

Center for the Advancement of Engineering Education
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The word cloud on the cover was produced at <http://www.wordle.net/>.
Word size is proportional to their frequency in the local inquiry questions presented in Subsection 2.10 of this report. These questions are based on Academic Pathways Study research and are designed to guide local efforts to improve the undergraduate engineering experience.

ENABLING ENGINEERING STUDENT SUCCESS

*The Final Report for the
Center for the Advancement of Engineering Education*

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CAEE-TR-10-02



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Center for the Advancement of Engineering Education
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Executive Summary

Today's engineering graduates will solve tomorrow's problems in a world that is advancing faster and facing more critical challenges than ever before. This situation creates significant demand for engineering education to evolve in order to effectively prepare a diverse community of engineers for these challenges. Such concerns have led to the publication of visionary reports that help orient the work of those committed to the success of engineering education. Research in engineering education is central to *all* of these visions.

The Need

Research on the student experience is fundamental to informing the evolution of engineering education. A broad understanding of the engineering student experience involves thinking about diverse academic pathways, navigation of these pathways, and decision points—how students choose engineering programs, navigate through their programs, and then move on to jobs and careers. Further, looking at students' experiences broadly entails not just thinking about their learning (*i.e.*, skill and knowledge development in both technical and professional areas) but also their motivation, their identification with engineering, their confidence, and their choices after graduation.

In actuality, there is not one singular student experience, but rather many experiences. Research on engineering student experiences can look into systematic differences across demographics, disciplines, and campuses; gain insight into the experiences of underrepresented students; and create a rich portrait of how students change from first year through graduation. Such a broad understanding of the engineering student experience can serve as inspiration for designing innovative curricular experiences that support the many and varied pathways that students take on their way to becoming an engineer.

However, an understanding of the engineering student experience is clearly not enough to create innovation in engineering education. We need educators who are capable of using the research on the student experience. This involves not only preparing tomorrow's educators with conceptions of teaching that enable innovation but also understanding how today's educators make teaching decisions. We also need to be concerned about creating the capacity to do such research—in short, we need more researchers. One promising approach is to work with educators who are interested in engaging in research, supporting them as they negotiate the space between their current activities and their new work in engineering education research. To fully support this process, we must also investigate what is required for educators to engage in such a path.

The Center

The Center for the Advancement of Engineering Education (CAEE) began research in January 2003 as one of two national higher-education Centers for Teaching and Learning funded by the National Science Foundation that year. Two divisions of the NSF provided support: Engineering Education and Centers (Engineering Directorate) and the Division of Undergraduate Education (Education & Human Resources Directorate). Originally funded for 2003–2007, supplementary funds from the Engineering Directorate allowed additional analysis and dissemination to continue through 2010.

This report describes the work of CAEE—work that addresses the issues highlighted above. CAEE engaged in four threads of activity:

- Academic Pathways Study (APS, 2003–2010)
- Studies of Engineering Educator Decisions (SEED, 2006–2010)
- Engineering Teaching Portfolio Program (ETPP, 2003–2006)
- Institute for Scholarship on Engineering Education (ISEE, 2003–2008)

These activities all involved an emphasis on the people in the engineering education system: students, educators, and researchers. The Center activities involved concurrent and interwoven emphasis on both research and capacity building. For example, while the first two efforts (APS and SEED) focused on research and the second two (ETPP and ISEE) were primarily capacity-building efforts, significant capacity-building outcomes were part of the first two efforts, and the last two efforts addressed important research questions. Finally, our activities were not only motivated by a desire to support future innovation, but themselves involved innovation—from the scale of the Academic Pathways Study, to the novelty of the Studies of Engineering Educator Decisions, to the emphasis on diversity in the Engineering Teaching Portfolio Program, and the flexibility of the Institute model.

Below, we summarize CAEE’s findings and outcomes, followed by highlights from our efforts to disseminate the results, including a set of research instruments and other materials that are available for use by others. We conclude with a look ahead at next steps and some questions for future research.

The Learning Experiences of Undergraduate Engineering Students: The Academic Pathways Study (APS)

The primary goal of the Academic Pathways Study was to create a rich and wide-ranging portrait of the undergraduate engineering learning experience, using multiple research methods and relying on the students’ own words for much of the data. Specific research questions focused on four areas:

- **Skills:** How do students’ engineering design skills and understanding of engineering practice develop and/or change over time?
- **Identity:** How do students come to identify themselves as engineers? How do these identities change as they navigate their education?
- **Education:** What elements of students’ engineering educations contribute to changes examined in the skills and identity questions above?
- **Workplace:** How do students conceive of their careers? What skills do early-career engineers need as they enter the workplace?

The Academic Pathways Study addressed these questions with a large, multi-faceted research effort that generated a broad and varied set of results. To summarize, the various components of the APS included the following:

- over 5,400 students from around the country
- multiple research methods (both quantitative and qualitative), including surveys, structured and semi-structured (ethnographic) interviews, engineering design tasks, and focus groups
- a four-year longitudinal study at four institutions

- a broad, national survey at 21 institutions
- an additional collaboration with National Survey of Student Engagement (NSSE) researchers that enabled a broad comparison of engineering undergraduates with those in other majors ($N > 11,000$)
- a study of over 100 newly hired engineering graduates and 15 of their managers at 14 companies and organizations

In this report, we provide not only details of the APS findings, but also information about the scope of the study and the specific analyses that led to the findings. In looking at our results, we expect that different people in the engineering community will have different reactions. Some findings confirm common beliefs, while others might contradict the reader's own experiences or otherwise challenge expectations. Many of the findings have multiple interpretations, and not all findings are directly actionable in the same way. A distinctive feature of this body of findings, besides the scope of the work, is that all of the results are grounded in data from a set of rigorously designed and conducted studies. To aid the reader, we have grouped the APS results by various aspects of the student experience.

Persistence in Engineering and Comparison with Other Majors

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, those who persist 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 a net loss of students of more than 15% (greater than most other majors). This 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 this group has strong representation of underrepresented groups (and therefore can contribute to diversifying engineering).

We also see that there are multiple pathways into engineering, and supporting less-traveled pathways has the potential for broadening participation in engineering. 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 (and do) learn about engineering through multiple sources—e.g., relationships with faculty, advisors, and peers; coursework; co-op/internship experiences; and extracurricular activities.

Motivation

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, in some cases, 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 factors have more influence with one demographic 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-year students, 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.

The Many Ways That Engineering Students Experience College

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.*, how they combine coursework and extracurricular involvement; how they engage in co-op, internship, and research opportunities; and how they make decisions about their future. Some students desire significant engagement in everything they do, others are more selective in their patterns of involvement, and some seem largely uninvolved in out-of-classroom activities. Even students who follow similar academic paths may experience their education differently. For example, students differentially experience curricular overload or pressure to represent their demographic group. Some of these trends are related to gender or underrepresented racial/ethnic minority (URM) status, whereas others are more aligned with underlying motivation and confidence factors. Still others may be influenced by programmatic structures and institutional settings. 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 the many ways they go about constructing and experiencing this education.

