to enhance students' design and problem-solving skills. At the **University of Michigan**, a minor in multidisciplinary design awards credit for out-of-class design activities when they are packaged with other design-related coursework. At **Virginia Tech**, co-curricular experiences during sophomore and junior years provide opportunities to engage in design projects that are supported with resources and dedicated physical space for student projects. These experiences bridge the focus on design in first-year and capstone courses and provide an innovative way to infuse "design across the curriculum."*

Interdisciplinary Competence

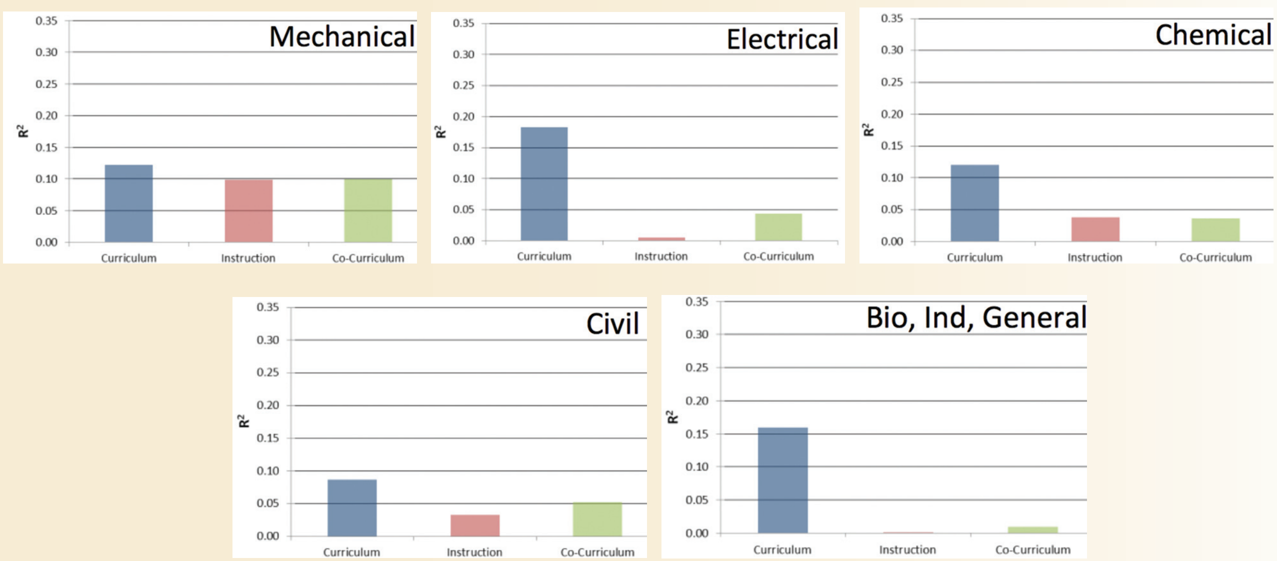
Business and industry leaders, as well as our global society, need engineers who have both disciplinary depth and interdisciplinary breadth. In *Educating the Engineer of 2020,* the NAE's blue-ribbon panel called for curricular reforms designed to provide a more holistic approach to engineering education and practice: "learning disciplinary technical subjects to the exclusion of a selection of humanities, economics, political science, language, and/or interdisciplinary technical subjects is not in the best interest of producing engineers able to communicate with the public, able to engage in a global engineering marketplace, or trained to be lifelong learners" (p. 52). The engineers of the future must combine a strong understanding of their disciplines with the ability to work across disciplines both within and outside the field of engineering. This skill set, which we labeled "interdisciplinary competence," is multidimensional. It includes an appreciation of perspectives from other disciplines as well as the ability to synthesize and integrate the knowledge and skills gained from other disciplines to understand or solve a problem. (See Appendix B for survey items comprising this scale.)

As was the case for the analysis of students' design and problem-solving skills, the P2P study used three sets of variables to model students' interdisciplinary skills: curriculum, instruction, and co-curricular activities. Figure 3.4 shows the variance in students' self-reported interdisciplinary competence that is explained by these variables (controlling for students' precollege characteristics).

As we found for design skills, the importance of these sets of variables differs by discipline.

- In Mechanical Engineering, the explanatory power of each of these variables is similar and consistent (if modest) across the predictor variables.
- In all of the remaining fields, the curriculum variables best explain the variance in interdisciplinary skill development; this difference is especially notable in case of Electrical Engineers and the combined group of Biomedical/Bioengineering, Industrial and General Engineering students.

Figure 3.4: Relative Influence[a] of Curricular Emphases, Instructional Methods, and Co-Curricular Participation on Students' Self-Reported Interdisciplinary Skills.



[a] R^2 indicates the proportion of variance in reported design skills that is attributable to three sets of college experiences

Box 3.C calls attention to the role that institutional cultures play in supporting educational efforts. In Box 3.D, we highlight examples of curricular approaches to promoting interdisciplinary skill development among undergraduates in the P360 case study institutions.

BOX 3.C: Institutional Cultures Supporting Interdisciplinary Competence

*At **Arizona State's** Polytechnic campus, the Advanced Technology Innovation Collaboratory supports interdisciplinary projects in which students, with faculty help, work on industry projects. ASU also benefits from a University-wide focus on interdisciplinarity. ASU's President since 2002, Michael Crow, has long been a proponent of interdisciplinarity, and his vision of the "New American University" supports that perspective and way of thinking. This vision, which focuses on interdisciplinary work that responds to societal needs, has helped develop new research centers and schools at ASU that address issues of sustainability and biotechnology. These university-level ventures contribute to a culture of interdisciplinary research and curriculum development.*

Influence of Curriculum and Instruction on Interdisciplinary Skills

Figure 3.5 shows the relative contributions of four curriculum-emphasis variables and two instructional variables to senior's self-reported interdisciplinary skills. We found that:

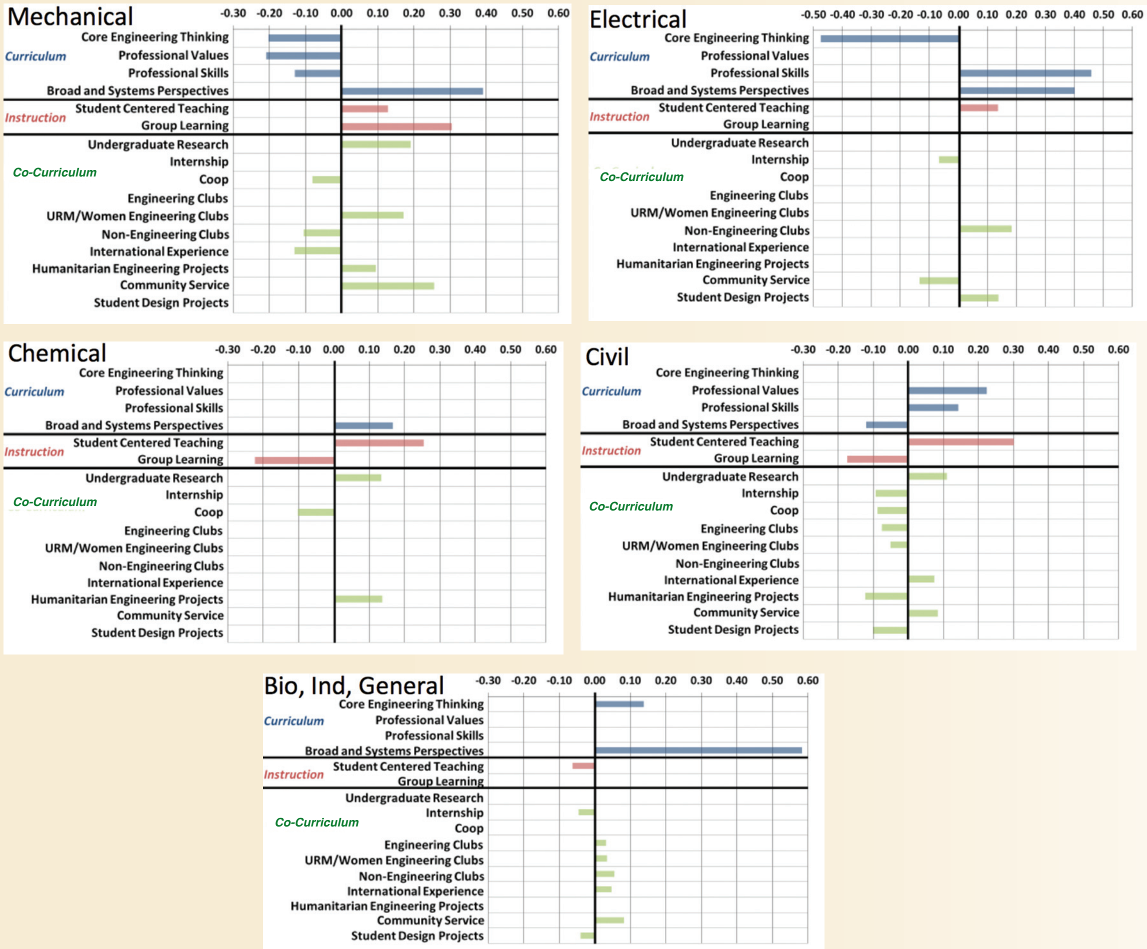
- A curricular emphasis on **Broad and Systems Perspectives** was most consistently related to interdisciplinary skills across the disciplines. The strongest relationship was observed for seniors majoring in Biomedical/Bioengineering, Industrial and General Engineering, while more moderate relationships were found in Electrical and Mechanical Engineering.
- In contrast, for Electrical Engineering seniors, an emphasis on **Core Engineering Thinking** (the use of theory in problem solving, generating ideas about problems and solutions, and creativity) was strongly related to lower reports of interdisciplinary skills. This finding may suggest that the kinds of problems that are stressed in Electrical Engineering courses are tightly focused and technical in nature.

Results for the instructional variables were somewhat mixed, with clearer results for Student-centered Instruction than Group Learning.

- **Student-centered Instruction** (which assesses the clarity of instructors' course expectations and instruction) was moderately related to reports of interdisciplinary skills for students in Civil Engineering, and to a lesser extent in Chemical Engineering.
- **Group Learning** (i.e., the use of active and group learning) was related to higher reports of interdisciplinary skills only for seniors in Mechanical Engineering. Group learning in other most engineering fields may be more focused on the development of discipline-specific knowledge and skills.

