Supporting Informed Decision Making to Improve Engineering Education

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While there is little debate about the need to improve engineering education, there are various ideas about how to best accomplish this goal. In this editorial, we focus on the notion of informed educator decision making as a key element of improving engineering education. We make the case for the need to support informed decision making through the lens of research conducted at the recently concluded Center for the Advancement of Engineering Education (CAEE). CAEE was funded by the National Science Foundation and was active from 2003 to 2010.

Informed decision making is a key premise of any professional activity. Professionals are assumed to have knowledge of effective practices, as well as knowledge of local circumstances, and thus be able to integrate both kinds of knowledge into a decision appropriate for a particular circumstance (Figure 1, bottom). For example, a doctor is responsible for integrating insights from medical research with knowledge of a patient's specific circumstances and conditions in order to decide how to best approach his/her medical care. To draw an analogy to the educational environment, an educator should be expected to integrate research on effective teaching practices with knowledge about a particular group of students in a particular context in order to decide how to approach the teaching of particular material to that group. This idea suggests that while there may be instructional practices that have been proven to be effective, there is not a "one size fits all" solution for improving engineering education. Rather, the decisions that educators make are complicated, because each teaching situation is unique in its own way by virtue of the students in the class and their past experiences, the instructor's expertise and past experiences, the content matter to be taught, the expected learning outcomes, the set of potential teaching materials that could be used, the pedagogical techniques that might be most effective, the curricular structure, the institution in which the educational experience is taking place, and the economic, societal, global, and environmental context of the time, to mention a few factors.

Further, there are myriad decisions associated with teaching situations, and each of these decisions has the potential to be made in an informed way. We have had conversations and

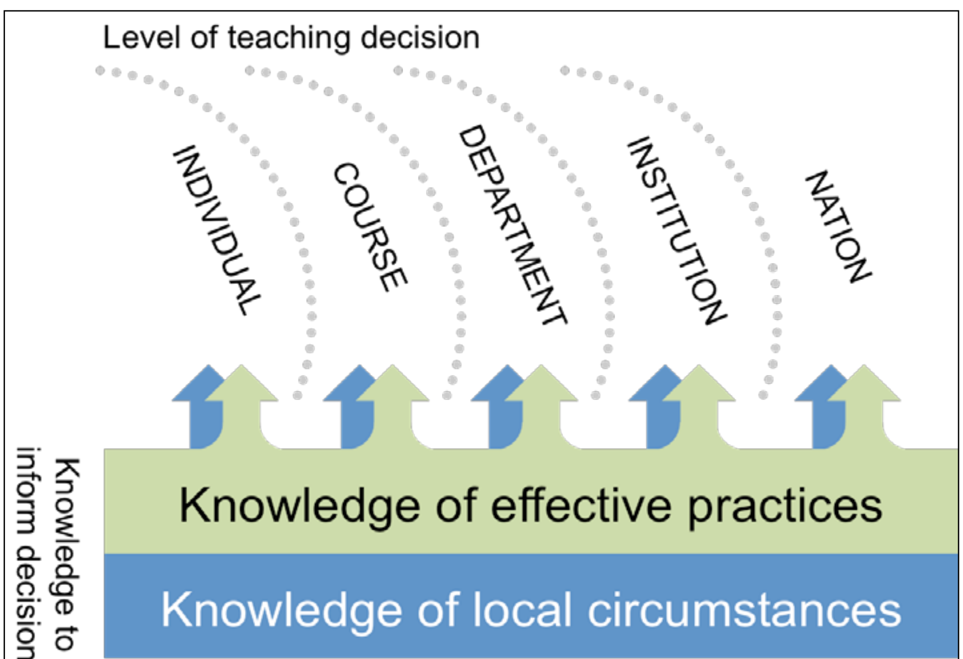

Figure 1. Teaching decisions at various levels, informed by integrated knowledge

conducted research with engineering educators about their teaching, using decision making as a lens. For most engineering educators, the teaching decisions that come to mind most easily are those at the course level—decisions about what content to address, what work to have students engage in, how to assess students, what book to use, etc. However, there are decisions at other levels that contribute to how effectively students learn (Figure 1, top). For example, educators are called upon to interact with individual students, such as in office hours, and thus need to make decisions about how to frame such interactions. More broadly, there are decisions at the department level that influence student learning (e.g., what courses to require in a curriculum, what policies to put in place across courses). Even more broadly, there are decisions made at the institution or even at a national level that influence student learning—decisions such as how to assign physical space to program activities or even how to fund engineering education. Because these decisions collectively influence student learning, we can talk about all of them as teaching decisions and aspire to have all such decisions made in an informed way.