Learning about Engineering, Becoming an Engineer

Students develop an engineering identity and learn about engineering from a variety of sources: co-op and internship experiences, their coursework and instructors, extracurricular activities, and personal contacts. We observed that these sources vary little by gender or URM status. On the one hand, APS findings showed that students were learning about engineering: By their senior year, most engineering students saw problem solving, communications, teamwork, and engineering analysis as key engineering competences and were using more engineering-specific language to express technical ideas. 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 professional and interpersonal skills (e.g., leadership, teamwork, communication, and business ability) 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. These findings suggest that the typical engineering curriculum may not be doing enough 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 do not always successfully transfer 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.

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.

In addition, when compared with first-year students, seniors are less involved in 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.

Positioning for Professional Success: Student Plans

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.

Early Experiences in the Work World

Those students who enter the work world after graduating face challenges on multiple fronts. They find that the problems they are solving are more complex and ambiguous than the problems 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, recently hired graduates 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.

Beyond the Academic Pathways Study

We hope the new insights about engineering student pathways gained through APS research, coupled with practice-related questions provided in Subsection 2.10, will facilitate reflection, stimulate discussion, and eventually inform action on campuses across the country. The APS team has already engaged multiple communities in productive discussions facilitated in multiple formats at a variety of major conferences. Better understanding the diversity in the experiences of our students will inform how we design, deliver, and improve engineering education. This diversity in student experiences brings to mind questions about how teachers accommodate such a wide range of student goals, choices, and pathways. As discussed next, another component of CAEE's research addressed aspects of the teaching of engineering.

Investigating Faculty Approaches to Teaching: Studies of Engineering Educator Decisions (SEED)

In the Studies of Engineering Educator Decisions work, we sought to gain insight into engineering teaching using an innovative approach: the collection and analysis of narratives about teaching decisions. To do this, we interviewed 31 engineering educators about two decisions that they had made: a planning decision (a decision made in advance of teaching) and an interactive decision (a decision made in the moment). Our interview protocol was designed based on principles from the Critical Decision Method, an approach used to study decision making in other domains. We then used the resulting narratives about the decisions and how they were made to investigate a variety of questions related to engineering teaching.

- In analyzing the decision narratives to better understand educator decision-making, we found that most participants reacted positively to the emphasis on decisions and decision making, and that all were able to provide rationale for their decisions (with both time and allusions to prior decisions as common features of their rationale). We also learned that the participants collectively mentioned a variety of sources of information as being useful in decision making (although research was infrequently mentioned as a source), and we identified five patterns in terms of satisfaction with their teaching decisions.
- Looking beyond their decision processes and toward what additional information the decision narratives could reveal, we analyzed the narratives to explore educators' use of teaching practices that are considered effective at helping students develop intrinsic motivation to learn. In this analysis, we found that engineering educators reported using a variety of teaching practices that are known to increase student motivation to learn, such as helping students see the relevance of material, helping students feel connected to the learning group, and helping students experience productive levels of engagement and challenge. We found less frequent mention of providing students with opportunities for autonomy, enabling all students to feel respected, and providing students with opportunities to demonstrate their growing competence.
- Driven by the broad issue of how engineering educators conceptualize engineering students, we analyzed the decision narratives to learn more about how engineering educators differentiate among students. In this analysis, we found that all of the educators differentiated among students at some point, that student behaviors were the most prevalent basis for differentiating among students, and that differentiation based on other dimensions (e.g., what students know, their educational classifications, their social classifications) was also prevalent but less so.

- In addition to these analyses, we also investigated the benefits of engaging in research on teaching decisions. We observed that engaging in research on teaching decisions has professional development benefits for the researchers who analyzed the decision narratives, the researchers who collected the narratives, and even the educators who were asked to provide the narratives.

In looking ahead, we believe the outcomes of this research may be useful for faculty development personnel in helping them to better understand their faculty clients. Additionally, the decision narratives themselves can be used by faculty developers to initiate fruitful discussions with faculty on problematic teaching issues.

We also believe that these results represent a starting point for additional research. Variations of this work could focus on collecting decision narratives related to specific constraints (e.g., decisions about assessment, decisions about student projects, decisions in working with freshman). In Section 3 of this report, we also offer a variety of more specific research questions that could be explored.

Finally, there are opportunities to bring these ideas together—for projects featuring not only the collection and analysis of decision narratives in specific domains but also active efforts to leverage (and document) the collection and analysis activities as professional development.

Supporting the Development of Future Faculty: Engineering Teaching Portfolio Program (ETPP)

The Engineering Teaching Portfolio Program was designed to assist engineering graduate students with an interest in teaching by advancing their thinking about teaching through the development and peer-based discussion of teaching portfolios. Each student's portfolio consisted of a teaching philosophy statement, a diversity statement, and several annotated teaching artifacts.

Significant ETPP outcomes include a comprehensive set of curricular and supplemental materials that are available for others to use, approximately 100 program “graduates,” and several small-scale spinoff efforts. In addition, the program's research component informed the development of the curricular materials and can be used by others interested in supporting graduate students.

ETPP is notable in the way it embeds opportunities to learn about teaching in the production of something inherently desirable to future faculty (the portfolio), includes conversations about diversity in prominent ways, and involves a way of talking about teaching that supports participation by people with a wide range of prior experiences.

Our experiences with multiple offerings of ETPP suggest that the educational power of portfolio construction comes from consideration of the significant questions that can be associated with portfolio construction (e.g., who am I talking to, what exactly do I want to say about my teaching, who judges teaching, how do I provide evidence of my strengths as a teacher, what counts as “good” teaching). Potential future work with ETPP includes more extensive data analysis to better understand how participants benefit from program participation, as well as additional program offerings and integration of APS results into the curriculum and supplemental materials.

Building Engineering Education Research Capacity and Community: Institute for Scholarship on Engineering Education (ISEE)

The Institute for Scholarship on Engineering Education (ISEE) sought to cultivate a diverse community of engineering education researchers. In addition, the team formulated principles and models for advancing this community of scholars.

Three cycles of the Institute for Scholarship on Engineering Education were held. The three cycles involved a total of 49 engineering education researchers (Institute “Scholars”) representing 20 institutions. Twenty (40%) were women and 17 (36%) were underrepresented minorities. All academic ranks (and other roles) were represented: 6 full professors; 12 associate professors; 9 assistant professors; 13 graduate students; and 9 staff members, including administrators and advisors.

Each ISEE cycle consisted of five main phases: (1) designing and/or adapting the Institute model, (2) recruiting Scholars for the current year’s Institute, (3) a week-long Summer Summit kick-off event at the host school, (4) activities during the academic year to support Scholars in conducting their studies, and (5) a culminating Leadership Summit event. The Summer Summit was designed to engage the Scholars in the process of engineering education research, introducing many to new techniques and ideas in educational research. Activities and discussions during the Summit helped Scholars refine their research questions, decide on appropriate methodology, and, very importantly, to form a community that could be sustained beyond the week-long meeting. After the Summit, Scholars typically returned to their respective campuses to conduct their research, with frequent electronic communication and interaction with fellow Scholars and the ISEE team.

Each Institute had a different theme. The individual projects for the 2004–2005 Institute primarily focused on classroom changes under the broad theme of “classroom as lab.” For the 2005–2006 Institute, Scholars worked on projects aimed at impact on engineering education at their campus (*i.e.*, a theme of “campus as lab”). The 2006–2007 theme was “Advancing Engineering Education Research to Meet the Needs of the 21st Century.” Scholars were recruited through a competitive, national application process and were asked explicitly to consider issues of diversity in their projects. As such, the focus of the 2006–2007 Institute was “nation as lab.”