Combined with our earlier findings regarding the role of the curriculum, this finding suggests that engineering faculty may need to model purposefully interdisciplinary thinking and dispositions in courses so that students can see what these looks like in practice.

Figure 3.5: Relative Contributions[a] of Students' Curricular, Instructional, and Co-Curricular Experiences to Their Self-Reported Interdisciplinary Competence by Engineering Field



[a] The numbers at the top of each figure are standardized regression coefficients (beta weights) that reflect the relative importance of a variable while controlling for all other variables in the model. Only statistically significant beta weights are shown.

Influence of Co-Curricular Activities on Interdisciplinary Skills

Our analysis of the effects of time spent in 10 out-of-class student activities on students' interdisciplinary skills suggests that engineering schools have yet to effectively marshal the co-curriculum to build this competency. The majority of the relationships between co-curricular activities and interdisciplinary skills are small or non-existent for all the disciplines studied. Significant findings are shown in Figure 3.5 (above).

- The one relationship that approaches practical significance is that between **Community Service** and interdisciplinary skills in Mechanical Engineering.
- Overall, these results probably reflect the types of experiences that students have in these organizations and programs. Those that sponsor discussions, explorations, or interactions with people or phenomena from different disciplines may positively influence interdisciplinary skills while those that focus on discipline-specific matters may have more salutary effects on students' disciplinary knowledge and skills.

Contextual Competence

Good engineering practice requires sensitivity to the fact that engineering problems and their solutions are embedded in a variety of relevant contexts. We defined "contextual competence" as an engineer's ability to anticipate and understand how social, cultural, environmental, political, and other contexts mediate the development of optimal engineering solutions. In addition to an understanding of the technical dimensions of an engineering problem, the contextually competent engineering has the ability to generate alternative solutions that try to balance competing context-related needs and to evaluate and judge the competing technical and contextual assets and liabilities of alternative solutions.

Box 3.D: Curriculum and Instruction to Promote Interdisciplinary Competence

General education requirements:
MIT's *college-wide general education curriculum appears to promote interdisciplinary connections by requiring to take "General Institute Requirements" (GIRs) in addition to their major-field requirements, including a science core, humanities, arts and social sciences, communication, and physical education.*

Multidisciplinary majors and minors:
Student demand and faculty interest at the ***University of Michigan*** *"pushed" academic minors and certificates in multidisciplinary design, entrepreneurship, and international experiences into the undergraduate curriculum. UM's 15-credit minor in multidisciplinary design requires two cycles of design-build-test projects that give students sustained encounters with interdisciplinary thinking.*

Interdisciplinary options in select courses:
Faculty at ***Virginia Tech*** *circumvented rigid curricula by incorporating interdisciplinary team experiences in courses required of more than one major, for example, requiring teams of electrical and civil engineering majors to work collaboratively in a microprocessor systems design course that both majors require.*

General Engineering majors:
Harvey Mudd's *Common Core curriculum gives students "essential knowledge" in the sciences, social sciences, and humanities. The experience challenges faculty to make connections across disciplines, but also builds students' abilities to make similar interdisciplinary connections. Team teaching is a common and accepted approach to ensuring that faculty members are prepared to teach in what one faculty member called a "horizontally integrated" program.*

As in previous analyses, we studied how three sets of factors influenced students' contextual awareness, statistically controlling the effects of students' precollege characteristics. As we have seen in previous sections, the factors that influence students' development of contextual competence vary by engineering field (see Figure 3.6).

- Once again, the types of curricular emphases that students report in their majors are the most consistent, and typically, the strongest predictor of their reported contextual competence.
  - In Chemical and Civil Engineering, the role of the curriculum is especially strong.
  - In Mechanical Engineering, in contrast, the curriculum, instructional methods, and co-curricular participation all contribute similarly to students' estimates of their contextual competence.
- Except in Mechanical Engineering, instructional variables appear to be least useful for developing students' contextual competence.
- Indeed, the co-curriculum is consistently a bigger contributor to contextual competence than are instructional approaches.

Figure 3.6: Relative Influence[a] of Curricular Emphases, Instructional Methods, and Co-Curricular Participation on Students' Self-Reported Contextual Competence.

[a] R^2 indicates the proportion of variance in reported design skills that is attributable to three sets of college experiences

Influence of Curriculum and Instruction on Contextual Competence

In this section we examine more closely the relationship among the curriculum and instructional variables and engineering undergraduates' contextual awareness. As suggested above and shown in greater detail in Figure 3.8, students' perceptions of their programs' curricular emphases are more consistently and strongly related to contextual competence skills than their instructional experiences.

- As we found for the other two outcomes, a curricular emphasis on **Broad and Systems Perspectives** was most consistently and positively related to higher levels of contextual awareness.
- The strongest relationship was observed in Mechanical, Civil and the combined fields of Biomedical/Bioengineering, Industrial, and General Engineering; a moderate influence was seen in Electrical Engineering.
- Focusing curricular attention on **Professional Skills** (such as leadership, teamwork, communication and project management) corresponded to higher reports of contextual competence skills for Electrical engineers, and an emphasis on **Professional Values** was linked to higher reported contextual competence among students in Biomedical/Bio-engineering, Industrial, and General Engineering.

Students' reports of contextual competence were not strongly influenced by the two instructional approaches we examined. Although Figure 3.8 reveals some significant relationships, these are small and not practically important. The only noteworthy finding is that higher reports of **Group Learning** experiences were associated with higher levels of reported contextual awareness for seniors in Mechanical Engineering.

Influence of Co-Curriculum on Contextual Competence

Finally, we examined how students' reports of the time spent in out-of-class experiences shaped their contextual competence. Figure 3.7 depicts the relationship between students' reports of contextual competence and their engagement in 10 co-curricular variables, revealing that very few appear to have a strong impact on students' development in this area.

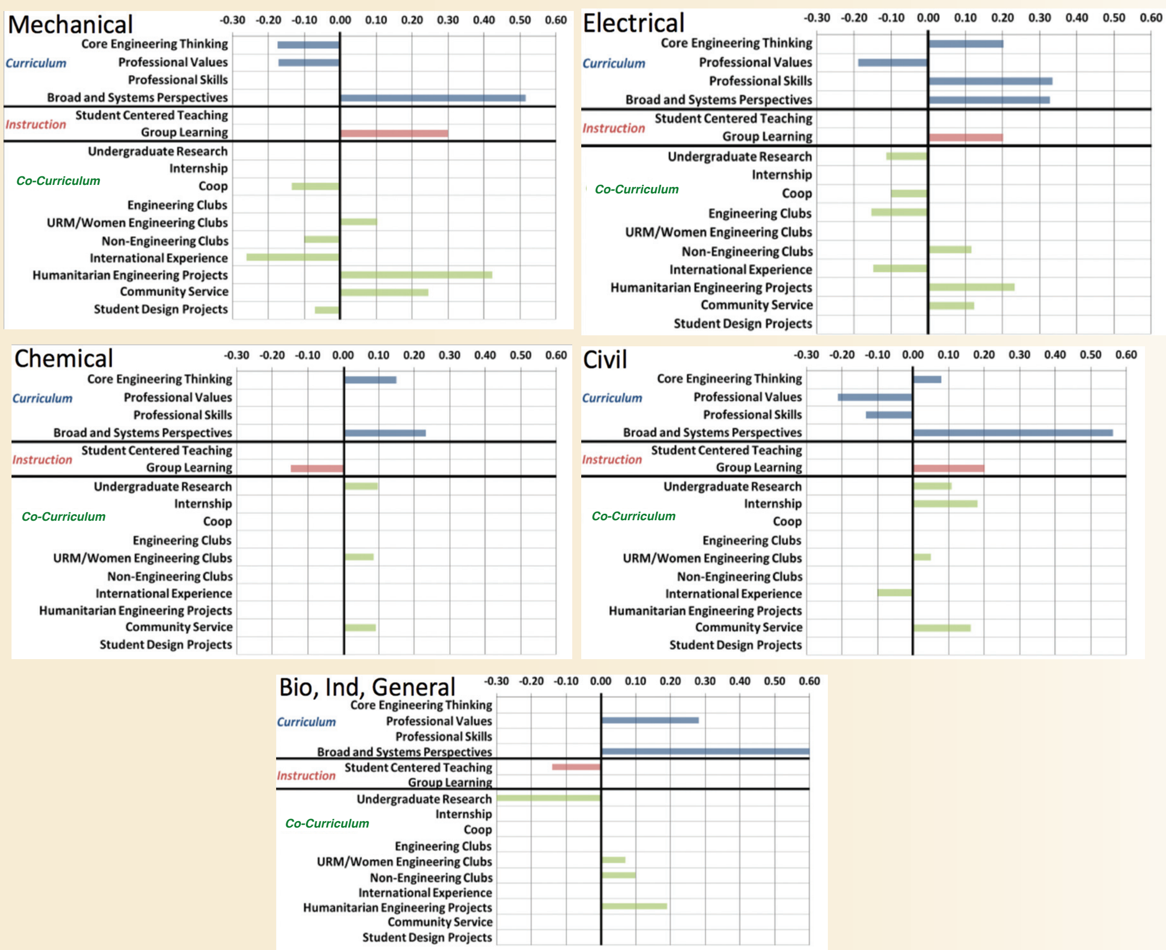
- The strongest effect is seen in Mechanical Engineering, where **Humanitarian Design Projects** were strongly associated with high levels of contextual competence. Similarly, increasing amounts of time spent on **Community Service** projects were linked to higher reports of contextual competence for seniors in Mechanical Engineering, although the effect is more moderate than for Humanitarian Design Projects.

- **International Experiences** were associated with lower self-reports of contextual competence, but this finding may reflect the reality that only about a quarter of the seniors across the fields studied had participated in any kind of international experience in the year preceding the survey administration. Moreover, we included short term, engineering-focused trips as well as semesters of study abroad in our measure, and the shorter-term international trips may not take full advantage of opportunities to consider the cultural and social dimensions of international travel.

- Also notable is the finding that the more time students in Biomedical/Bioengineering, Industrial and General Engineering spent in **Undergraduate Research**, the lower their estimates of their contextual competence. This finding may suggest that the research projects in which students are engaged are highly focused and technical in nature. We saw this same pattern in our findings regarding design skills and we note that our measure of contextual competence includes a number of items that are design-related.

- The consistently small, and sometime inverse, relationships between time spent in student clubs and reports of contextual competence suggest that these activities do not emphasize the larger contexts in which engineering is practiced.

