E Appendix: Looking Ahead: Ideas for Future Research

This appendix consists of sets of questions intended to stimulate conversation about future work in the field of engineering education. The questions cover seven categories: student pathways, learning engineering, significant learning experiences, engineering knowing, teaching engineering students, researching issues in engineering education, and bringing about change in engineering education.

The questions within each category were assembled with the following principles in mind:

1. In each category, we start with questions that are directly grounded in CAEE research results. In some of the categories, later questions introduce broader issues that have arisen during the course of our research on the student learning experience, the faculty teaching experience, and the community of scholars in engineering education.
2. We intentionally produced sets of questions that are extensive and far reaching. This is in keeping with our goal of stimulating new ideas and debate in the growing, interdisciplinary community that is engaged in scholarship in engineering education.
3. We include questions that are at multiple levels of detail, in order to satisfy the interests of a wide range of readers.
4. Each category includes many types of questions. Some of the questions seek understanding of engineering students, engineering educators, and engineering researchers on dimensions examined in our existing work. Others concern explanations for specific CAEE findings, possible interventions, and more overarching philosophical issues.

E.1 On Pathways

- What are the effects of institution, curriculum, student characteristics, and motivation on engineering persistence, migration, and career decision-making?
- What characterizes informed decision-making with respect to a student's choice to major in engineering? What factors are considered? What trade-offs are made? How do these factors and trade-offs differ for students with different backgrounds? Do they differ for students at various points in their pathways to an undergraduate degree?
- What are the barriers to migrating into colleges of engineering? What are the "gatekeeper" courses (e.g., math)?
- What core elements of engineering should P–12 students learn so that they can come to college prepared to enter engineering majors? What aspects of engineering should be taught at what grade levels in the P–12 system?
- Thinking about the pre-college setting, what activities and experiences promote middle and high school students' interest in engineering? To what extent must these

activities and experiences create both intrinsic and extrinsic motivation to study engineering to be effective?

- How can we best support students when they question whether to remain in engineering majors?
- With an already crowded undergraduate curriculum, how can we help students catch up, if they did not take enough math and science in high school?
- Why do students become less involved in their courses as seniors?
- How can our understanding of changes in student engagement over time inform efforts to increase student engagement? What accounts for differences in levels of engagement among students?
- What is it about interaction with faculty and involvement in engineering extracurricular activities that inspires and sustains students' passion for engineering? How can we better capitalize on the motivating features of both formal and informal learning experiences?
- How do financial challenges affect students' undergraduate experiences?
- What characterizes informed decision-making with respect to a student's choice to pursue post-graduate work or graduate school? What factors are considered? What trade-offs are made? How do these factors and trade-offs differ for students with different backgrounds or at various points in their educational pathways?
- In what ways do graduating students differentiate between the notions of a first job and a long-term career when they are making future plans? Are they better prepared to consider one over the other?
- For students who have both engineering and non-engineering career plans, what accounts for the breadth of their plans? *E.g.*, do they have a specific, long-term vision of a professional pathway combining engineering and non-engineering pursuits, or are they uncertain of what opportunities will come their way?
- How many students attend engineering school as a stepping stone to non-engineering careers? What do they see as the advantage of an engineering undergraduate degree?
- How does parental background affect interest in engineering employment and graduate study? Does having parents with an engineering background affect a student's choice to follow a particular academic pathway? Is there a relationship between socioeconomic status and interest in engineering?
- How many students who express interest in engineering graduate school as graduating seniors attend graduate school at some point in their career? What factors affect their interest? What are the significant supports and barriers associated with attending graduate school?
- How do early-career professionals and new graduate students reflect on and interpret their undergraduate experiences? In what ways do their undergraduate experiences help (or hinder) them in their new pursuits?
- What are the lessons learned from students' transitions to the workplace and graduate school? How do these lessons vary with industry, graduate school, size of organization, *etc.*? How can these lessons be fed back into and inform undergraduate

education? How can they be fed forward to graduate schools and engineering firms to help students' make a smoother transition?

- As graduates look back on their undergraduate experiences, what elements of their experiences do they see as most valuable? How do these elements compare with the ones they thought were important when they were in school?
- What aspects of students and their educational experiences exhibit the most variation (*e.g.*, in student background, interests, post-graduation plans)?
- How do students' pathways vary with gender and race/ethnicity? In what ways do underrepresented students' college experiences differ from those of majority students? Even in cases where the experiences are ostensibly the same, to what extent are underrepresented and majority students impacted differently by the experiences?