The Institutes had a powerful impact on the participating Scholars in three broad areas: building skills, knowledge, and experience; broadening their career paths; and helping to foster their membership in the broader community of engineering education researchers. In terms of impact on their institutions, Scholars’ projects addressed existing concerns on several campuses. Examples include examining a set of engineering fundamentals courses on one campus, investigating the benefits of “empowering” students at another campus, and supporting Hispanic students transferring from community colleges.

ISEE served as a model for others interested in organizing similar community-building activities. A paper describing the design of the Institutes and an example schedule for the week-long kick-off event are available on the CAEE web site.

Finally, a research study of 13 engineering education researchers detailed two significant aspects of their pathways into the field of engineering education research: the importance of a community of practice perspective and the development of composite identity. This study further extended our understanding of capacity building for engineering education research.

Getting the Word Out: Publications, Presentations, Research and Program Resources, and People

The CAEE team recognized from the outset that a significant part of our mission was to get the word out about the work of the Center. A fundamental part of this activity was sharing news about the research and results with as wide a variety of audiences and in as many different venues as possible. These dissemination activities began early in the life of the Center and are continuing after the formal end of the grant period.

From January 2003 to June 2010, CAEE productivity included

- over 130 papers and journal articles in both engineering education and education publications;
- 9 plenary, keynote, and invited presentations at national conferences and meetings;
- 9 conference special sessions; and
- more than 25 workshops to a wide variety of audiences.

In addition to published research findings and presentations, CAEE created a set of materials that can be used by others in conducting their own research. These materials include two surveys, four sets of interview protocols, two engineering design task exercises, and program design and materials for ETPP and ISEE. The Academic Pathways Study team prepared a report and complete documentation package describing the design and implementation of the APS. We have already seen that these APS tools and materials are being used extensively by other researchers.

Capacity building was also a critical part of the Center's impact. An explicit goal in assembling the team was to combine researchers from both engineering and education departments who had a mix of quantitative and qualitative research expertise. Over the course of the grant, the Center grew to involve 63 faculty members and staff, 41 graduate students, and almost 50 undergraduates during the period 2003–2010. As research scientists and graduate students moved on to faculty positions at other campuses, they typically continued their involvement with CAEE, spreading the Center's influence even further.

Future Work

The Academic Pathways Study results call attention to certain areas of educational research that warrant further analysis. For example, considering the diverse programs and student perspectives we observed across the institutions we studied, it makes sense that other institutions have their own nuances to be explored. We also observed substantial changes in students between their first and senior years, both in terms of learning and development. This warrants further inquiry into the middle years—the experiences of sophomore and junior level students. Further, APS longitudinal research focused on the experiences of students who spend the entirety of their undergraduate careers at one institution. However, APS cross-sectional research shows that this represents only a portion of engineering students. Studies of community college and transfer students are becoming more important as students increasingly follow this academic path. Finally, there are important questions concerning students who never consider or enter engineering.

Given that the current Studies of Engineering Educator Decisions work focused on participants from a single institution, extending the research to confirm or refine findings reported here would be valuable. Such additional data could also be used to further investigate issues such as the role of research results in informing teaching decisions; the

relationship between satisfaction, dissatisfaction, and additional change; and the broad issue of how engineering educators conceptualize students.

Building on the Engineering Teaching Portfolio Program efforts, we could further explore the ways in which the portfolio construction activities help participants reflect on their existing ideas about teaching and ultimately develop a more sophisticated, integrated, personalized, and actionable understanding of teaching. Building on research on the community of engineering education scholars that was conducted as part of the Institutes for Scholarship in Engineering Education, we could expand our investigations into how people enter and navigate the field of engineering research, even as the community itself is growing.

The future work ideas above represent direct extensions of our work. In our report, we also go farther by offering a broad set of research questions organized into seven areas: questions related to (1) student pathways; (2) student learning of engineering; and (3) the role of significant learning experiences; as well as questions related to (4) engineering knowing, (5) teaching engineering, (6) researching issues in engineering education, and (7) bringing about change in engineering education.

Closing Comments

Engineering education is a rich and vibrant area for research, with many opportunities for in-depth scholarship that can contribute significantly to improving engineering education for many constituencies. In 2010, as CAEE comes to an end, the engineering education community is much larger, more distributed, more interdisciplinary, and has expertise in a wider range of research methods than when we began our work in 2003.

CAEE contributed to this expanding field during our seven years of funding, not only through the generation of a rich body of research results, but also by demonstrating the scope of research and program activity that a large center is uniquely capable of accomplishing. CAEE also contributed to the growth of the engineering education community through the many individuals who were involved directly and collaboratively with the Center and through the community-building efforts of ISEE.

We feel that CAEE has been a significant contributor to growth in these areas, as well as to important efforts of helping to use research findings to improve engineering education. As the engineering education community moves forward, we anticipate further research-based improvements to engineering education, ensuring that a diverse cadre of engineering graduates are prepared for the challenges they will face in the coming years.

1 Introduction

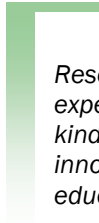
1.1 Situating Our Work

Today's engineering graduates will solve tomorrow's problems in a world that is advancing faster and facing more critical challenges than ever before. This situation creates significant demand for engineering education to evolve in order to effectively prepare a diverse community of engineers for these challenges.

Such concerns have led to the publication of visionary reports that help orient the work of those committed to the success of engineering education. For example, the *Engineer of 2020* (National Academy of Engineering 2004) offers a blueprint for the knowledge and skills future engineers will need in order to function effectively in the future. *Creating a Culture for Scholarly and Systematic Innovation in Engineering Education* (Jamieson and Lohmann 2009) emphasizes the need for a culture of innovation in engineering education in order to create and disseminate educational activities and curricula that are effective at preparing students for the future. *Engineering for a Changing World* (Duderstadt 2008) presents a systems perspective on innovation, locating innovation not just within the curriculum but within a larger framework that is composed of engineering education and engineering practice.

Research in engineering education is central to *all* of the visions described in these reports. Research can shed light on how students develop their competencies, the effectiveness of innovations, and how a systems perspective affects the endeavor. The report *Educating Engineers: Designing for the Future of the Field* (Sheppard *et al.* 2008) represents a significant contribution to this research space, with its goal to “understand, through field research, how the educational practices of the schools form future engineers.” (p. xix). A broad sense of the research needed for engineering education was addressed by the NSF-sponsored conversations referred to as the Colloquies on Engineering Education (Adams *et al.* 2006).

Research on the student experience is a fundamental kind of research for informing the evolution of engineering education. A broad understanding of the engineering student experience involves thinking about pathways, navigation, and decision points—how students choose engineering programs, navigate through their programs, and then move on to jobs and careers. Further, looking at students' experiences broadly entails not just thinking about their learning (*i.e.*, skill and knowledge development in both technical and professional areas) but also their motivation, their identification with engineering, their confidence, and their choices after graduation.



Research on the student experience is a fundamental kind of research for enabling innovation in engineering education.

In actuality, there is not one singular student experience, but rather many experiences. Research on the engineering student experience can look into systematic differences across gender, disciplines, and campuses; gain insight into the experiences of underrepresented students; and create a rich portrait of the changes from students' first year through graduation. Such a broad understanding of the engineering student experience can serve as

inspiration for designing innovative curricular experiences that support the many and varied pathways that students take on their way to becoming an engineer.