Figure 3.7: Relative Contributions[a] of Students' Curricular, Instructional, and Co-Curricular Experiences to Their Self-Reported Contextual Competence by Engineering Field



[a] The numbers at the top of each figure are standardized regression coefficients (beta weights) that reflect the relative importance of a variable while controlling for all other variables in the model. Only statistically significant beta weights are shown.

Students and faculty in our case study institutions often pointed to student organizations such as WISE, NSBE, SHPE, and SWE as contributing to students' contextual competence. Similarly, they cited engineering-related volunteer service either at the local level or linked to national or international groups (e.g., Engineers Without Borders) as building students' awareness of the role of context in engineering practice. Findings from our national survey suggest, however, that these organizations and experiences are not a substitute for curricular attention to the role of social, cultural, environmental, and other factors in engineering problem-solving and practice.

Box 3.E: Leveraging the Co-Curriculum to Promote Contextual Competence

Institutions that seek to link student learning inside and outside the classroom could take a cue from those institutions that financially supported co-curricular activities and linked the formal curriculum with the co-curriculum. Examples include support for students' out of class design activities. ***Arizona State's*** *Office for Global Engagement offers a portfolio of opportunities, programs, and partnerships that facilitate student and faculty engagement in global and professional activities.* ***Michigan*** *has underwritten BLUElab, a student organization focused on sustainability, and allowed students to earn academic credits for out-of-class design competitions through its multidisciplinary minor program.*

The Role of Design Courses in Student Learning

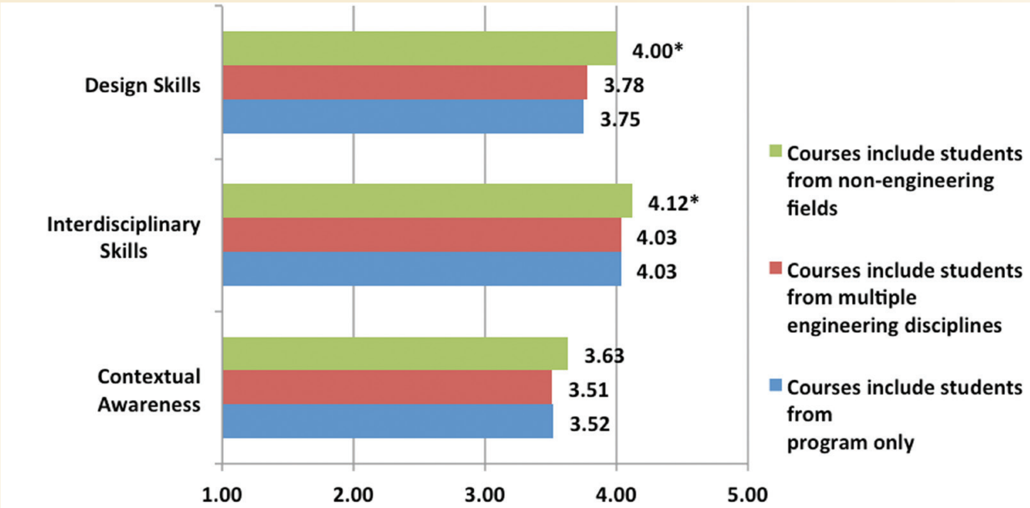
In this final section of Part 3, we suggest how the nature of undergraduate design courses may influence engineering students' development of professional skills. Findings reported in Part 2 of this report reveal that design courses play an important role in providing students with opportunities to apply their problem-solving and professional skills (Figure 2.7). Further examination of these courses suggests that the structure of the course (e.g., whether it is restricted to students in a single program, involves students from multiple engineering disciplines, or enrolls students from engineering and fields outside engineering) is also related to students' learning outcomes. We compared students' self-reported learning outcomes for these three types of first-year and capstone design courses.

Our analyses of sophomore students' learning outcomes indicated no statistically significant differences based on the type of first-year design course taken. This finding may be attributable to the fact that the first-year design experience varies in important ways by department and institution. The first-year design experience may also be less intense and less dependent on engineering knowledge and skills than the capstone experience, where we found some statistically significant differences in learning outcomes.

As shown in Figure 3.8, seniors who enrolled in a capstone course with peers from outside engineering reported significantly higher design skill levels (mean=4.00) than students in courses that included peers only from other engineering fields (3.78), or from single-discipline courses (3.75). The effect sizes for these differences (.36 and .33) are, modest, but potentially meaningful in practice.

Seniors who took a capstone course with students from outside engineering also reported higher levels of interdisciplinary competence (mean = 4.12) than those who took their capstone that included students from multiple engineering programs (4.03). While this difference is statistically significant, the effect size (.2) for this difference is not practically meaningful. Other differences in Figure 3.8 are not statistically significant, yet it is worth noting that the overall comparisons in this analysis suggest that engaging with peers from outside one's discipline is at least marginally related to higher learning outcomes. These findings suggest further study of the nature of the capstone design experiences and its influence on the development of students' knowledge and professional skills is warranted.

Figure 3.8: Comparison of Self-Reported Design Skill Ratings of Seniors in Design Courses with Differing Student Composition



*Asterisks indicate a statistically significant difference ($p<0.05$). For Design Skills, there is a statistically significant difference between students in courses that include students from non-engineering fields and both those in courses that include students from multiple disciplines and those in courses that includes students from the same program only. For Interdisciplinary Skills, there is a statistically significant difference between seniors in courses that include students from non-engineering fields and those in course that include students from multiple disciplines.

* * * * *

The analyses presented in this part of our report revealed considerable similarity across engineering disciplines in the emphasis on the knowledge and skill sets targeted for this study. The analyses presented in this section, however, reveal that engineering subdisciplines matter in terms of students' learning: the variables that best explain differences in students' self-assessments of their learning vary by engineering field. Yet, it is also clear that the formal curriculum, more than types of instruction and participation in out-of-class activities, is the surest route to promoting students' learning in three of the important knowledge and skill sets needed by the "engineer of 2020" – design skills, interdisciplinary competence, and contextual competence. In addition, analyses of the relationship between students learning and the type of first-year and capstone design course offered suggests that working with students from different fields of study, both in and beyond engineering, has positive impacts on students' design and problem-solving skills and their awareness of the importance of contextual factors in engineering problem-solving. Greater alignment between the kinds of problems students solve in courses, instructional strategies such as assessments that stress the integration of knowledge and skills from different disciplines, and purposeful linkages between in- and out-of-class activities could optimize students' development of these critical engineering skills and dispositions.

Part 4: Potential Barriers to Realizing the Vision of *The Engineer of 2020*

This final set of findings reveals some of the challenges facing engineering schools and programs that want to embrace the vision of the "Engineer of 2020" fully. These include the reality that few engineering faculty (or those in other fields, for that matter) are well prepared to teach undergraduates, so professional development serves as a means to 'make up for lost time.' Additional challenges arise from institutional reward systems that prioritize research over teaching, but also from faculty members' themselves, who hold different beliefs about what is, and is not, their responsibility as a teacher.

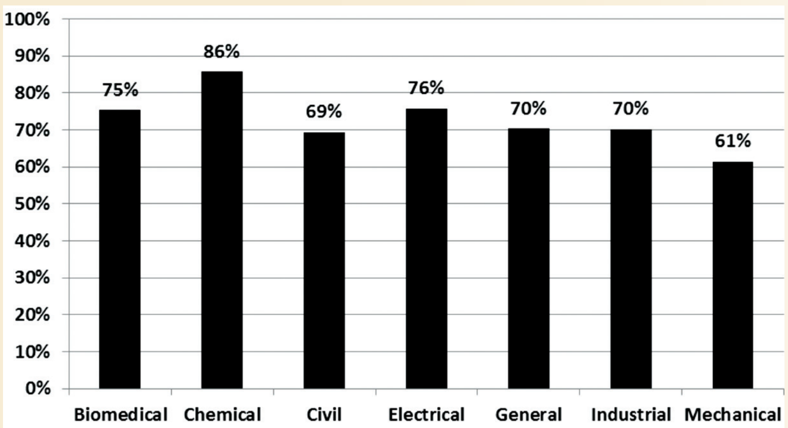
Getting to 2020: Faculty Preparation to Teach and Engagement in Professional Development

Where do engineering faculty have conversations about ideas like those in *The Engineer of 2020*? Department meetings are one possible venue for more formalized discussions, but if the engineering community wanted to pave the way for curricular and instructional reforms that would help prepare a diverse student population for the engineering workplace of the future, graduate education should be a critical starting point. One of the striking, if not surprising, findings of our study, however, is how very few engineering faculty reported any formal preparation to teach before taking their first faculty position.

In our survey, we asked tenured/tenure-eligible faculty and full-time, fixed-term instructors whether they had any of the following before taking their first teaching position: attended a program for graduate students on how to teach, took a course on college teaching, completed a certificate in teaching, or taught in K-12 schools. We also specifically asked if they had "no formal training."

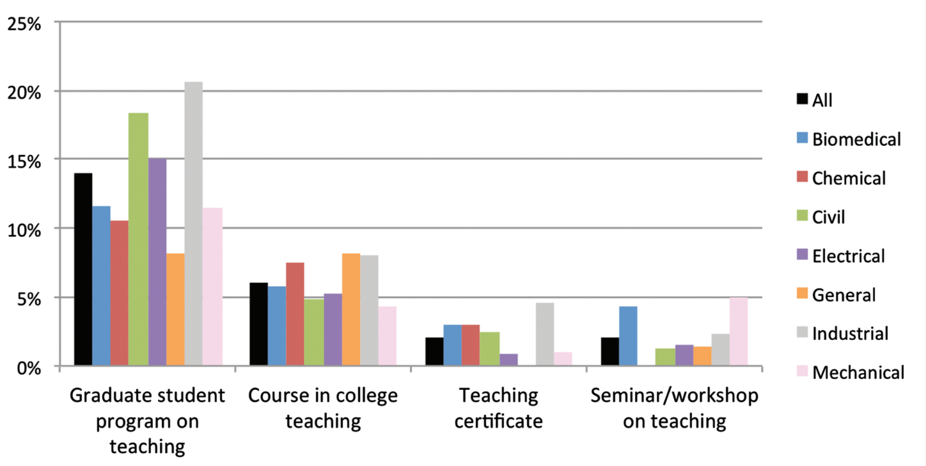
Across the disciplines we studied, approximately 70% of engineering faculty members and instructors reported *no* formal preparation to teach (Figure 4.1). Mechanical engineers reported the most formal training in teaching, with nearly 40% reporting at least some level of preparation, including graduate school programs, courses, or certificates. Chemical engineers reported the least, with 86% reporting no formal training at all (10 percentage points higher than any other engineering discipline in our study). These overall low levels of formal preparation, of course, are not unique to the field of engineering, but they are nonetheless worth noting given the past two decades' persistent calls for instructional reforms in the field.