Against this backdrop, the work of the Center for the Advancement of Engineering Education can be understood as a collection of work to promote and support informed decision making. These efforts are described in detail in the center's final report, which can be downloaded from the CAEE website at http://www.engr.washington.edu/caee/. As we will discuss below, part of the center's work—the Academic Pathways Study (described in detail in Chapter 2 of the final report)—created not only an extensive collection of research about engineering students in different contexts but also produced tools and ideas that can help researchers study new issues and help educators collect and interpret relevant, local information. In another part of the center—Studies of Engineering Educator Decisions (described in detail in Chapter 3 of the final report)—we looked directly at educator decision making by conceptualizing the notion of teaching decisions and by providing a benchmark for the ways in which educators are making informed decisions. Finally, we sought to bring these threads together through a series of workshops inviting educators to practice connecting findings from the Academic Pathways Study with specific teaching decisions. In the following text, we briefly describe the Academic Pathways Study, the Studies of Engineering Educator Decisions, and the workshops we conducted, coupling the results of these studies in an effort to enable informed teaching decision making.

Supporting Informed Decision Making: The Academic Pathways Study

The Academic Pathways Study (APS) was a large study of the undergraduate engineering student experience from the student perspective. The study included multiple samples (both longitudinal and cross-sectional), multiple methods, and data from many campuses across the U.S. To elaborate, we collected data from four samples of students that encompassed over 16,000 students overall. This included survey data from 272 institutions and more in-depth data from four institutions, collected using a range of methods (surveys, structured interviews, ethnographic interviews and observations, and engineering design tasks). We also interviewed over 100 early-career engineers at a variety of public and private organizations to gain insights on the issues engineering graduates have as they transition to the next step in their careers.

Results from the Academic Pathways Study

Details about APS research methods, samples, and results, as well as citations for papers where specific results are described in more depth, can be found in Chapter 2 of the final report. The findings span many areas of the college experience. Students in the study were found to be successful in learning the skills and language of engineering. They were becoming more confident as designers at the same time as they were taking positive steps in developing their identities as engineers. Many of the students who had an engineering co-op or internship developed a better understanding of what engineers do through those practice-based experiences. While the students were developing these skills, they also experienced challenges. Some students experienced the engineering curriculum as a heavy workload in a competitive environment. This led to stress for some, and for others it led to a "stick it out to the end" perspective. Another stress point for some students was the perceived disconnect between the early courses that focus on math and science, and courses in the latter years where more realistic engineering is taught with more projects and team-based experiences. Finally, while both male and female students took the same courses and engage in the same learning activities, their *experiences* of these settings and activities, as well as associated outcomes (e.g., feelings of preparedness and confidence), differed in multiple ways.

Though the APS was focused on the pathways of engineering students, we expect that many of the experiences reported in the final report about choosing and committing to a major are relevant to other STEM majors (and perhaps to higher education choices more generally). In terms of persistence rates, we found that undergraduates who start in engineering majors tend to stick with their majors as much as students in other fields (across STEM, as well as the social sciences, arts, and humanities). However, students are less likely to switch *into* engineering majors than into other STEM majors. Mindful of such similarities and differences among the STEM fields and beyond, we encourage those readers dedicated to educating students in non-engineering fields to read this editorial (and the CAEE final report) and consider what these APS research questions and findings suggest about the undergraduate experience in your respective disciplines. Table 1 (at the end of this article) presents the headlines from the subsections of the 75 pages of the final report that describe APS findings (Chapter 2). This table provides a sense of the breadth of the findings that resulted from this research.

Beyond the Academic Pathways Study: Creating Capacity with Instruments, Questions, and Communities

It is rarely the case that the result of one piece of research can be picked up and directly transferred to another academic setting. While the scope of the APS findings is both broad and deep, they are based on data situated in time and context, and as previously discussed, each educator's situation is distinctive in some way. In this section, we describe a set of instruments, questions, and some community-building activities CAEE engaged in to create capacity to both investigate local circumstances and conduct more general engineering education research.