However, an understanding of the engineering student experience is clearly not enough to create innovation. For example, we need educators who can use the research in the context of their own teaching and broader teaching innovations. We need educators who are prepared to innovate, which in turn requires being prepared to use the research on the student experience. This involves not only preparing tomorrow's educators with conceptions of teaching that enable such innovation but also understanding how today's educators make teaching decisions.

We also need to be concerned about creating the capacity to do such research—we need more researchers. While this can involve dedicated programs to train Ph.D. level researchers, we need additional innovative ways to create capacity. One promising approach is to work with educators who are interested in engaging in research, supporting them as they negotiate the space between their current activities and their new work in engineering education research. To fully support this process, we must also investigate what is required for educators to engage in such a path.

This report describes the work of the Center for the Advancement of Engineering Education (CAEE)—work that addresses the issues highlighted above. CAEE engaged in four threads of activity:

- Academic Pathways Study (APS, 2003–2010)
- Studies of Engineering Educator Decisions (SEED, 2006–2010)
- Engineering Teaching Portfolio Program (ETPP, 2003–2006)
- Institute for Scholarship on Engineering Education (ISEE, 2003–2008)

These activities all involved an emphasis on the people in the engineering education system: students, educators, and researchers. The Center activities involved concurrent and interwoven emphasis on both research and capacity building. For example, while the first two efforts (APS and SEED) focused on research and the second two (ETPP and ISEE) were primarily capacity-building efforts, significant capacity-building outcomes were part of the first two efforts, and the last two efforts addressed important research questions. Finally, our activities were not only motivated by a desire to support future innovation, but themselves involved innovation—from the scale of the Academic Pathways Study, to the novelty of the Studies of Engineering Educators Decisions, to the emphasis on diversity in the Engineering Teaching Portfolio Program, and the flexibility of the Institute model. In the rest of this report, we present the results of this work.

1.2 A Short History of the Center

1.2.1 The Center

The Center for the Advancement of Engineering Education (CAEE) began research in January 2003 as one of two national higher-education Centers for Teaching and Learning funded by the National Science Foundation that year. Two divisions of the NSF provided support: Engineering Education and Centers (Engineering Directorate) and the Division of Undergraduate Education (Education & Human Resources Directorate). Originally funded for 2003–2007, supplementary funds from the Engineering Directorate allowed additional analysis and dissemination to continue through 2010.

1.2.2 The Team

CAEE began as a team of scholars from Colorado School of Mines, Howard University, Stanford University, the University of Minnesota, and the University of Washington (the lead institution). During the course of the grant, the team grew to include researchers from other institutions including Purdue University, Olin College of Engineering, Virginia Tech, University of Illinois at Champaign-Urbana, and the University of Rochester. Over the duration of the grant, team members included 63 faculty, research scientists, and staff; 41 graduate research assistants; and almost 50 undergraduates who were involved in the research.

The CAEE team included over 100 faculty members, research scientists, graduate students, and staff, as well as almost 50 undergraduate students.

1.2.3 The Research

CAEE research was focused on the broad areas of

- the engineering undergraduate learning experience and school-to-work transition,
- understanding engineering educator teaching decisions,
- the professional development of engineering graduate students using teaching portfolios, and
- activities and models for expanding the engineering education research community.

Over 5,700 individuals (including undergraduate students, graduate students, early-career engineers, practicing educators, faculty, and administrators) participated in CAEE activities.

These areas aligned with four major strands of the research which are described below:

The **Academic Pathways Study (APS, 2003–2010)**, led by Sheri Sheppard, represented the most in-depth portion of CAEE’s research with approximately 80% of the personnel resources. APS activities included the longitudinal (160 participants) and cross-sectional (over 4,200 participants) studies of engineering undergraduates’ learning experiences. In addition, over 100 early career engineers and several of their managers participated in investigations of the transition to work. The APS also included smaller-scale, targeted studies that examined specific aspects of engineering student learning and experiences.

The **Studies of Engineering Educator Decisions (SEED, 2006–2010)**, led by Jennifer Turns, investigated the teaching decisions of 31 engineering faculty using a semi-structured

interview protocol. Participants represented nine engineering departments and a range of academic ranks from non-tenure track to assistant, associate and full professors (with several also serving in administrative positions). The sample included nine women.

The **Engineering Teaching Portfolio Program (ETPP, 2003–2006)**, led by Jennifer Turns and Angela Linse, was designed to use teaching portfolios to enhance the professional development of engineering graduate students. In iterative development of the ETPP, the team used a semi-structured interview protocol and field observations with over 100 participants. The curriculum and supplemental materials were outcomes of this study, in addition to the research findings.

The **Institute for Scholarship on Engineering Education (ISEE, 2003–2008)**, led by Robin Adams, conducted three year-long Institutes that were specifically designed to expand the engineering education research community (involving 49 researchers representing 20 institutions). The design and implementation of the three Institutes served as a basis for developing models in engineering education research that can be adopted and adapted by others. Thirteen Institute Scholars also participated in a companion study of the pathways of scholars into engineering education research.

1.3 Goals of This Report and a Reader’s Guide

1.3.1 Goals of This Report

This report provides an overview of the work of the CAEE team during the seven years of the grant. The report accomplishes several goals:

- summarizes highlights from the findings, organized by the major themes of
 - the engineering student learning experience,
 - faculty approaches to teaching,
 - development of graduate students interested in teaching careers, and
 - building the community of engineering educators and engineering education researchers
- includes references to publications for further investigation by the reader
- lists key CAEE-developed materials for use by other researchers
- offers two sets of questions—one that can serve as a guide for using our results locally, and a second set that discusses future research directions
- serves as encouragement and a model for those undertaking similar work

1.3.2 Reader’s Guide to the Sections

Section 1 provides a general **framing for our research and provides a brief overview of CAEE** including the major research areas.

Section 2 presents **findings on undergraduates and early career engineers** from the Academic Pathways Study (APS). This extensive section concludes with a summary of findings (Subsection 2.10) that includes a set of research-based “local inquiry questions” (also compiled in Appendix D) that can guide efforts to improve the undergraduate engineering experience.

Section 3 presents findings from the **research into engineering teaching** (SEED, Studies of Engineering Educator Decisions).

Section 4 describes the development of an innovative portfolio program and accompanying tools to **support graduate students interested in teaching** careers (ETPP, the Engineering Teaching Portfolio Program).

Section 5 gives details and examples of **community building in engineering education** drawn from the Institute for Scholarship on Engineering Education (ISEE) program and the three year-long Institutes.

Section 6 summarizes CAEE **activities to get the word out** to a variety of audiences at both local and national levels. It also provides a list of **resources** that were developed by the team and can be used by others. (These resources are available through the CAEE web site and include survey and interview instruments and a “behind the scenes” look at the design and development of the Academic Pathways Study.)

Section 7 presents **ideas for further work** to effect change on campuses and conduct more research.