Figure 4.1: Faculty Members' and Instructors' Reports of *No* Formal Teaching Preparation by Engineering Field



The picture of instructional preparation gets even bleaker when we acknowledge how broadly the E2020 faculty survey defined "formal preparation" to teach. Figure 4.2 reveals that overall less than 15% of faculty reported that they had attended *some* kind of program for graduate students on how to teach. That program could have been a day-long or an hour-long – our data do not tell us anything about program focus or duration, but our definition is surely generous in what it allows respondents to count. Less than 10% of the more than 1,100 faculty and instructors in any discipline reported took a course on college teaching, and less than 5% earned a certificate for, college-level teaching or attended a seminar or workshop on teaching. It seems entirely reasonable to conclude that engineering faculty (like many in other fields of study) do not have a lot of preparation to do what they are asked (and paid) to do in the classroom.

Figure 4.2: Faculty and Instructors' Reports of Formal Teaching Preparation by Engineering Field



Engineering faculty, of course, may continue to learn about teaching once they enter the profession. Our analyses (not shown) reveal that only about 25% of engineering faculty and instructors reported that they did *not* engage in any professional development related to instruction in the year prior to our survey. About 20% participated in at least one or two of these activities.

Faculty and instructors participated in a variety of types of instructional development opportunities (Figure 4.3).

- More than 60% reported making a "significant effort to improve my teaching or one of my courses."
- Over 40% reported reading about education topics.
- Almost a third report taking classes or working in industry to improve their knowledge or skills; such professional development can enhance both research and teaching activities.
- Similarly, 30% report attending a workshop on teaching, learning or assessment.
- About 15% reported writing a conference paper, article or chapter on a teaching or learning topic in the past year, or attending an engineering education conference.

Figure 4.3: Faculty and Instructors' Reports of Participation in Activities to Improve Teaching and Learning by Position and Academic Rank

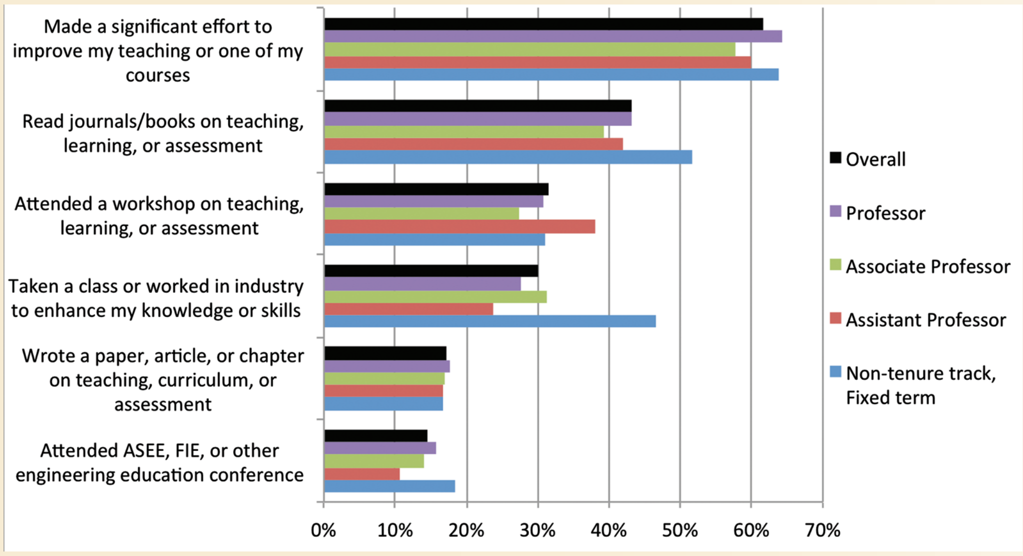
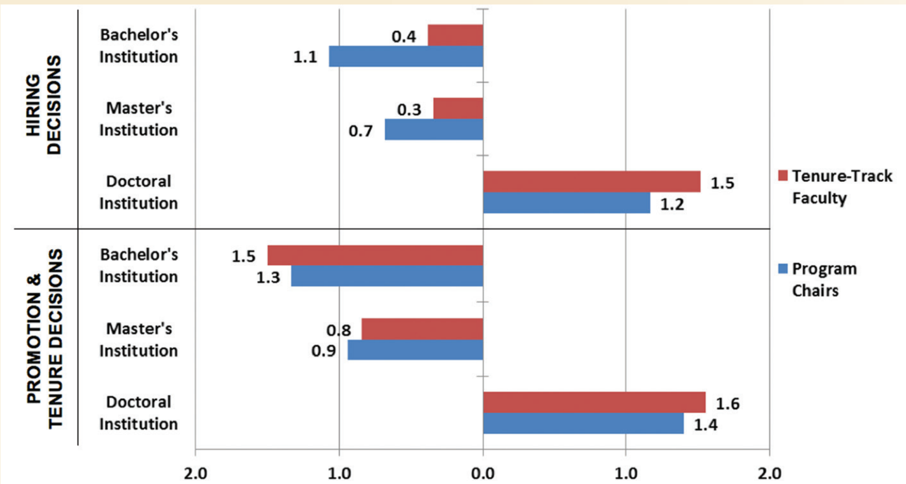


Figure 4.3 also indicates that, however modest the level, participation in instructional development activities is fairly consistent across appointment types and academic ranks. Assistant professors are slightly more likely to attend workshops on teaching, learning, and assessment, and non-tenure-track instructors are somewhat more likely to read about teaching, take classes or work in industry to enhance their skills and knowledge. It is sometimes assumed that non-tenure-track faculty are less committed to their professional development, but this finding and other studies (e.g., Umbach, 2007) reveal that full-time, non-tenure-track instructors are similar to their tenured and tenure-eligible peers in their commitment to teaching.

Faculty Perceptions of Institutional Reward Systems

The choices that faculty members make are influenced, to some extent, by their perceptions of what is rewarded by their colleges and universities, as well as by what they personally value (Blackburn & Lawrence, 1995; Lawrence, Ott, & Bell, 2012; Tierney & Minor, 2004). When we asked tenured and tenure-line faculty in different kinds of institutions – those in which the highest degrees offered were baccalaureate, master's, or doctoral – we confirmed what most observers of higher education suspect: Faculty in doctoral universities report that research is rewarded more than teaching in both promotion and tenure and hiring, while those in baccalaureate and master's institutions perceive that teaching is more important than research, but, interestingly, more so in hiring decisions than in promotion and tenure decisions (see Figure 4.4). Given the topics in this section, the analyses reported below are based only on the aggregated responses of tenure-track and tenured faculty.

Figure 4.4: Faculty Members' and Program Chairs Perceptions of the Weight Given to Research and Teaching in Promotion and Tenure and Hiring Decisions



Measured on a 7-point scale where the midpoint of the scale (0) is equal weight on teaching and research.

The finding of greater importance, however, is that that while program chairs and faculty have very similar perceptions of the weight placed on teaching and research in the hiring process (no statistically significant differences between the groups), they disagree somewhat regarding the relative weight of teaching and research in promotion and tenure decisions. Faculty and chairs in master's and doctoral institutions appear to be somewhat more aligned in their views of what counts in promotion and tenure, but the differences between chairs and faculty in doctoral institutions are statistically different.

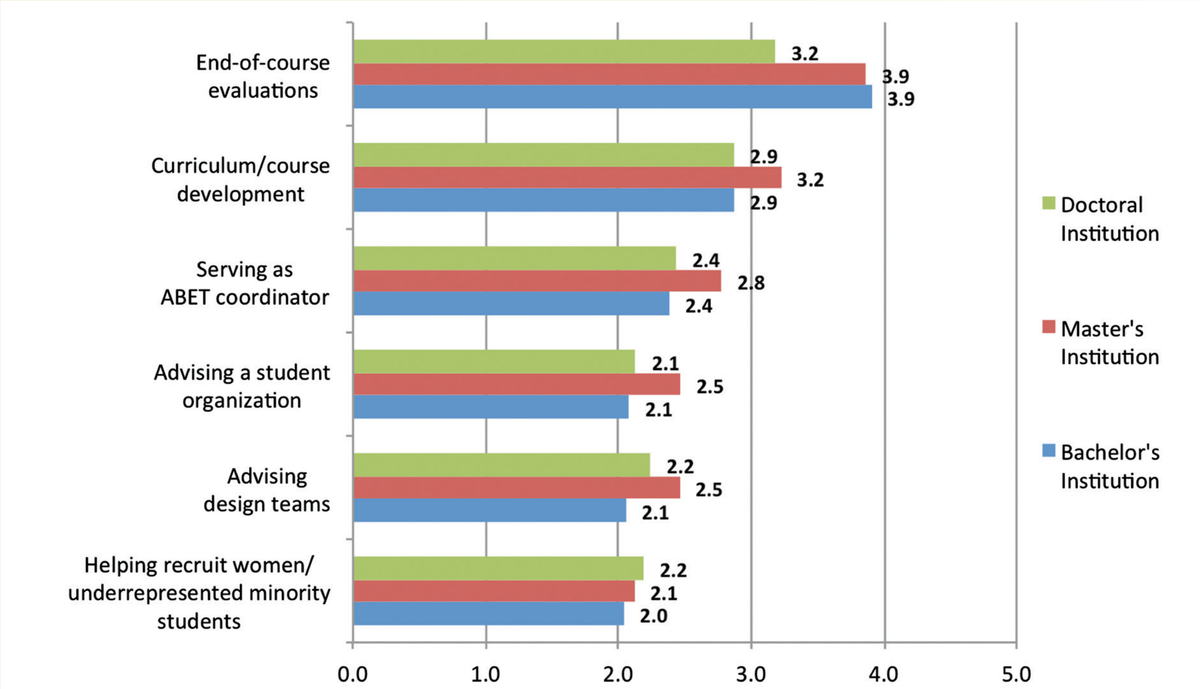
The finding that chairs and faculty differ in their assessments of the value placed on teaching and research in reward systems aligns with earlier findings from the *Engineering Change* study, which was conducted on a nationally representative sample of 40 engineering schools (Lattuca et al., 2006).

