2.10 Enabling Success for Engineering Students: A Summary of Research on Student Learning Experiences

Section 2 of this report described the Academic Pathway Study (APS)—its research design, as well as a sampling of key results. For more information about the APS, the reader is invited to the see Section 6 for a description of our research instruments, Appendix A for a full list of our papers, and the CAEE web site (http://www.engr.washington.edu/caee/) to see research briefs on a large number of our papers.

We close our discussion on the APS by providing short summaries of six key topics that have emerged from the research findings described in the preceding subsections:

(1) Welcoming Students into Engineering,
(2) Understanding and Connecting with Today's Learners,
(3) Helping Students Become Engineers,
(4) Developing the Whole Learner,
(5) Positioning Students for Professional Success, and
(6) Welcoming Students into the Work World.

After each summary, questions informed by the research are provided to facilitate reflection and discussion on how a particular topic plays out on an individual campus and in an individual classroom. All of the questions are compiled and presented in their entirety in a list entitled "Local Inquiry Questions" that appears in Appendix D.

For readers in academia, we invite you to consider how these findings might stimulate conversation on your campus, and how they might influence how you go about educating engineering students. For readers in industry and other areas outside academia, we invite you to consider how our findings might be useful as a guide for helping students get the most out of their co-op and internship experiences and for successfully integrating newly graduated engineering students into the working world. For readers involved with policy and funding decisions, we invite you to use our findings as a basis for thinking about future efforts to build and support a vibrant and inclusive engineering educational system.

In the larger frame, as part of the community invested in today's and tomorrow's engineering education, we invite your involvement in helping create the best education possible for today's engineering students.

2.10.1 Welcoming Students into Engineering

Perhaps surprisingly, we found evidence that persistence in engineering majors is comparable to that in other majors; in other words, students who start in engineering majors tend to stick with their majors as much as students in other fields. Even so, engineering has some things to be concerned about. Those who persist—even those who seem to be deeply committed to engineering—may have significant and important doubts about staying in their engineering majors. Those who leave engineering majors are disproportionately from groups underrepresented in engineering, including first-generation college attendees. This results in a less diverse graduating class. In addition, few students migrate *into* engineering majors after starting college, resulting in an over 15% net loss of students (more than most other majors). Low in-migration is partly related to the curricular inflexibility and overloaded nature of some program structures. Students who do not begin college as engineering majors need to take key prerequisites, which often necessitates extending their undergraduate studies by one or more terms. Noteworthy, however, is that some 10% of engineering graduates do migrate into engineering, and that this group has strong representation of underrepresented groups (and therefore can contribute to diversifying engineering).

What we see is that there is not a single pathway into engineering, that opening up those pathways less traveled has the potential for broadening participation in engineering, and that even those students who seem to be firmly committed to majoring in engineering may have doubts about it being the right pathway for them. Students should be encouraged to explore and choose pathways through early college experiences that are tied to key motivational factors and that let students "try engineering out." Students can learn about engineering through multiple sources—*e.g.*, relationships with faculty, advisors, and peers; coursework; co-op/internship experiences; and extracurricular activities.

Some relevant questions to consider on your campus:

- **Informed Decision Making:** Does your college offer courses or programs (such as speaker series) that reveal to students the range of jobs and careers within the engineering field? How are students encouraged to integrate a variety of experiences into informed decision making on majoring in engineering? Do they have an accurate and sufficient understanding of the field of engineering and their place in it? How is re-examination of their decisions to stay in engineering supported through advising?
- **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? How much migration in is happening at your institution? How might this pathway be expanded? 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? Where do they find support? What organizations, faculty, student groups, and peers help students navigate through the institution? Does your institution support varied pathways through the undergraduate experience?

2.10.2 Understanding and Connecting with Today's Learners

Students are motivated to study engineering by a variety of factors, such as psychological/ personal reasons, a desire to contribute to the social good, financial security, or even seeing engineering as a stepping stone to another profession. Some factors are strong among all engineering students—for example, intrinsic psychological and behavioral motivation. Some have more influence with one group than another. For example, being motivated by mentors is stronger among women, whereas being motivated by the "making" and "doing" aspects of engineering (behavioral motivation) is stronger among men. Motivation is related to several important outcomes. For first-years, enjoyment of engineering for its own sake (psychological motivation) is correlated with intention to complete an engineering major, and, for seniors, it predicts intention to enter into engineering work or graduate school. Given these relationships, it is important for everyone responsible for engineering education to better understand the nature of student motivation and how it might be leveraged to attract a wide variety of students to engineering and to provide them with opportunities to explore different aspects of engineering.

Just as motivation to study engineering is not identical for all students, neither is the way students construct and experience their college education—*i.e.*, their level of engagement with their courses and teachers, and how they combine coursework and extra-curricular involvement, as well as co-op, internship, and research opportunities. Some students desire significant engagement in everything they do, others are more selective or focused in their involvement, and some are largely uninvolved in out-of-classroom activities. Throughout their college careers, women tend to be more involved in extracurricular activities (both engineering and non-engineering) and ascribe more importance to these activities than do men. These trends also vary with the individual's levels of psychological motivation and confidence in professional and interpersonal skills, and by class standing (first-year *vs.* senior). Of equal importance, even with similar choices, the "lived" experience may vary, in terms of a sense of curricular overload or pressure to represent one's demographic group. These findings suggest opportunities for improved advising and curricular program design, based on a deeper understanding of what students desire from their college education and how they go about constructing and experiencing this education.