In addition, the report contains five appendices:

- Appendix A: References and Cumulative Bibliography
- Appendix B: Cumulative Team List and Advisory Board Members (2003–2010)
- Appendix C: APS Headlines (summarizing Section 2)
- Appendix D: Local Inquiry Questions (drawn from Section 2.10)
- Appendix E: Looking Ahead: Ideas for Future Research (expanded from Section 7)

2 *Student Learning Experiences: The Academic Pathways Study*

This section of the report discusses CAEE's research on the educational experiences of engineering undergraduates as examined in the Academic Pathways Study (APS). Discussion of findings is organized by the large themes that emerged during the course of analysis. In some cases, findings may not be especially surprising, but they do provide empirical confirmation and form part of the larger story. In other cases, intriguing findings bring up questions that merit further research. We hope that the range of findings we present will interest engineering educators, policy makers, and other engineering education researchers. The selected findings create a rich portrait of the learning experience of engineering undergraduates as they move through four years of school and beyond.

After an overview of the APS's overarching research questions and methods, most of Section 2 describes a broad range of results, organized by theme. These results draw on over 100 papers based on the APS research, three dissertations, several unpublished analyses, and selected works by other researchers. The closing subsection contains broad-brush summaries of the key APS research findings that are described in greater detail in the preceding subsections. It also contains questions informed by this research for faculty, administrators, and staff to use in considering how to better support student success in following an engineering pathway through their programs. The topics covered in this section are as follows:

- **2.1 Overview of the APS:** Research questions, samples and cohorts, methods
- **2.2 The College Experience:** Engineering students compared to other majors
- **2.3 Motivation to Study Engineering:** Motivational factors in choosing to study and persist in engineering
- **2.4 The Engineering College Experience:** Educational experiences as related to demographics, confidence, motivation, and other factors
- **2.5 Engineering Knowledge, Conceptions, and Confidence:** Understanding of and confidence in engineering, and engineering practice
- **2.6 Engineering Design Knowledge, Conceptions, and Confidence:** Understanding of and confidence in engineering design
- **2.7 Looking Beyond Graduation: Student Plans:** Post-graduation plans of engineering students
- **2.8 Looking Beyond Graduation: Experiences in the Work World:** Early-career experiences in the engineering workplace
- **2.9 Summarizing Results about Diversity:** Findings related to underrepresented students
- **2.10 Enabling Success for Engineering Students:** Summary of the findings and questions to ask in guiding efforts to enable student success

2.1 Overview of the APS

The primary goal of the Academic Pathways Study was to create a rich and wide-ranging portrait of the undergraduate engineering learning experience, using a variety of research methods and relying on the students' own words for much of the data.

The APS represents the largest portion of CAEE's research, with approximately 80% of the center's budget allocated to researcher support. During the course of the APS, over 130 faculty, research scientists, graduate and undergraduate research assistants, and staff representing 12 universities and six national organizations were involved in the research. Detailed research design began in early 2003, and data were collected during the 2003–04 through 2007–08 academic years. The original funding was from 2003 to 2007, and NSF provided supplemental funds to enable two additional years of work. Data analyses continued into 2010.

The research questions being addressed by APS are listed in Table 2.1-A and consider how today's educational systems support students learning to be engineers.

Table 2.1-A: APS research questions

Focus	Research question
Skills	How do students' engineering design skills and understanding of engineering practice develop and/or change over time?
Identity	How do students come to identify themselves as engineers? How do these identities change as they navigate their education?
Education	What elements of students' engineering educations contribute to changes examined in the skills and identity questions above?
Workplace	How do students conceive of their careers? What skills do early-career engineers need as they enter the workplace?

2.1.1 Individual Studies

To investigate these research questions, we designed a series of longitudinal and cross-sectional studies of engineering undergraduates' learning experiences and transition to work. In addition, we drew on the National Survey of Student Engagement (NSSE) data set to provide the basis for a large-scale comparison between engineering students and students from other academic disciplines.

Table 2.1-B summarizes the number of participants and institutions/organizations for the different studies. Following the table, the studies are described briefly, including goals, methodology, and complete duration (including initial study design, data collection, subsequent analyses, and dissemination). For a more detailed description of the APS design and methodology, see the CAEE technical report "An Overview of the Academic Pathways Study: Research Processes and Procedures" (Sheppard *et al.* 2009; available on the CAEE web site).

Table 2.1-B: APS cohorts, samples, and studies with number of participants, institutions/organizations, and methods (S: survey, I: structured and/or semi-structured (ethnographic) interview, F: focus group, O: observation, D: engineering design task)

Study	Participants	Institutions/ organizations	Data collection	Methods
Longitudinal Cohort	160	4	2003–2007	S I O D
Broader Core Sample	842	4	2007	S
Broader National Sample (APPLES)	4,266	21	2008	S
NSSE Comparative, Longitudinal Data Set	11,812	247	2002–2007	S
Single-School, Cross-sectional Sample	160	1	2005–2006	S F
Transition to Workplace Studies	101 new hires, 15 managers	14	2007–2008	I O
Difficult Concepts Study	19 students, 23 faculty	1	2004–2006	S I

Longitudinal Cohort (2003–2009)

The Longitudinal Cohort consisted of 160 undergraduate engineering students (40 at each of four diverse campuses). The students were paid a stipend to participate in the study from 2003 to 2007, beginning with their first year in college and into their fourth year. Oversampling increased the number of participants from underrepresented groups in engineering. The initial sample comprised approximately 61% men and 39% women. Just under 60% of the participants were white or Asian-American, with the rest being from underrepresented racial/ethnic minority (URM) groups. To put these numbers into perspective, at the national level, 19.5% of engineering graduates are female, and 12% are from underrepresented racial/ethnic groups (National Science Foundation 2010; see 2006 data (most recent available) in Tables 4 and 6).

The APS research team used four primary data collection methods for the Longitudinal Cohort: surveys, structured and semi-structured (ethnographic) interviews, observations, and short engineering design tasks, as described below. In addition, academic transcripts were collected for all participants, and exit interviews of those leaving an engineering major were conducted.

- The **Persistence in Engineering (PIE) Survey** was designed to identify and characterize the fundamental factors that influence students' intentions to pursue an engineering degree and to practice engineering as a profession. The survey was built following an extensive review of engineering education literature and previous national surveys on undergraduate education. The PIE survey was administered to the entire Longitudinal Cohort seven times: twice in each of the students' first three years and once in their senior year.
- The **structured interviews** extended and expanded on the PIE survey with a focus on specific information related to the students' engineering education and identity development. The structured interviews used a fixed set of questions and lasted approximately one hour. A primary goal was to elicit qualitative data in the form of the students' own words. Twenty-four students at each of the four campuses participated in the structured interviews through their first three years.
- **Semi-structured (ethnographic) interviews** and **ethnographic field observations** were used to gather data from a smaller set of participants (16 per campus for the semi-structured interviews, of which 8 also participated in limited field observations in their first year). The focus was on extending the understanding of both the local cultures of engineering student experiences and students' pathways through these experiences. Researchers examined activities such as intense project work, exam periods, and extracurricular activities.
- The **engineering design tasks** were short (approximately 10 minutes) "engineering tasks" designed to investigate how students approach open-ended engineering design problems at various stages of their academic careers. Following each design task, participants were asked to discuss their answers as a means for researchers to better understand students' approaches and the reasoning behind them. The design task data were supplemented by responses from specific questions included in the PIE survey that related to students' conceptions of design and engineering work. Administration of the design tasks varied during the course of the study and was coupled with the structured and/or semi-structured interviews, depending on the year.

Subsection 6.2 of this report describes available resources, including the surveys and protocols for each particular method mentioned above.