While sample sizes may have affected the significance levels for the current analysis, prudence suggests that more discussion and greater transparency regarding what counts in hiring and promotion and tenure decisions may lead to better understandings of how such decisions are made.

We also found that faculty perceptions of the kinds of activities and productivity levels that count in promotion and tenure vary by institutional types in predictable ways (analysis not shown). Faculty in all kinds of institutions – even those in teaching-oriented baccalaureate institutions – believed that education-related conference papers, publications and grants were valued slightly to moderately in promotion and tenure decisions, but in all kinds of institutions, engineering-specific products were valued more. These findings are consistent with previous research findings indicating that the emphasis on research productivity across academic disciplines affects all sectors of higher education (Fairweather, 1996; Schuster & Finkelstein, 2006). Such beliefs, regardless of their validly, are important since they may shape faculty members' choices about where to spend their time and energies.

Figure 4.5 presents an array of teaching and service activities and faculty members' perceptions of their value in promotion and tenure decisions (measured on the same five-point scale described above). Faculty in all types of institutions believe that end-of-course evaluations of teaching quality carry the most weight in these decisions, although those perceptions are notably less frequent among faculty members at doctoral degree-granting institutions.

Figure 4.5: Faculty Members' Ratings of Importance of Service and Teaching-related Activities in Promotion and Tenure Decisions by Type of Institution



Scale: 1 = Not at all, 2 = Slightly, 3 = Moderately, 4 = A good deal and 5 = A great deal.

Faculty across institutional types also tend to believe that service activities are "slightly important" in promotion and tenure decisions. Of these service activities, curriculum development appears to be most valued, which may be a promising sign for expanded innovation in undergraduate engineering education.

The following differences are statistically significant findings:

- Engineers in master's institutions say their institutions are more likely to value curricular development activities and service as an ABET coordinator than do faculty in doctoral institutions.
- Master's institution faculty members are also more likely than both doctoral and baccalaureate institution faculty to report that advising design teams and student organizations is valued in promotion and tenure at their institutions.

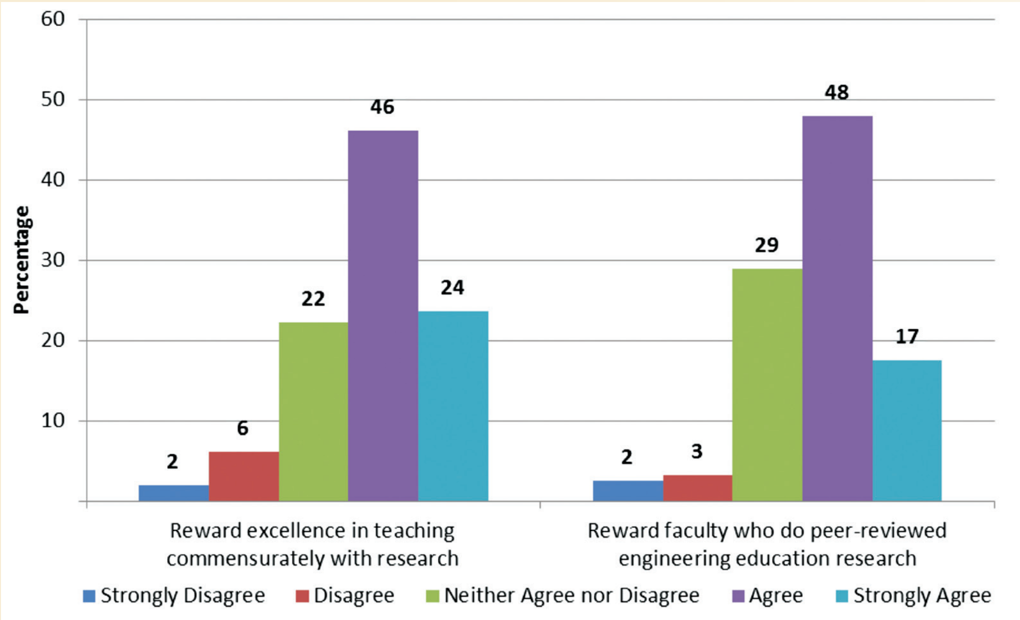
We found no significant differences by institutional type in faculty members' assessments of the value assigned to end-of-course evaluations or to recruitment efforts intended to bring more women and historically underrepresented students into engineering. Whereas student course ratings receive "moderate" to "a good deal" of emphasis, recruiting diverse colleagues and students was viewed as only "slightly important" in promotion and tenure decisions. Considering the need to improve teaching, the heavy reliance on co-curricular student activities for developing students' professional skills, and the pressing need to diversify the engineering workforce, greater incentives – and perhaps also clearer and more explicit communication about what is valued in the faculty reward systems – appear to be needed.

In addition to asking faculty what they believed counted in hiring and promotion and tenure decisions, we asked faculty what engineering programs should reward. Figure 4.6 indicates that:

- 70% of the faculty surveyed believed their engineering programs should reward excellence in teaching commensurate with research.
- Only 8% strongly disagreed or disagreed with this statement.
- Two-thirds also agreed (48%) or strongly agreed (17%) that their programs should reward faculty who publish peer-reviewed engineering education research.
- Nearly 30% of faculty, however, neither agreed nor disagreed with this latter statement, suggesting a lack of consensus about rewarding this form of scholarship.

Findings such as these can be useful conversation-starters among program faculty, as well as among members of promotion and tenure committees, about the extent to which faculty members' values are reflected – or not – in such decisions.

Figure 4.6: Faculty Members' Beliefs about Rewards for Teaching and Engineering Education Research



Engineering faculty members need a clear understanding of what is valued institutionally and how much it is valued in critical decisions such as promotion and tenure, decisions with significant consequences for both individuals and institutions. Regular and straightforward communication about the criteria and standards for making these decisions will also benefit faculty, for whom the promotion and tenure decision can be extremely stressful.

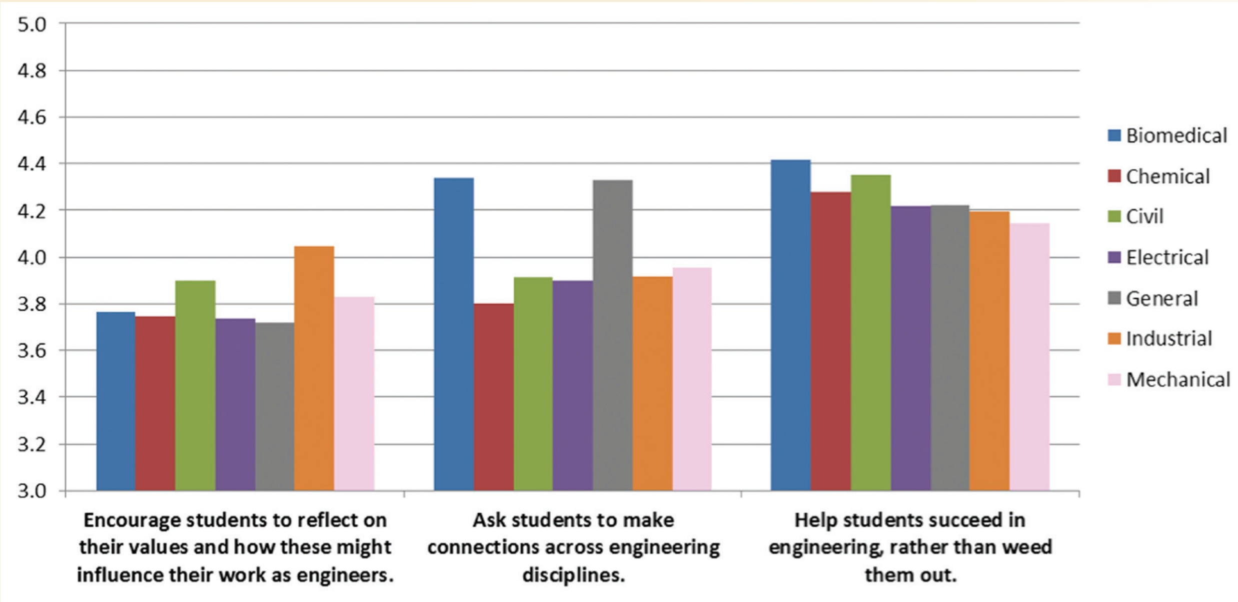
Faculty Members' Beliefs about Their Teaching Responsibilities

Our survey asked faculty and instructors a number of questions designed to assess the level of their agreement with statements that capture key ideas about teaching and undergraduate education appearing in reports such as the NAE's *Engineer of 2020* and ASEE's *Innovation with Impact* (Jamieson & Lohmann, 2012). Respondents used a five-point Likert scale, where 1 = Strongly Disagree, 2 = Disagree, 3 = Neither Agree nor Disagree, 4 = Agree, and 5 = Strongly Agree.

When asked to respond to the statement that "As a teacher, it is your responsibility to encourage students to reflect on their values and how these might influence their work as engineers," faculty and instructors across the engineering disciplines studied consistently hover below "agree" (Figure 4.7). The .9 standard deviation for this question (not shown) suggests some variation in faculty opinion, although it is noteworthy that Industrial Engineering faculty agreed more with this statement than their counterparts in other engineering fields.

In contrast, when asked whether it was their responsibility to ask students to make connections across engineering disciplines, faculty and instructors across disciplines tended to agree, although those in biomedical/bioengineering and general engineering agreed more with this statement than did other faculty. There is, again, some variation among faculty across fields (.79 standard deviation, not shown).