1) **Instruments to collect local data**. The survey instruments and interview protocols used in the APS can be accessed on the Resources page of the CAEE website.
2) **Questions**
    - *Local Inquiry Questions*. A set of questions to stimulate connections of APS research findings to individual campuses was developed. A sampling of these questions is presented in Table 2, at the end of this article. The full set of questions can be seen in Appendix D of the final report (pp. 203–206). They are also listed with a summary of the research that motivates the questions in Section 2.10 of the report (pp. 86–92).
    - *Ideas for Future Research*. Many ideas for future research came up throughout the CAEE research project. A set of these ideas is presented in Appendix E of the final report (pp. 207–213). For a flavor of some of these ideas, Table 3 presents the section headings and two items sampled from each section.
3) **Communities.** In addition to instruments and questions, CAEE contributed to the engineering education community's capacity to engage in research through the training and professional development of many scholars. Along with the many graduate students and post-doctoral researchers who contributed to CAEE, this included a diverse group of engineering educator scholars from 20 institutions who participated in one of three Institutes for Scholarship on Engineering Education (ISEE). Through the institutes, we developed models for building and sustaining engineering education research communities (described in Chapter 5 of the final report), which later influenced the design of other capacity-building and research-to-practice workshops. One principle underlying the models is to focus on "change" decisions at three of the levels illustrated in Figure 1: class as lab (to maximize learning in specific courses), campus as lab (to build a local network for educational transformation), and nation as lab (to address the diversity needs of the 21st century). Other principles include a waterfall recruitment strategy for building community over time; a user-centered approach to identify and address challenges scholars come in with or experience during the ISEE; a scaffolded, iterative research design process; and an awareness of impact as a central motivator for engineering education researchers.

Data such as that provided by the APS or made possible through APS capacity-building efforts can help support engineering educators in making informed decisions. In the next section, we explore the range of decisions that such information can support and also benchmarking efforts to understand how educators are currently making teaching decisions.

Supporting Informed Decision Making: Defining and Describing Educator Decisions

What teaching decisions do educators make? How do they make those decisions? What information do they take into account when making those decisions? Such benchmark information is important for efforts to support informed decision making, and creating such information was a key part of the CAEE mission. To study educator decision making, we took a naturalistic approach in that we asked educators to identify specific decisions that they had made and then discuss how they made the decisions and their satisfaction with the outcomes of the decisions. More specifically, using a critical decision method interview, we asked 31 educators (faculty members of all ranks across nine engineering departments on one campus) about a planning and an interactive decision. We then used the decision narratives provided by the educators to explore a variety of issues associated with teaching decision making.

When we analyzed the decision narratives to better understand educator decision making, we found that this approach to discussing teaching resonated with most of the educators. Below we illustrate this resonance using quotes from the interviews:

(1) Most of the educators we interviewed recognized the importance of our emphasis on decisions and decision making:
- "Well, I mean there [are] all kinds of decisions on all kinds of different levels."
- "I mean there's just so many—everything is a—you know, is a decision."

(2) The types of decisions the educators mentioned varied widely:
- Which classes to teach
- Choosing a textbook
- Creating a plagiarism policy
- How to get students into teams
- Adding writing assignments to promote better discussions
- Whether to skip a topic in real-time in the classroom

(3) Some educators elaborated on distinguishing features of decision levels:
- "Strategic decisions—so that's the stuff you do before you actually teach the class…and the tactical decisions, where that's in class or during the class as the course goes along."
- "A couple of levels. There's a big-scale structural, what should the students be taking, and…the really microscopic of, this student is giving this excuse…what do you do?"

(4) The educators provided rationale for their decisions:
- "Well, I'm trying to communicate to students in all classes that teaching and learning is not about regurgitation."
- "I'm always motivated by what can be done most efficiently."

More in-depth analyses of the interviews were conducted in several areas. First, we found that while educators mentioned using a variety of sources of information when making decisions about teaching (e.g., their peers, teaching workshops, prior experiences with students in their own teaching), they seldom mentioned using scholarly research.

Additionally, we looked at how educators differentiate among students and what teaching practices educators use to help students develop intrinsic motivation to learn. These analyses indicate ways in which the educators are invested in their students successfully learning the material they are teaching. In the final part of this piece, we highlight our specific efforts to bring these threads of CAEE activity together.