Note that for the qualitative portion of the research (interviews and design tasks), student participants were assigned pseudonyms. These pseudonyms are included in many of the quotations that appear in the following sections.

The four schools that participated in the Longitudinal Cohort were from across the U.S. and of varying size and institutional type. They were a public research university devoted to engineering and applied science; a comprehensive, historically Black, private university; a private research university; and a very large, public research university.

For additional information on the design of the Longitudinal Cohort research and the PIE survey in particular, see Eriş *et al.* 2005.

Broader Core Sample (2006–2008)

The Broader Core Sample served as a pilot for the Academic Pathways of People Learning Engineering Survey (APPLES, described in the next paragraph), as well as a means to gather further data from additional students at the four Longitudinal Cohort schools. The approximately 10-minute survey was given to a cross-sectional group of over 800 first-year to senior undergraduates in early 2007. Most participants were engineering majors, but the

sample also included “switchers,” or students who were interested in engineering at one time and subsequently switched to a non-engineering major (about 10% of the sample). (Switchers are discussed further in Subsection 2.2.2.)

Broader National Sample: APPLES (2007–2009)

The Broader National Sample, also known as the **Academic Pathways of People Learning Engineering Survey** or **APPLES**, was a cross-sectional survey study of over 4,200 engineering undergraduates at 21 campuses of varying size, location, student demographics, and mission. The survey was administered in late winter through early spring of 2008. The APPLE Survey is a shorter version of the Longitudinal Cohort PIE survey described above. Similar to the Broader Core Sample, the Broader National Sample included not only engineering students but pre-engineering and “switcher” students as well. The sample included approximately 16% underrepresented minorities (URM) in engineering. Women and men represented approximately 35% and 65% of the sample, respectively. (These race/ethnicity and gender data were obtained from a multiple-choice question on the APPLE Survey.) For more detailed descriptions of the Broader Core and Broader National Sample (APPLES) surveys, see Sheppard *et al.* 2010 and Donaldson, Chen, *et al.* (2007, 2008).

NSSE Comparative, Longitudinal Data Set (2008–2009)

We collaborated with researchers from the National Survey of Student Engagement (NSSE) in order to situate APS findings about engineering students in the broader context of other college students with a wide range of majors. The NSSE sample included a total of 11,812 students at 247 institutions who responded to the NSSE survey as first-year students in the spring of 2002, 2003, or 2004 and again as prospective graduates three years later, in the spring of 2005, 2006, and 2007, respectively. (Lichtenstein *et al.*, forthcoming; McCormick *et al.*, forthcoming)

Single-School, Cross-sectional Sample (2005–2006)

The Single-School, Cross-sectional Sample participants were drawn from a large, public university in the Midwest that was not involved in the original Longitudinal Cohort research. The sample targeted 160 undergraduate students distributed across their first through fourth years. The PIE survey was administered in the fall and spring of the 2005–06 academic year. In addition, six focus groups were conducted in the spring of 2006 to supplement quantitative information from the survey and with an emphasis on including transfer students. (Korte and Smith 2007)

Transition to the Workplace Studies (2006–2009)

The Transition to the Workplace Studies focused primarily on the early career experiences of recently-hired graduates. The studies involved over 100 early career engineers (and 15 of their managers) employed in a range of private companies and public agencies. Data were collected using interviews and observations. Related findings concerning post-graduation plans are based on survey data collected from the Broader National Sample (APPLES).

Six distinct data sets were collected:

- Thirty newly hired graduates and six managers at a global vehicle manufacturing company
- Eighteen newly hired graduates at a national food manufacturing company
- Nineteen newly hired graduates and four managers at a smaller manufacturer of computer components

- Nineteen newly hired graduates and five managers at a state-government agency for transportation
- Seven newly hired graduates: five at a county public works department, one at a state transportation agency, and one at a small aerospace firm
- Eight engineering graduates (from one of the APS Longitudinal Cohort schools) employed at a variety of engineering firms

Difficult Concepts Study (2004–2006)

A separate study focused on difficult concepts in engineering mechanics (e.g., force) and electrical circuits (e.g., voltage). Nineteen seniors (10 majoring in electrical engineering and 9 majoring in civil/mechanical engineering) at a public research university devoted to engineering and applied science participated in hour-long interviews designed to probe their understanding of these concepts. Prior to beginning the research with the students, 10 faculty members in circuits/electrical engineering and 13 in mechanical/civil engineering were surveyed using an iterative Delphi process to develop the interview questions.

2.1.2 Notes About Section 2

The remainder of this section provides selected findings from APS research; we did not attempt to provide an exhaustive summary of all of the work accomplished during the study. In addition to characterizations of engineering students as a group, some of the selected findings are the results of comparisons between various subsamples of interest, e.g., comparisons by class standing, by gender, and by race/ethnicity. For those readers who are interested in delving deeper into the research, we have included references in the text that identify the sources for specific findings, as well as a full list of our publications to date in Appendix A, Subsection A.2.

In the interest of focusing directly on the APS findings, we have included only a few references to other work from the literature, e.g., to provide useful theoretical background and/or terminology. This limited set of external references is listed in Appendix A, Subsection A.1. Those interested in seeing our discussion and interpretation of results situated in the context of the broader engineering education literature are directed to the individual APS papers and articles cited throughout this section.

Data from the APPLE Survey instrument administered to the Broader National Sample are referred to throughout the report and are not referenced each time they are discussed. The quantitative APPLES (4,266 students) and PIE survey (160 students) data are accompanied by excerpts, often including quotations, from the qualitative research (“smaller-*n*” interviews and design tasks). The discussion of APPLES results focuses on comparisons of the first year and senior year data. See the full APPLES report for more details (Sheppard *et al.* 2010).

Prior APS-related publications refer to the cohorts and samples in slightly different ways. The APS overview technical report (Sheppard *et al.* 2009) refers to the Single-School, Cross-Sectional Sample as the Cross-Sectional Cohort and the Transition to the Workplace Studies as the Workplace Cohort. Earlier publications refer to the Longitudinal Cohort as Cohort 1, the Broader Core Sample as Cohort 3, and the Broader National Sample as Cohort 4. The Transition to Workplace Studies grew out of research efforts initially referred to as Cohort 2.

2.2 The College Experience

The Academic Pathways Study involved multiple cohorts/samples of students, the largest of which included 4,266 undergraduates from 21 institutions across the U.S who participated in the Academic Pathways of People Learning Engineering Survey (APPLES). As part of an extended analysis of the APPLES data, we also collaborated with researchers from the National Survey of Student Engagement (NSSE) to compare our data on engineering undergraduates with NSSE's findings about students in engineering, as well as other majors. NSSE researchers performed a search of students who took the NSSE survey in both their first and senior years and found nearly 12,000 useable cases representing a broad range of undergraduate majors. This subsection presents details of our comparative analysis, accompanied by additional APS results relating to persistence in engineering majors. See Subsection 2.1.1 for details about APPLES and the NSSE data set.