Figure 4.7: Faculty Members' Views, by Discipline, of Their Responsibilities as Teachers to Promote Reflection, Crossdisciplinary Connections, and Student Success



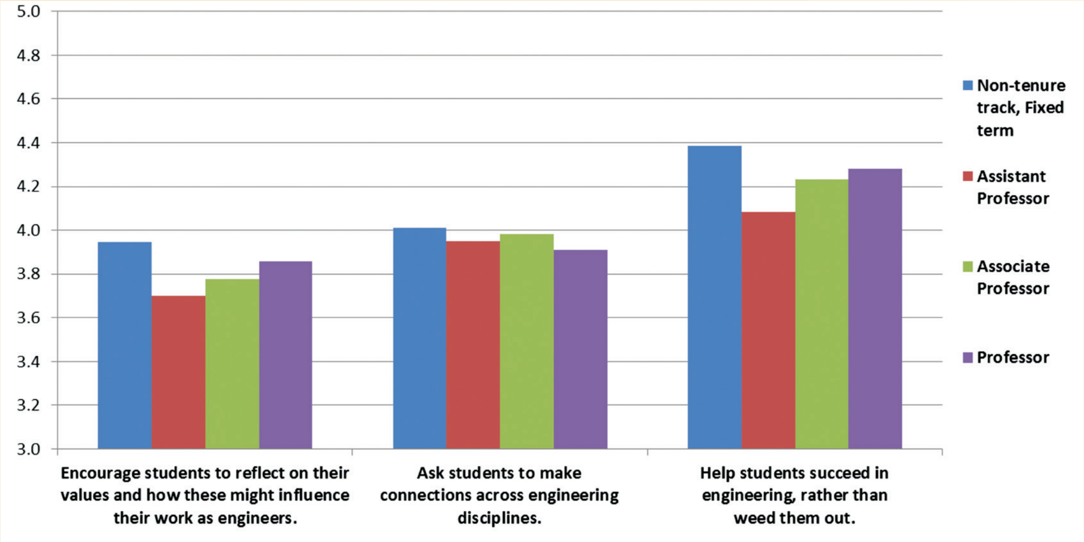
Scale: 1 =Strongly disagree, 2 = Disagree, 3 = Neither agree nor disagree, 4 = Agree, 5 = Strongly agree

Those concerned that engineering faculty are likely to view themselves as "gatekeepers" rather than educators may be reassured by the finding that engineering faculty and instructors across the seven disciplines we studied tended to agree with the statement that part of their role is to help students succeed rather than to "weed them out" of the field. How faculty and instructors act on this belief is an important topic for future research.

Figure 4.8 reports how faculty at different academic ranks responded to these same questions about their responsibilities as teachers.

- Instructors agreed significantly more than assistant professors that their role is to encourage students to reflect on their values and their potential influence on their engineering practice.
- Faculty of all types and ranks tended to agree that they should ask students to make connections across engineering disciplines.
- Full and associate professors, however, agreed significantly more than assistant professors that their role is to promote student success.
- Instructors agreed significantly more than their tenured/tenure-line counterparts that they should help students succeed rather than weed them out of engineering.

Figure 4.8: Faculty Members' Views, by Academic Rank, of Their Responsibilities as Teachers to Promote Reflection, Crossdisciplinary Connections, and Student Success

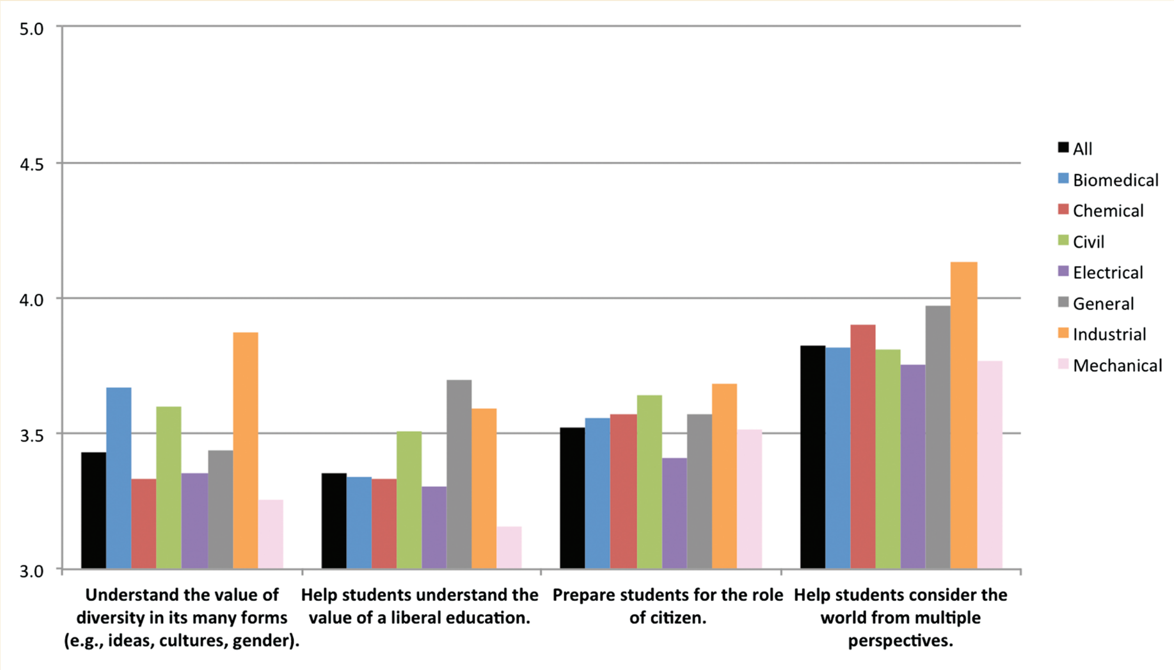


Scale: 1 =Strongly disagree, 2 = Disagree, 3 = Neither agree nor disagree, 4 = Agree, 5 = Strongly agree

There appears to be some inconsistency between the high level of support for asking students to make connections across disciplines (Figure 4.8) and the very few opportunities that students have for interdisciplinary design experiences in their engineering major (see Table 2.1) and the modest emphasis on disciplinary connections in the curriculum (Figure 2.4). This seems to suggest that the desire for greater attention to disciplinary interconnections has not yet affected the undergraduate curriculum.

As shown in Figure 4.9, faculty and instructors responses to statements about their role in helping students understand the value of diversity and of liberal education varied by engineering field hover overall just above the midpoint of the response scale – neither agree nor disagree.

Figure 4.9: Faculty and Instructors' Views, by Discipline, about Teachers' Responsibilities to Help Students Understand the Value of Diversity, Liberal Education, Preparation for Citizenship, and Seeing through Multiple Perspectives



Scale: 1 =Strongly disagree, 2 = Disagree, 3 = Neither agree nor disagree, 4 = Agree, 5 = Strongly agree

- Overall, faculty opinions about whether it is their responsibility to help students understand the value of diversity varied (standard deviation = 1.0; not shown).
    - Biomedical, civil, and industrial engineers agreed significantly *more* than mechanical engineers that it is their responsibility to help students "understand the value of diversity in its many forms (e.g., ideas, cultures, gender)."
    - Electrical engineers agreed significantly *less* than civil and industrial engineers with this statement about the importance of diversity.
- Engineering faculty as a whole tended to be noncommittal regarding their contribution to students' understanding of liberal education.
    - Faculty in General Engineering programs agreed significantly *more* than those in Electrical Engineering programs that they should help students understand the value of a liberal education.
    - Faculty in Civil, General and Industrial Engineering agreed significantly *more* than colleagues in Mechanical Engineering that they should help students understand the value of a liberal education.
- There appears to be more consistent – but still only moderate – support across engineering disciplines for the idea (prominent in the 2004 NAE report) that engineering programs should prepare students for their roles as citizens. There is a statistically significant difference, however, only between the ratings of Civil and Electrical Engineering faculty on this statement, with Civil Engineering faculty registering more support.
- Faculty and instructors were more inclined to consider helping students see the world from multiple perspectives as one of their responsibilities. The average rating for faculty in all the fields surveyed was above 3.8.
    - Industrial Engineering faculty were significantly more likely to support this statement than faculty in Civil, Electrical and Mechanical Engineering.
    - Although one might expect support for teaching about the value of diversity to align with an emphasis on multiple perspectives, it did not. For engineers, the term multiple perspectives may not be associated with differences in viewpoints due to one's gender, race, or cultural background.

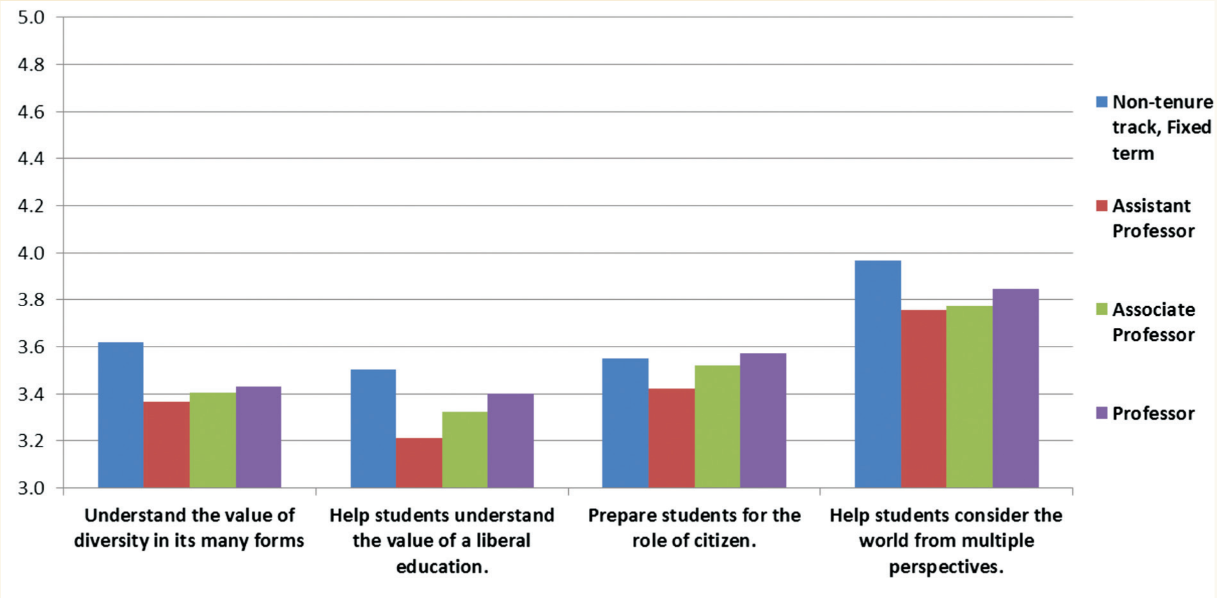
Although faculty generally supported the idea of helping students consider multiple perspectives, opportunities to work with students from other engineering disciplines are not common, and interdisciplinary design experiences that involve students from fields beyond engineering are rare. For many engineering faculty, helping students make connections across fields and view the world from multiple perspectives seems to be confined within the boundaries of the engineering disciplines. NAE's aspiration for an engineering profession that embraces "crossdisciplinary fertilization" and "openness to interdisciplinary efforts involving non-engineering disciplines" appears to be far from realization (2004, p. 50).