E.2 On Learning Engineering

- What engineering concepts are most difficult for students to learn and why? What makes some concepts more difficult to learn than others? How can we better teach difficult concepts?
- How can engineering design be integrated into more engineering learning experiences?
- How can students be taught to better consider context in engineering design? How can students be taught to better take into account users and other important stakeholders in engineering design?
- What life experiences can contribute to students' consideration of context in engineering design? Are these experiences correlated with gender, race/ethnicity, socioeconomic status, and/or other demographic factors?
- How can we help students better understand the integrated, interdisciplinary nature of engineering?
- To what extent and in what ways do engineering students exhibit interdisciplinary respect (*i.e.*, respect for other disciplines, individually and in combination with each other or with engineering)? How do engineering students compare with students in other disciplines in terms of interdisciplinary respect? How does entering the workplace affect interdisciplinary respect? How can we better educate engineering students to respect the knowledge and contributions of people from other disciplines?
- How can engineering-focused educational activities be augmented to foster more development of professional skills?
- In what specific ways is reported family income related to confidence in professional and interpersonal skills?
- How can we help improve engineering undergraduates' listening ability (in addition to their speaking and writing skills)?
- How can students' conative capacity, self-efficacy, and locus of control be leveraged to enhance student learning? How do they interact with one another to affect overall student success in college?

- What helps students recognize the areas in which they need more knowledge or skills? How can students learn how to seek out and acquire the knowledge and skills they need?
- How do we foster self-directed learning in our students?
- In what ways can reflecting on educational experiences enhance students' intellectual and professional growth? How can we help students learn and practice this kind of metacognitive reflection?
- How do we foster lifelong learning in our students?
- How does the relationship between confidence and competence vary across student populations, across skill sets, and within students over time (*i.e.*, during the course of their undergraduate years)? What strategies can be used to help students more accurately assess their competence, such that competence and confidence are aligned?
- How does student identification with engineering (*i.e.*, having an engineering identity) vary across students and within students over time? How does having strong identification with engineering support student success in engineering educational activities? Are there ways in which having a strong sense of identification with engineering can hinder students?

E.3 On Significant Learning Experiences

- How do students decide which extracurricular activities to be involved in? How do students benefit from these activities, both engineering-related and non-engineering-related? How can engineering programs support students to get the most benefit from their extracurricular experiences?
  - Why are co-ops, internships, and research experiences so often reported by students as significant learning experiences?
  - Is there a way to bring the most important aspects of those experiences into the classroom?
  - How can we help students link what they are learning in these experiences to what they learn in the classroom?
  - How can we ensure that co-ops, internships, and research experiences lead to significant engineering learning?
- Why does students' perception of the importance of professional and interpersonal skills remain unchanged during the undergraduate years, even though they are participating in more activities requiring these skills?
- Why are engineering students less likely than students in other majors to take advantage of international learning experiences? Are the primary reasons lack of time and schedule flexibility? What do the students who go on these experiences gain? Given the global nature of contemporary engineering work and professional contexts, how can we better facilitate students' international learning experiences? How can engineering programs make a more concerted effort to include these kinds of experiences? Is there a way to design local (*i.e.*, on-campus) learning experiences that

teach some of the same skills and concepts that students learn when they travel overseas?

- Why do relatively few engineering students take advantage of extracurricular community service and other social good project opportunities? What do the students who engage in these experiences learn? How do we reconcile relatively low involvement in these activities with the level of interest in making a difference in the world that engineering students report?
- How can we better support students' participation in service-learning curricular experiences? What do the students who engage in these experiences learn?
- Why is it that school is *not* identified by more students as a source of their learning about the engineering profession? What does this indicate about engineering education?