2.2.1 Engineering Students Compared with Other College Students

Other researchers (e.g., Astin 1993; Sax 2008; Beyer, Gillmore, and Fisher 2007; Fairweather 2009) have shown the value of looking at how the college experience is affected by a student's disciplinary field. Their research approach and sometimes provocative findings inspired us to compare engineering students' experiences to those of students in other fields. We considered engineering in comparison with six groups of majors: science/technology/math, computer science, business, social sciences, arts and humanities, and a group composed of all other majors. The engineering majors made up 5% of the seniors we considered, as shown in Figure 2.2-A. This percentage of engineering students is comparable with their representation in the U.S. college student population more generally (National Science Foundation 2010, Table 5-2006; Chen 2009). This subsection draws extensively on the analysis we did with the NSSE data set to offer a broad overview of the college experience and complements these findings with explanatory insights from our detailed Longitudinal Cohort study.

Figure 2.2-A: The majors of graduating seniors in the NSSE data set ($N = 11,817$)

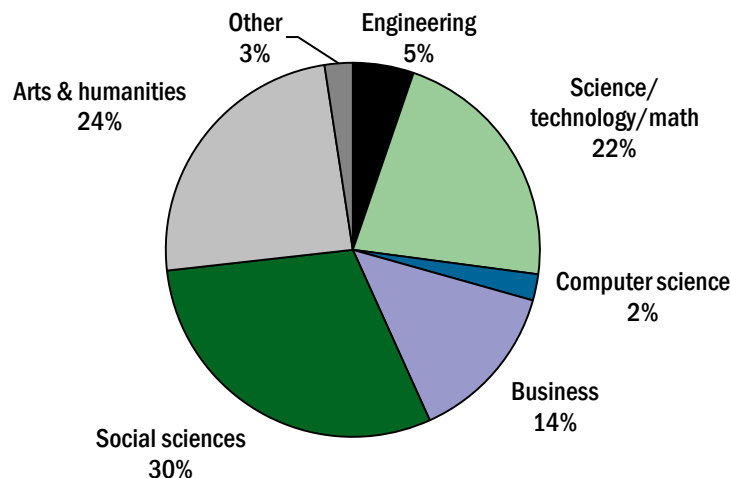
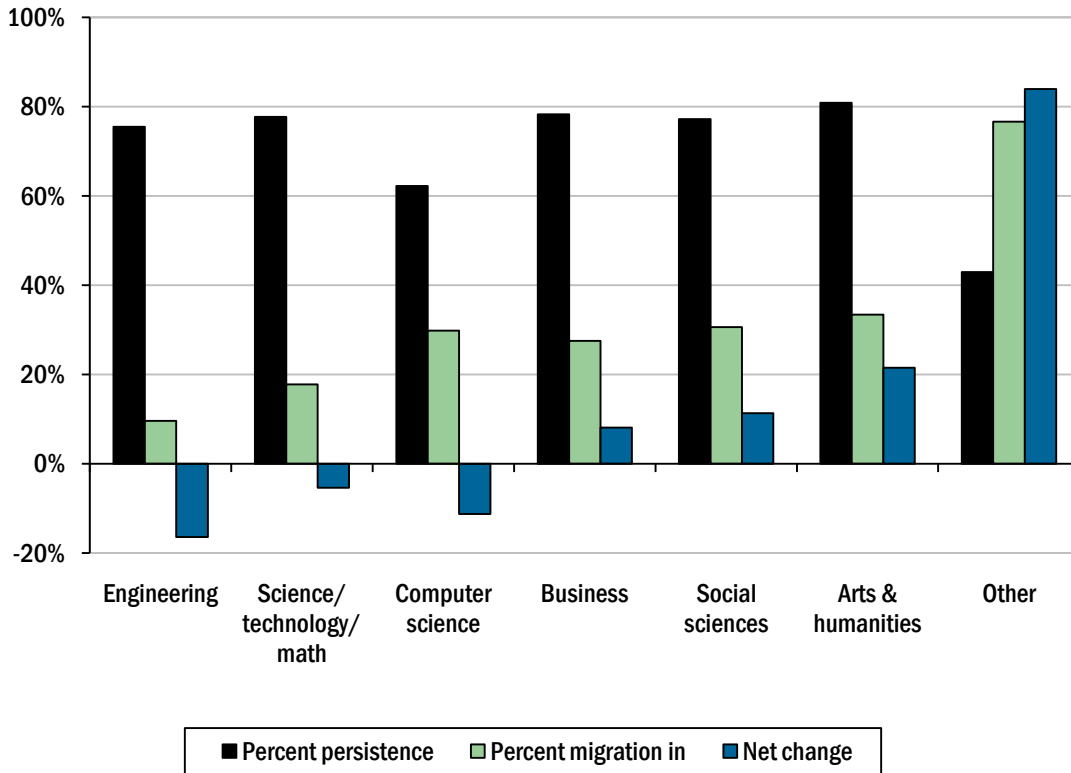


Figure 2.2-B: Persistence in matriculating major (left bars), migration into major (middle bars), and net loss/gain in major (right bars) in the NSSE sample



Engineering majors are as likely to persist as are other majors.

There is strong evidence that persistence among engineering students is comparable to other majors, as shown in Figure 2.2-B. However, engineering has the lowest percentage of *migration in*. This disparity results in engineering having the greatest percentage decrease in students relative to other majors when both *persistence* and *in-migration* are considered. In Figure 2.2-B, the rightmost bars show net change, where engineering has a 16% drop in students by the senior year.

Definitions

persistence: ratio of students remaining as seniors in a major area relative to the number matriculating in that major

migration in: proportion of students who as seniors are in a major area different from the one in which they matriculated

There are similarities among, but also differences between, engineering majors and other majors with respect to learning and college-experience measures.

Engineering students are similar to non-engineering majors in a variety of ways. For example, they are equally engaged with their studies (e.g., interaction with faculty, participation in extracurricular activities) as students in other majors. In addition, they are similar in other factors, ranging from self-reported GPA to overall satisfaction. However, engineering students differ from students in other majors in certain learning gains (Figure 2.2-C). Engineering students make greater gains in practical competence and higher order thinking, but lower gains in personal and social development and general education. (McCormick *et al.*, forthcoming; Lichtenstein *et al.* 2010)

Figure 2.2-C: Mean values for selected engagement variables for seniors in the NSSE sample, by major group