Supporting Informed Decision Making: Linking Educator Decisions and Research Findings

For educators striving to make informed teaching decisions, data such as those provided by (or made imaginable by) the Academic Pathways Study represent a potentially valuable resource. However, it can take an investment of time and reflection to identify the relevance of research findings to specific teaching decisions. Further, it seems plausible that educators might benefit, in general, from practice at connecting research findings to varied teaching decisions. To address these ideas, our most recent CAEE activity has been to develop a research-to-practice workshop structure and conduct these workshops in a variety of settings.

These research-to-practice workshops have had three core elements: (1) an introduction of the notion of teaching decisions, (2) the identification of a small set of APS findings to discuss with participants, and (3) activities in which participants make connections between the presented findings and their own teaching decisions. In specific workshops, we varied the set of findings that were presented. We also varied the ways in which we organized the process of connecting decisions to findings, resulting in two workshop models.

Workshop Model 1

Linking Research to Teaching Decisions: A Research Finding-centric Approach

We ran the first of these workshops in 2008, with a single workshop design presented initially at Frontiers in Education and then again at the Professional and Organizational Development conference. In these workshops, we focused on research findings concerning (1) student engagement, specifically that engineering students become increasingly disengaged in both engineering and non-engineering courses over their undergraduate years; (2) self-confidence, specifically that male engineering students have significantly higher self-confidence than female students in math, science, and open-ended problem solving; and (3) consideration of context in design activity, specifically that among first-year engineering students, females tend to situate engineering design problems in broader contexts than males. We opened the workshop with a discussion of these three findings and then transitioned into the issue of teaching decisions. After introducing the idea of teaching decision making, we asked participants to identify a range of teaching decisions they had made, and then invited participants to think about their decisions as we explained some of the findings from our studies of educator decisions. The third and final part of the workshop, the connection phase, was organized in a finding-centric manner. We invited participants to organize into groups around a research finding of interest and then to discuss how the finding could be used to inform a range of decisions, such as the ones that participants had already identified. While a formal evaluation of these workshops was not conducted, a striking feature of the workshops was the level of engagement and the range of ideas that were generated.

For a campus workshop held in 2009, the workshop model was augmented to include focus on local data and teaching decisions. Opening presentations included national findings from the APS, selected based on the preferences of prospective participants. Each national finding was accompanied by analysis of related local data collected on campus specifically for the workshop. Then, participating faculty engaged in small-group discussions about how these findings (national and local) might affect their teaching decisions at the individual, course, and department levels. Addressing topics of local interest, interleaving national and local data, and active interest and support from local leadership contributed to the success of this workshop.

Workshop Model 2

Linking Research to Teaching Decisions: A Teaching Decision-centric Approach

More recently, we have run two workshops in which we varied this structure by presenting the idea of teaching decisions before presenting the APS findings and by organizing the connecting phase in a decision-centric manner, rather than a finding-centric manner. Moreover, we customized the selection of the findings to the venue in which we presented. At the 2011 Women in Engineering ProActive Network conference, we focused on findings that featured gender differences related to extracurricular involvement, consideration of context in design, and student confidence. At the later 2011 American Society for Engineering Education conference, we focused on findings of more general interest—specifically, findings related to engineering student engagement in enriching educational experiences, student-faculty interactions and student motivation, and workplace support and barriers. In both workshops, we opened with a discussion of teaching decisions, with particular attention on the idea of teaching decisions at different levels (i.e., decisions associated with individual students, at the course level, at the department level, at the institution level, and at the national level). Then, before transitioning to the discussion of the APS findings, we invited participants to identify teaching decisions of personal relevance to keep in mind while listening to the presentation of the APS findings. Finally, in the connection phase of the workshop, we invited participants to form groups around a specific level of teaching decision (e.g., individual students, course) and then make connections between decisions at that level and the presented research findings. As with the previous workshops, we did not formally evaluate the workshop but noted significant engagement and a breadth of significant insights.