Despite evidence of some support for the proposition that faculty in preparing students for their civic roles (widely believed to provide the foundations for citizenship), many engineering faculty do not appear to view liberal education as worthy of promotion. This may reflect a lack of understanding of what the term means or what a liberal education entails. Faculty discussions of their program curricula might include consideration of how undergraduate programs might achieve the NAE's vision of engineers who are solidly grounded in mathematics and sciences, but who have an expanded vision of design cultivated through studies in the humanities, social sciences, and economics (p. 49).

Figure 4.10 offers some insights into who may be most open to such ideas. The figure presents faculty responses by academic rank to these same questions about curricular emphasis on diversity, liberal education, citizenship education, and multiple perspectives. Our analyses revealed statistically significant differences between non-tenure-track and assistant professors on three of the four statements.

- Non-tenure -track faculty are significantly more likely than assistant professors to believe they have a responsibility to help students understand the value of diversity and of liberal education, and to help students consider the world from multiple perspectives.
- Full professors are also significantly more likely than assistant professors to believe they should help students understand the value of a liberal education.

Figure 4.10: Faculty and Instructors' Views, By Academic Rank, about Teachers' Responsibilities to Help Students Understand the Value of Diversity, Liberal Education, Preparation for Citizenship, and Seeing through Multiple Perspectives



Scale: 1 =Strongly disagree, 2 = Disagree, 3 = Neither agree nor disagree, 4 = Agree, 5 = Strongly agree

Deans and policy makers might explore ways to take advantage of senior faculty members' perspectives in the interest of developing both good citizens and good ideas.

* * * * *

Achieving the vision of the "Engineer of 2020" requires that engineering schools and programs align their undergraduate curricula and instructional practices with goal of preparing engineers to work collaboratively on complex problems in technologically fluid and culturally diverse contexts. The challenge to realizing this vision begins in graduate school, where only 30% of engineering faculty reported having any formal preparation to teach before offering their first course – even when "formal preparation" is very generously defined. Fortunately, many faculty members report making personal efforts to improve their teaching, taking courses or working in industry to enhance their content knowledge, by reading engineering education journals, and attending workshops on teaching, learning, or assessment.

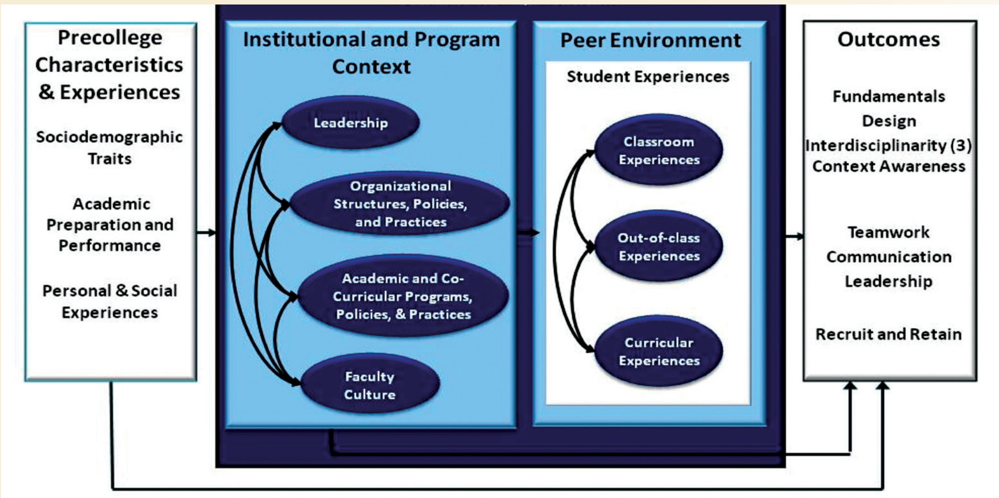
Still, faculty reward and incentive systems can discourage a strong focus on the educational mission. Faculty in many universities report a heavy emphasis on research (and less on teaching) in their programs' promotion and tenure and merit salary decisions, which may deter some from spending substantial amounts of time on curricular and instructional projects to improve students' learning and career preparation. Interestingly, faculty respondents across the different kinds of colleges and universities agree their engineering programs should reward excellence in teaching commensurate with research.

A final challenge is the difficulty of linking beliefs about what engineering education *should* be with what is actually done in the classroom. Although engineering faculty support many of the goals associated with the vision of *The Engineer of 2020*, curricular realities lag behind. While the engineer of the future will need to work on interdisciplinary problems in interdisciplinary teams, integration of disciplinary perspectives into the undergraduate curriculum does not appear to be a widely shared goal. Engineering faculty view the need to help students make connections among engineering disciplines as their responsibility, but innovative engineering solutions may require seeking new connections *beyond* the field's borders.

Appendix A: E2020 Study Methods

The Prototype to Production (P2P) and Prototyping the Engineer of 2020 (P360) studies rest on a conceptual framework originally developed by Terenzini and Reason (2005) that brings coherence to over 50 years of research in higher education (Figure A.1). In general, the model hypothesizes that pre-college characteristics shape students' engagement with various aspects of their institution. Students' levels of engagement are affected by a variety of curricular (e.g., general education coursework, academic major coursework, socialization to the major), classroom (e.g., pedagogies and instructor behaviors), and out-of-class experiences and conditions, all of which occur within an institutional context that includes an institution's internal organizational characteristics, structures, practices, policies, and faculty and peer cultures and environments (for a more detailed discussion, see Lattuca & Litzinger, 2014). P2P survey questions, as well as P360 interview protocols, map onto this framework to organize data collection and analysis.

Figure A.1: Conceptual framework



P2P Study Methods

To develop the six survey instruments for the P2P study, the research team designed a rigorous, two-year process that included 1) literature reviews on key topics; 2) individual interviews with administrators, faculty members, and alumni at Pennsylvania State University and City College of New York (institutions with project team members); and 3) focus-group interviews with students at those same institutions. We used what we learned from these information gathering efforts to develop the six survey instruments. We pilot tested the 4-year student and faculty surveys at Pennsylvania State University prior to administering them to the target populations at our sampled institutions. Surveys for program chairs and associate deans were reviewed by administrators in small focus groups. The community college student survey was reviewed and pilot tested at Hostos Community College in New York City.

We used the American Society for Engineering Education's institutional databases for guidance in drawing this study's samples using institution- and program-level information for the 2007–08 academic year for enrolled students and faculty. Our study focused on seven engineering disciplines (biomedical/bioengineering, chemical, civil, electrical, general, industrial, and mechanical). Institutions in the final sample are representative (with respect to type, mission, and highest degree offered) of the national population of institutions offering baccalaureate degrees in engineering.

The final sample of four-year institutions closely mirrors the proportions of public and private institutions with accredited engineering programs in the seven targeted fields (Table A.1). We statistically corrected for any variations by institutional type (e.g., doctoral-granting) in our analyses. Table A.2 lists the institutions that participated in the study.

Table A.1: Characteristics of Four-Year Institutions in P2P Sample

Institutional Characteristics	Population[1]	31-Institution Sample
Institution Type		
Doctoral	66.3%	61.3%
Master's	26.1	19.4
Baccalaureate	7.6	19.4
	100%	100%
Control		
Public	66.7%	61.3%
Private	33.3	38.7
	100%	100%

[1]The population of eligible institutions included 288 colleges and universities that offered at least two of the six engineering subfields targeted for the study.

Table A.2: P2P Institutional Sample

Research Institutions:
Arizona State University (Main & Polytechnic)[1]
Brigham Young University
Case Western Reserve University
Colorado School of Mines
Dartmouth College
Howard University
Johns Hopkins University
Massachusetts Institute of Technology[1]
Morgan State University[2]
New Jersey Institute of Technology
North Carolina A&T[2]
Purdue University
Stony Brook University
University of Illinois at Urbana-Champaign
University of Michigan[1]
University of New Mexico[3]
University of Texas, El Paso[3]
University of Toledo
Virginia Polytechnic Institute and State University[1]

Master's/Special Institutions:
California Polytechnic State University[3]
California State University, Long Beach[3]
Manhattan College
Mercer University
Rose-Hulman Institute of Technology
University of South Alabama

Baccalaureate Institutions:
Harvey Mudd College[1]
Lafayette College
Milwaukee School of Engineering
Ohio Northern University
Penn State Erie, The Behrend College
West Virginia University Institute of Technology

[1] P360 Study Institution
[2] Historically Black College/University
[3] Hispanic-Serving Institution

Each survey was administered to the appropriate target-population group. Penn State's Survey Research Center completed data collection through web-based and/or paper questionnaires. Table A.3 provides information on the populations, respondents, and response rates for each survey. The response rate for faculty members was on a par with those of earlier surveys completed by the research group and others, but the student participation rate was below expectations. Survey fatigue appears to be a likely explanation; other researchers report low response rates, suggesting the ubiquity of online surveys as the source of the problem. Thus, the low rates appear not to be a problem specific to the P2P surveys (see, for example, Baruch, 1999; Porter & Umbach, 2006).

We accounted for differences in the proportional distributions between student and alumni respondents and their parent population by weighting cases to adjust for any response bias due to gender, race/ethnicity, class year, and discipline within an institution, as well as to adjust for differences in institutional response rates. Table A.4 shows that the weighted sample of engineering students reflects the overall population of undergraduate engineers from our sample of institutions. Similar adjustments were made with the faculty dataset. The faculty sample was adjusted for response bias relating to academic rank, gender, race/ethnicity, discipline, and institutional response rate. (Information on faculty and alumni samples can be accessed at http://deepblue.lib.umich.edu/handle/2027.42/107462.)