Some relevant questions to consider on your campus:

- **Listening:** How do you get feedback from students about the effectiveness of various elements of your program? Do faculty listen to students about the effectiveness of their teaching? What mechanisms can be put in place to encourage more timely and effective use of teaching evaluations by instructors? How can what is learned through evaluations be better aligned with program improvement? Do you provide an environment where students listen to each other?
- **Student Passion:** What motivates students on your campus to choose an engineering program? What can they be passionate enough about to keep them in an engineering program? Does your program include elements that will ignite and sustain student passion?
- **Variability/Commonality:** How are students in your college of engineering similar to one another? How are they different from one another? 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?
- **Supporting Diversity:** Do individuals from traditionally underrepresented populations feel supported and included in the engineering community on your campus? Do faculty, students, and administrators recognize and support the important voices brought to engineering from individuals of all backgrounds?

2.10.3 Helping Students Become Engineers

Students develop an engineering identity and learn about engineering from a variety of sources: from co-op and internship experiences, from their coursework and instructors, from extracurricular activities, and from personal contacts. We observed that these sources vary little by gender or URM status. By senior year, most engineering students in the Longitudinal Cohort saw problem solving, communications, teamwork, and engineering analysis as key engineering competences and were using more engineering-specific language to express technical ideas; this is good news. However, comparing juniors and seniors to first-years and sophomores, we saw that the more advanced students did *not* exhibit greater attentiveness to the broad context of engineering design problems (though women considered broad context more so than men on some engineering design tasks).

In addition, seniors did *not* perceive the broader range of professional and interpersonal skills—leadership, public speaking, and business abilities, as well as communications, teamwork, and social skills—as being any more important than did their first-year counterparts, even having had project-based learning, design experiences, and, possibly, co-op or internship experiences. This suggests that the typical engineering curriculum could do more to help students carry what they learn in first- and second-year math and science courses into the more engineering-focused classes in their latter years.

These gaps suggest that some students fail to integrate the knowledge they are gaining about engineering from the various sources and across their years of study into a more complex, complete understanding of what it means to be an engineer. Furthermore, students are not always successful at transferring specific course knowledge and skills to real-world problems and settings. For instance, they may not anticipate how the teamwork skills they develop in courses using project-based learning are applied when working as an intern on a globally distributed design team. Alternatively, they may not recognize that the organizational skills needed to manage multiple projects in their co-op assignment are similar in nature to the skills they learned in leading a student organization.

Some relevant questions to consider on your campus:

- **Student Identity as an Engineer:** Do the students you teach know what engineers really do? Do they identify themselves as engineers? How does your program help them do this? Can they articulate what they are bringing to the engineering profession? Do faculty and administrators think about a student's engineering identity as an element of student development in the undergraduate years?
- **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? How do design experiences in upper-division courses build on design experiences in early courses?
- **Learning Engineering:** How do you confirm that students have learned and retained the basic skills of engineering? Have your students acquired the language of engineering? Have they mastered the concepts that are difficult to understand? Can they define and solve engineering design problems? Do they have the skills and confidence to meet society's grand challenges?
- **Well-Rounded:** How broadly do engineering students on your campus conceptualize engineering? How many areas beyond math, science, and analysis would students list as important components of engineering? How skilled are your graduates in the many aspects of the engineering profession?
- **Designing in Context:** Do your graduates have the design skills they need? Do your students consider the broad context of engineering problems as they solve them? Do they 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?

2.10.4 Developing the Whole Learner

Engineering students report experiencing considerable intellectual growth during their undergraduate years; they learn to apply key math and science support tools, and learn to take on substantial challenges in their design work. In addition, their college studies promote gains in confidence in many of the professional and practical skills increasingly called for in practice. However, studying engineering may mean students are not able to take advantage of other parts of a college education. For example, engineering students report lower gains in personal growth and fewer opportunities to study abroad than students in other majors. Some engineering students also report a sense of curricular overload. Furthermore, graduates report feeling underprepared to take on engineering problems and decision-making in real-world engineering practice, where the work often involves multidisciplinary teams, and technical and non-technical factors may be of comparable weight. Compared with first-years, seniors are less involved in their engineering courses, are less satisfied with their instructors (though they interact with them more frequently) and are less satisfied overall with their college experience. In spite of these relative differences, seniors reported having significant learning experiences, especially those that were in-depth and presented them with a challenge.