Closing Comments

CAEE's work supports informed decision making in engineering education by conceptualizing the idea of teaching decisions, by illustrating the range of teaching decisions associated with engineering education, by exploring the ways in which educators already make informed teaching decisions, by creating a large base of information about students that can be used by educators to inform teaching decisions, and by conducting workshops to help educators make connections between these research findings and their teaching decisions. Making informed teaching decisions can be challenging, and, in fact, entire fields of scholarship (such as behavioral decision theory) are devoted to understanding the complexities of decision making in life and in professional activity. At the same time, supporting educators in making informed teaching decisions—decisions that integrate what is generally known about effective teaching practice with knowledge of the local circumstances of the decision—is an important element in the work of improving engineering education.

For more information about the Center for the Advancement of Engineering Education, see the center web site (http://www.engr.washington.edu/caee/), which includes research instruments, program materials, a catalog of center publications, the final report, and other resources. The final report is also available in print from Morgan & Claypool Publishers:

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Table 1: Compilation of the subsection titles or "headlines" in the Academic Pathways Study chapter of the CAEE final report. For detailed findings, see Chapter 2 of the report.

The College Experience

- Engineering majors are as likely to persist as are other majors.
- There are similarities among, but also differences between, engineering majors and other majors with respect to learning and college-experience measures.
- Engineering persisters are more likely to be male and white, and less likely to be first generation college students.
- Women are more likely to migrate into engineering.
- Where do the switchers go? Where do engineering in-migrators come from?
- On many measures, engineering persisters and switchers are similar.
- On some measures, persisters and switchers are different.
- Persisters and switchers differ in intention to complete an engineering major.
- Commitment of persisters increases over the four years.
- Entering students interested in engineering often have limited knowledge of engineering.
- Range of intentions to complete an engineering major
- Level of commitment to engineering depends on students' identification with engineering activities.

Motivation to Study Engineering

- Top motivational factors are behavioral, psychological, social good, and financial.
- Mentors and parents are less salient motivators.
- Motivational factors are interrelated.
- Motivation remains essentially constant over the four undergraduate years.
- Other aspects of motivation: Status, portability, and sticking it out
- Motivation varies with gender and major.
- Motivation is correlated with persistence and satisfaction.
- Identity development as an engineer viewed within a framework of sponsorship
- An example of a lack of engineering sponsorship for a student's interests.

The Engineering College Experience

- Positive differences between seniors and first-years
- Negative differences between seniors and first-years
- Women and men, alike…and different
- Identification with engineering: Variations in perceptions of personal cost, enjoyment, and future usefulness
- Transfer students' experiences
- Socioeconomic status
- On some measures, the groups are the same.
- Synthesizing the differences to characterize each group
- High psychological motivation, high professional/interpersonal confidence (M/C)
- Low psychological motivation, low professional/interpersonal confidence (m/c)
- High psychological motivation, low professional/interpersonal confidence (M/c)
- Low psychological motivation, high professional/interpersonal confidence (m/C)
- Demographics by group
- An emerging picture of involvement

Engineering Knowledge, Conceptions, and Confidence

- Students' understanding of engineering disciplinary knowledge changes over time.
- Some students struggle with the shift from "book problems" to open-ended problems.
- Use of engineering-specific language increases during the undergraduate years.
- Students' knowledge of engineering does grow from first to senior year.
- Co-ops and internships build knowledge of engineering.
- Many seniors did not perceive gaining knowledge of engineering from school-related experiences.
- Are capstone projects not realistic and too late in the curriculum?
- Students recognize different skills as important in engineering.
- Learning about engineering is mostly similar among women and men.
- Importance of and preparedness with engineering skills and knowledge

- Not all confidence levels are equal; women's confidence lags in some areas.
- Students exhibit low confidence in professional and interpersonal skills.
- Confidence in math and science skills remains constant.
- Non-engineering factors largely contribute to confidence in interpersonal skills.
- Possible explanations for differences in perceived importance and confidence in key skills
- Even graduating seniors misunderstand some key engineering concepts.
- Faculty are often unaware of misunderstandings and the difficulty of these concepts.

Looking Beyond Graduation: Student Plans

- Nearly 80% said "yes" to engineering work, and 20% were unsure or leaning away.
- Co-ops, internships influence post-graduation plans to pursue engineering.
- Forty percent considering engineering graduate school.
- Seniors still unsure about their plans.
- More than 60% of engineering graduates had a combination of plans.
- An engineering degree can provide a basis for many future options.
- URM students were initially more interested in engineering graduate school.
- URM women and men think differently about post-graduation options.
- Women's plans similar to men's, but…
- Psychological motivation/interest an important factor
- Confidence in professional and interpersonal skills an important factor
- Institutional differences can have strong influences on student pathways.