Table A.3: P2P survey response rates for six stakeholder groups

	Number of Surveys Sent	Number of Respondents	Response Rate
Associate Deans	32	29	91%
Program Chairs	125	86	69%
Faculty	2,942	1,119	38%
4-year Students	32,737	5,249	16%
Alumni	7,307	1,403	19%
2- year Students	8,261	1,245	15%

Table A.4: Characteristics of the population of 2008 engineering students, survey respondents, and their institutions

	288-Institution Population [a] (N = 136,761)	31-Institution Sample [a] (n = 32,565)	Respondents [b] (n = 5,249 [c])
Discipline			
Biomedical	6.5%	6.5%	6.3%
Chemical	10.4	10.4	10.5
Civil	19.5	16.0	18.1
Electrical	21.8	21.4	18.9
Industrial	6.1	6.0	4.9
Mechanical	32.1	27.8	34.7
General	3.6	11.9	6.6
	100.0%	100.0%	100.0%
Gender			
Men	81.5%	80.7%	80.6%
Women	18.5	19.3	19.4
	100.0%	100.0%	100.0%
Race/Ethnicity			
African American	5.2%	5.9%	4.3%
Asian or Pacific Islander	12.1	12.3	13.2
Hispanic	6.5	6.1	11.2
Amer. Indian/Alaskan Native	0.6	0.6	0.3
Other [d]	6.1	7.2	12.9*
Foreign	5.9	7.1	7.3
Caucasian	63.5	60.7	50.9
	100.0%	100.0%	100.0%
Level			
Sophomore	6.1%	27.9%	22.3%
Junior	39.0	29.0	35.0
Senior	54.9	43.1	42.7
	100.0%	100.0%	100.0%

[a] Weighted by discipline, class standing, gender, race/ethnicity, institutional response rate
[b] Weighted by discipline, gender, race/ethnicity, institutional response rate
[c] Weighted by discipline, gender, race/ethnicity, faculty rank, institutional response rate
[d] Other category includes Naturalized citizen, Middle Eastern, Multirace, and Other.

To maintain the maximum number of cases and, thus, statistical power, missing data were imputed for each sample group (except program chairs and associate deans). To facilitate interpretation, we used factor analytic techniques to reduce data from several survey items into fewer, more reliable and interpretable measures (i.e., scales). Each survey item was assigned to a factor based on the magnitude of the loading, the effect of keeping or discarding the item on the scale's internal consistency reliability, and professional judgment. We formed factor scales by taking the sum of respondents' scores on the component items of a factor and dividing by the number of items in the scale, as recommended by Armor (1964).

P360 Study Methods

The P360 case study institutions were identified through quantitative analyses of a nationally representative dataset developed for a previous study of the effects of ABET's outcomes-based EC2000 accreditation criteria and consultation with the E2020 National Advisory Board.

In 2007–08, the research team divided into three smaller teams of faculty members and graduate research assistants from engineering and/or education to conduct the six case studies. Data collection relied on multiple sources of evidence: 1) personal and group (or focus) interviews with faculty members, administrators, students, and professional staff (e.g., admissions and student support services); 2) observations of classes and notable academic programs; 3) archival records (e.g., meeting minutes) and other artifacts (e.g., websites, ABET self-study documents). Triangulating data from these sources enabled corroboration of facts and events at each case study site. We visited each case study institution at least twice to identify and study the factors that appeared to be shaping each institution's performance. Table A.5 provides information about the participants by case study site.

Table A.5: P360 case study participants

Institution	Administrators	Faculty	Students	Other	Total
Arizona State University	24	33	21		78
Harvey Mudd College	11	20	24	7 industry liaisons	62
Howard University	12	28	62		102
MIT	20	17	16		53
University of Michigan	27	31	45		103
Virginia Tech	11	30	21	8 alumni/ae	70
Total	105	159	189	15	468

Each interview (individual and group) was transcribed verbatim, and the research team catalogued these and all other materials collected during site visits. After the second site visits, all transcripts, observations, notes, and documents (course syllabi, program descriptions, brochures, etc.) were combined into a dataset contained and analyzed in NVivo 8.0. During fall 2009 and spring 2010, research teams completed their analyses of the individual cases in preparation for a cross-case analysis, held in July 2010 with the full P360 research team who identified common themes across the six case study sites. Data from the P2P surveys of students and faculty members augmented and provided support for the validity of the qualitative analyses.

Appendix B: Scale Variables and Reliabilities

Independent variable scales with item components. Cronbach's *alpha* indicates the internal consistency reliability.

Program Chair Scales
Curricular Emphases
(1=Little/No emphasis, 2=Slight, 3=Moderate, 4=Strong, 5=Very Strong, 6=Not applicable)

Design Skills scale (alpha=.78)
Stem: How much does your program curriculum emphasize:

Generating and evaluating variety of ideas about how to solve a problem
Emerging engineering technologies
Defining a design problem
Creativity and innovation
Solving problems from real clients (industry, government, etc.)
Producing a product (prototype, program, simulation, etc.)
Systems thinking

Interdisciplinarity scale (alpha=.86)
Stem: How much does your program curriculum emphasize:

Understanding how non-engineering fields can help solve engineering problems
Applying knowledge from other fields to solve an engineering problem
Understanding how an engineering solution can shape and be shaped by environmental, social, cultural, political, legal, economic, and other considerations
Making explicit connections to knowledge and skills from other fields Integrating knowledge from engineering and other fields to solve engineering problems

Professional Values scale (alpha=.79)
Stem: How much does your program curriculum emphasize:

Examining beliefs and values and how they affect ethical decisions
The value of gender, racial/ethnic, or cultural diversity
Ethical issues in engineering practice
The importance of life-long learning

Professional Skills scale (alpha=.79)
Stem: How much does your program curriculum emphasize:

Leadership skills
Working effectively in teams
Professional skills
Written and oral communication skills
Project management skills

Faculty Scales
Curricular Emphases
(1=Little/No emphasis, 2=Slight, 3=Moderate, 4=Strong, 5=Very Strong, 6=Not applicable)

Design Skills scale (alpha=.85)
Stem: How much does your program curriculum emphasize:

Generating and evaluating variety of ideas about how to solve a problem
Emerging engineering technologies
Defining a design problem
Creativity and innovation
Solving problems from real clients (industry, government, etc.)
Producing a product (prototype, program, simulation, etc.)
Systems thinking

Interdisciplinarity scale (alpha=.86)
Stem: How much does your program curriculum emphasize:

Understanding how non-engineering fields can help solve engineering problems
Applying knowledge from other fields to solve an engineering problem
Understanding how an engineering solution can shape and be shaped by environmental, social, cultural, political, legal, economic, and other considerations
Making explicit connections to knowledge and skills from other fields
Integrating knowledge from engineering and other fields to solve engineering problems

Professional Values scale (alpha=.81)
Stem: How much does your program curriculum emphasize:

Examining beliefs and values and how they affect ethical decisions
The value of gender, racial/ethnic, or cultural diversity
Ethical issues in engineering practice
The importance of life-long learning

Professional Skills scale (alpha=.89)
Stem: How much does your program curriculum emphasize:

Leadership skills
Working effectively in teams
Professional skills
Written and oral communication skills
Project management skills

Student scales
Curricular Emphases
(1=Little/No emphasis, 2=Slight, 3=Moderate, 4=Strong, 5=Very Strong)

Core Engineering Thinking scale (alpha=.85)
Stem: Overall, how much have the courses you've taken in your engineering program emphasized each of the following:

Generating and evaluating ideas about how to solve an engineering problem
How theories are used in engineering practice
Emerging engineering technologies
Defining a design problem
Creativity and innovation

Professional Values scale (alpha=.82)
Stem: Overall, how much have the courses you've taken in your engineering program emphasized each of the following:

Examining my beliefs and values and how they affect my ethical decisions
The value of gender, racial/ethnic, or cultural diversity in engineering
Ethical issues in engineering practice
The importance of life-long learning

Professional Skills scale (alpha=.88)
Stem: Overall, how much have the courses you've taken in your engineering program emphasized each of the following:

Leadership skills
Working effectively in teams
Professional skills (knowing codes and standards, being on time, meeting deadlines, etc.)
Written and oral communication skills
Project management skills (budgeting, monitoring progress, managing people, etc.)

Broad and Systems Perspective scale (alpha=.84)
Stem: Overall, how much have the courses you've taken in your engineering program emphasized each of the following:

Leadership skills
Understanding how non-engineering fields can help solve engineering problems
Applying knowledge from other fields to solve an engineering problem
Understanding how an engineering solution can be shaped by environmental, cultural, economic, and other considerations

Student Scales
Instruction
(1=Never, 2=Rarely, 3=Sometimes, 4=Often, 5=Very often)

Student-Centered Teaching scale (alpha=.81)
Stem: In your engineering courses, how often have your instructors:

Set clear expectations for performance
Conveyed the same material in multiple ways (in writing, diagrams, orally, etc.)
Explained new concepts by linking them to what students already know
Used examples, cases, or metaphors to explain concepts
Answered questions or gone over material until students "got it"

Group Learning scale (alpha=.77)
Stem: In your engineering courses, how often have your instructors:

Provided guidance or training in how to work effectively in groups
Provided hands-on activities and/or assignments
Used in-class, small group learning
Assigned group projects

Student Scales
Outcomes

[a] 1=Weak/None, 2=Fair, 3=Good, 4=Very good, 5=Excellent
[b] 1=Strongly disagree, 2=Disagree, 3=Neither agree nor disagree, 4=Agree, 5=Strongly agree

Design Skills scale (alpha=.92)
Stem: Please rate your ability to:[a]

- Evaluate design solutions based on a specified set of criteria
- Generate and prioritize criteria for evaluating the quality of a solution
- Producing a product (prototype, program, simulation, etc.)
- Apply systems thinking in developing solutions to an engineering problem.
- Brainstorm possible engineering solutions
- Take into account the design contexts and the constraints they may impose on each possible solution
- Define design problems and objectives clearly and precisely
- Ask questions to understand what a client/customer really wants in a "product"
- Break down a design project into manageable components or tasks
- Recognize when changes to the original understanding of the problem may be necessary
- Develop pictorial representations of possible designs (sketches, renderings, engineering drawings, etc.)
- Undertake a search before beginning team-based brainstorm

Interdisciplinary Skills scale (alpha=.80)
Stem: Do you agree or disagree? [b]

- I can take ideas from outside engineering and synthesize them in ways to better understand a problem
- I can use what I have learned in one field in another setting or to solve a new problem
- I see connections between ideas in engineering and ideas in the humanities and social sciences
- I enjoy thinking about how different fields approach the same problem in different ways
- Given knowledge and ideas from different fields, I can figure out what is appropriate for solving a problem.
- Not all engineering problems have purely technical solutions
- In solving engineering problems I often seek information from experts in other academic fields.
- I value reading about topics outside of engineering

Contextual Competence scale (alpha=.91)
Stem: Please rate your:[a]

- Ability to use what you know about different cultures, social values, or political systems in engineering solutions
- Ability to recognize how different contexts can change a solution
- Knowledge of contexts that might affect the solution to an engineering problem
- Knowledge of the connections between technological solutions and their implications for whom it benefits

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