Some relevant questions to consider on your campus:

- **Balance:** Are your students satisfied with their undergraduate experiences as engineering students? Are they able to balance between their engineering and non-engineering extracurricular activities? Is there balance between individual and team experiences, well-defined and open-ended problems, and design and analysis experiences? Are your students able to find balance between the academic and social aspects of their lives?
- **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?
- **In-Depth Learning Opportunities:** Do your students have opportunities to have learning experiences that help them extend their understanding of engineering, *e.g.*, internships, co-ops, service learning, research or international experiences, and project-based learning? Do you help your students reflect on these experiences and integrate them into their understanding of the engineering profession? How might these reflections be integrated into program assessment and improvement?
- **Learning Environment:** How would you characterize the learning environment on your campus? Is there an atmosphere of students in competition with each other? Do students feel overloaded by a demanding curriculum? Do all students feel that your institution would like them to succeed? Do your students develop confidence in their abilities as engineers? Are your students excited when they graduate, or do they seem to be just sticking it out to the end?
- **Asking Questions:** What helps your graduates recognize the areas in which they need more knowledge or skills? Do they know how to seek out and acquire the knowledge and skills they need? Do they feel enabled to continue the learning process after they graduate?

2.10.5 Positioning Students for Professional Success

About 30% of the engineering students we studied had post-graduation plans focused exclusively on engineering (work and/or graduate school). These students were strongly motivated to study engineering for intrinsic psychological reasons and were likely to have had co-op and/or internship experiences. In general, these same students were among those who were less confident in their professional and interpersonal skills than those considering non-engineering professional endeavors post-graduation.

Most other students conceived of their careers as combining engineering and non-engineering components. Some of these students expected different degrees of engineering specificity in their work, changing as their careers progressed. Others may still have been uncertain, even as graduation approached, as to whether an engineering or non-engineering path would be the best fit for them. These patterns might also have been influenced by the focus of the institution that students attended. In any case, faculty, staff, and programmatic structures generally do little to acknowledge (much less support and advise) students looking at combining engineering and non-engineering endeavors in their career plans.

Some relevant questions to consider on your campus:

- **Post-Graduation Plans:** What resources are available at the department, college, and institution levels for guidance in job and career planning? Do your students feel enabled to enter a variety of professions? Are they prepared to be effective in those professions? What plans do your graduating students have? Are they considering a career in engineering, another field, or both? Work in industry or the public sector? Graduate school in engineering or another field?
- **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? Are they prepared for their long-term careers or just their first jobs? Can they effectively communicate their ideas to multiple audiences in the many modes they need to?
- **Interdisciplinary Respect:** Do your graduates understand the value of skills and perspectives from individuals in fields other than engineering? Do they respect both other fields *and* the individuals who practice in these fields? Are they able to work with these individuals?
- **Meet Grand Challenges:** How prepared are your graduates to take on the wide range of roles—in government, industry, and academia—required for engineers to address the grand challenges that face the globe and its inhabitants?

2.10.6 Welcoming Students into the Work World

Those students who enter the work world after graduating face challenges on multiple fronts. They find that the problems that they are solving are more complex and ambiguous than the problems that they solved in school. The structures of their new work environments are unfamiliar and multi-faceted, and it can be difficult for newly hired engineers to find the information they need. Sometimes, they feel that they are not allowed sufficient exposure to the “big picture” of where they and their work activities fit into the goals of the work group or company. These new hires also find that they are working with larger, more diverse teams than they experienced in school—teams that are composed of engineers and non-engineers, coworkers, and customers or clients. They must often learn new terminology and new communication skills.

- **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? Are they supported when they need to seek out information and advice? Are they given appropriate orientation, support and mentoring from others in the organization?
- **Working in Diverse Teams:** Are your industry-bound graduates prepared to work with a wide variety of coworkers and customers or clients in different roles and settings? Do they understand the value of skills and perspectives from individuals in fields other than engineering? Do they understand that decisions can often incorporate more factors than those that pertain only to the engineering aspects?
- **Communicating Effectively:** Do your graduates have an appreciation for the needs and interests of different audiences when talking about their work or a problem? Are

they able to listen to others and effectively incorporate input? Can they communicate their ideas to multiple audiences in the many modes they need to?

2.10.7 Next Steps: Let the Discussions Begin

We hope the new insights about engineering student pathways gained through APS research, coupled with practice-related questions above, will facilitate reflection, stimulate discussion, and eventually inform action on your campus. The APS team has already engaged multiple communities in productive discussions facilitated in a variety of formats at major conferences, including the American Society for Engineering Education's annual conference, Frontiers in Education, the Professional and Organizational Development Network in Higher Education's annual conference, and the Women in Engineering ProActive Network's annual conference. Other ways of responding to these findings and questions could be less formal: an individual faculty member considering how APS findings might affect how design is taught or a conversation between an engineering educator and a faculty development professional about effective teaching. Alternatively, it might be an individual student taking greater ownership for connecting their work and school experiences. It might also take the form of discussion at the department or institution level between faculty, administrators, and staff, as part of a broader review of how effectively a particular program is in enabling academic and professional success for students on a variety of educational pathways.

Doing this—understanding the experiences of our students and integrating these insights into how we design, deliver, and improve engineering education—will result in education that excites more students about engineering and better prepares them to become the technology experts and leaders so needed to address the increasingly complex problems faced by the global community.