Looking Beyond Graduation: Experiences in the Work World

- Technical problems are more complex and ambiguous in the work world.
- Many different players and processes can affect decisions.
- Support from managers and co-workers is very important and can vary greatly.
- Differences in age or outside interests can impede camaraderie.
- Rotation of new engineers can inhibit forming strong relationships with coworkers.
- Teamwork was much different in the workplace than in school.
- Understanding one's role
- Getting a sense of the bigger picture
- Company education efforts could be insufficient
- The importance of communication and documentation
- Communicating with non-engineers
- Learning to use a new language

Summarizing Results about Diversity

- Gender, motivation, and approaches to engineering
- Gender, motivation, and major
- Gender, URM, and mentor influence
- Gender and extracurricular activities
- Gender and curricular overload
- Gender and race/ethnicity in the classroom
- Gender and professional and interpersonal skills
- Gender and engineering knowledge gain
- Confidence in math and science skills
- Gender and conceptions of design
- Gender and confidence in design abilities
- Gender and approaches to design
- Graduate school
- Engineering work

Table 2: Sampling of Local Inquiry Questions stemming from the Academic Pathways Study and intended to guide campus discussions (complete set of questions in Appendix D of the CAEE final report)

Welcoming Students Into Engineering

- Migration in: Are there opportunities in the first years of college at your school (such as “introduction to engineering” seminars or courses) that allow students to explore engineering? Are there institutional barriers that discourage students from transferring into engineering?
- Pathways: What is the range of pathways that your students take through your curricula? Does your institution support varied pathways through the undergraduate experience?

Understanding and Connecting with Today’s Learners

- Student Passion: What motivates students on your campus to choose an engineering program?
- Variability/Commonality: How well do faculty and policy makers on your campus understand similarity and variability in your students’ motivation, background, interests, learning challenges, confidence, and future plans?

Helping Students Become Engineers

- Connecting Across the Years: Does your college connect the early learning experiences in the first two years (math- and science-focused) to the more engineering-focused experiences in the later years?
- Designing in Context: Do your students think about the users and other stakeholders of an engineered solution, and all aspects of the life cycle? Are they considering global, environmental, societal, economic, and cultural context in engineering design?

Developing a Whole Learner

- Significant Learning Opportunities: How does your institution provide learning opportunities that students consider significant, including experiences that connect with what students find meaningful, present students with a challenge, ask students to be self-directed learners, give students ownership over their learning, and facilitate development of a broad vision of engineering?
- Asking Questions: Do your graduates recognize when they do not know something? Do they have the skills to find the answers to their questions? Do they feel enabled to continue the learning process after they graduate?

Positioning Students for Professional Success

- Ability to Practice: What challenges do your graduates face when they begin practice or graduate school? What helps facilitate their transition? Do they know how to seek out the information and advice they need?
- Interdisciplinary Respect: Do your graduates understand the value of skills and perspectives from individuals in fields other than engineering?

Welcoming Students into the Work World

- Practicing Engineering: What challenges do your newly hired engineering graduates face when they begin a job? What can you do to help facilitate their transition?
- Working in Diverse Teams: Are the new hires able to work with a wide variety of coworkers and customers or clients in different roles and settings? Do they understand that decisions can often incorporate more factors than those that pertain only to the engineering aspects?

Table 3: Sampling of ideas for future research from the CAEE final report (complete set of questions in Appendix E of the CAEE final report)

On Pathways

- What are the effects of institution, curriculum, student characteristics, and motivation on engineering persistence, migration, and career decision-making?
- 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?

On Learning Engineering

- 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?
- What life experiences can contribute to students' consideration of context in engineering design?

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?

On Engineering Knowing

- 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?
- 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?

On Teaching Engineering Students

- 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?
- 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)?

On Researching Issues in Engineering Education

- 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)?

On Bringing About Change in Engineering Education

- What critical configurations of circumstances or environments (i.e., tipping points) are more likely to bring about change?
- How can we best learn from specific, individual success stories and leverage them to effect larger-scale change?