E.4 On Engineering Knowing

- What math knowledge and skills are needed at what points throughout the engineering curriculum? How might better alignment of prerequisite courses with needed knowledge and skills affect recruitment of students into engineering?
- What are the fundamental concepts that are common to multiple engineering disciplines? What is the "minimum set" of skills and concepts necessary for engineering practice? How do the increasing complexity and scale of engineering problems affect what we consider to be the "base" of engineering knowledge?
- What aspects of engineering are important for all undergraduates to understand, regardless of their major?
- In addition to becoming a practicing engineer, what should an engineering education be preparing students for?
- How do we help students understand and reconcile the sometimes competing signals of engineering as a job (do what your boss says) and engineering as a profession (do what is good for society)? How do we help students identify and incorporate ideas about social consequences in their engineering design activities?
- To what extent should we characterize engineering expertise in a holistic manner, *e.g.*, by considering an engineers' habits of practice, value systems, life experiences, ethics? (We might call this concept "engineering wisdom.") What aspects of engineering wisdom could be taught during the undergraduate years?
- How might an understanding of engineering concepts and approaches enable the general public to be more informed participants in a democratic society?

E.5 On Teaching Engineering Students

- How do engineering educators make significant decisions about the educational experiences they design?

- How can we support faculty in understanding variability in the classroom (*e.g.*, in student background, interests, post-graduation plans) and how to use it to enhance teaching?
- A thousand students, a thousand stories: How can the community better understand the aspects of students' lives that contribute to important differences in their educational experiences?
- In what ways can a structured examination of decision-making guide faculty with their teaching?
- What are the most effective representations and methods for conveying engineering education research findings to engineering educators (*e.g.*, academic papers, less formal written descriptions, visual representations, vignettes, personas)?
- In what ways can engineering curricula be restructured to promote persistence, migration, and preparation for engineering workplaces?
- How can APS findings about students' motivation to study engineering, including their interest in effecting social good, inform the design of teaching innovations?
- How can engineering educators address aspects of engineering practice that fall outside traditional engineering learning outcomes (*e.g.*, tolerance for ambiguity, excitement about engineering, issues of identity, engineering failures, metacognition, skills of flexibility, and adaptability)?
- What curricular methods and practices promote retention and application of engineering concepts across the curriculum, particularly in solving ambiguous, dynamic, real-life engineering problems?
- What aspects of an engineer's education are best served by campus-based experiences? By industry-based experiences? By technology-enhanced experiences? By service-learning experiences?
- How can engineering expertise be characterized in a way that educators can use to facilitate more effective teaching?
- What apprenticeship models of teaching can be employed to teach key elements of engineering practice?
- What assessment methods are most effective for measuring aspects of engineering learning?
- What tools and practices can we use to better assess the meaning and significance of students' learning experiences from the perspective of the students themselves?
- How can we take advantage of innovative assessment approaches and tools such as electronic learning portfolios to allow students to create richer and more holistic representations of the experiences that contribute to their becoming engineers?
- How can these learner-centered approaches to assessment be used to better inform faculty, departments, and institutions, as well as graduate schools and employers, about students' formal and informal experiences in engineering education?
- How is teaching engineering the same as and different from teaching math, physical sciences, biological sciences, social sciences, the humanities, and the arts?

- How can new faculty be better supported in aligning classroom innovations with engineering education research?
- How can engineering learning be better supported by industry? Are there "best practices" within and/or across companies that could be incorporated in undergraduate engineering education? What is the common thinking/wisdom, if any, about mentoring new engineers?

E.6 On Researching Issues in Engineering Education

- How can we support engineering faculty who want to pursue engineering education research?
- In what ways do the process and experience of conducting research on learning and teaching change how an educator designs learning experiences?
- What types of standards are currently used for evaluating scholarly contributions in engineering education? How do these standards influence the nature of the research that takes place (*e.g.*, in terms of topics and research design)?
- What types of support would help engineering education researchers create and manage interdisciplinary research teams?

E.7 On Bringing About Change in Engineering Education

- How can the extensive variability of engineering students and their pathways through their educations be leveraged in service of improving engineering education?
- How do we support faculty and program planners in effecting change?
- How do we support engineering educators in engaging in critical reflection on their own teaching?
- What technological infrastructure (*e.g.*, databases, tools) would accelerate both research advances and the rate at which research results are used to influence educational practice and outcomes?
- How do innovations get promoted and adopted across institutions? What is the adoption pattern and history that past innovations have traced before becoming "common practice," *e.g.*, in the form of ABET requirements?
- What theories of change are most appropriate for what campus/department cultures?
- What critical configurations of circumstances or environments (*i.e.*, tipping points) are more likely to bring about change?
- How can deans and other administrators promote innovation in engineering education? What approaches have been successful in achieving buy-in from faculty and support from university-level administration?
- How can we best learn from specific, individual success stories and generalize from them to effect larger-scale change?