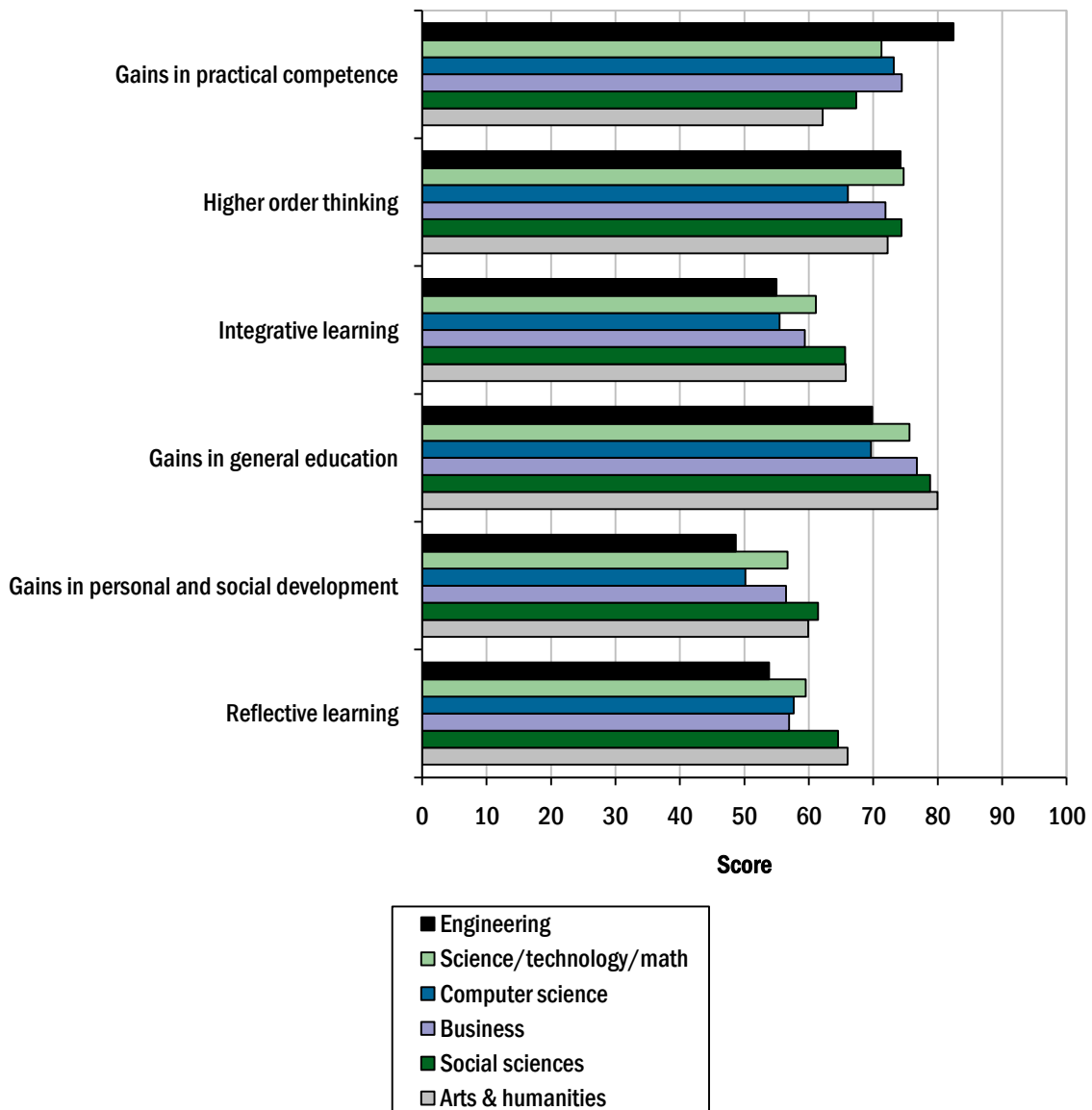
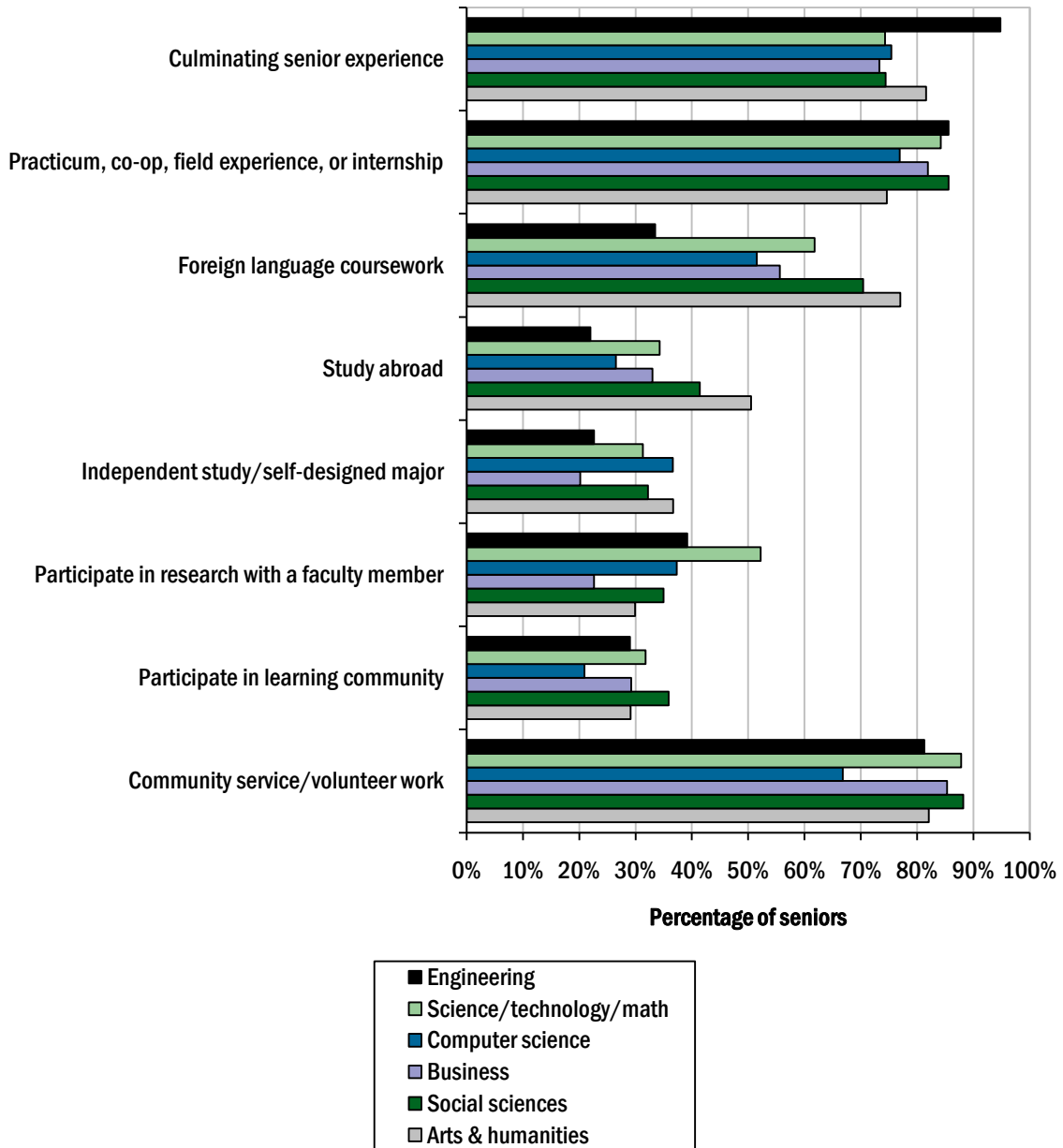


Figure 2.2-D: Percentage of seniors in the NSSE sample who have already done or plan to do each enriching experience, by major group. “Culminating senior experience” includes capstone courses, theses, projects, and comprehensive exams.



In terms of enriching educational experiences, engineering majors are more likely to have a culminating senior experience (e.g., a capstone project) but less likely than other majors to study abroad or take foreign language coursework (Figure 2.2-D). Additionally, engineering majors report spending more time preparing for their courses than students in any other major. (Lichtenstein *et al.* 2010, Stevens *et al.* 2007)

2.2.2 Comparing the Demographics and Pathways of Switchers and In-Migrators

Engineering persisters are more likely to be male and white, and less likely to be first-generation college students.

The demographic picture of engineering persisters compared to *switchers* that is painted by the NSSE data set provides insights about the extent to which engineering draws in and retains a diverse set of students. (Our definition of *switcher* (right) builds on the STEM education work of Seymour and Hewitt (1997) but focuses specifically on engineering.) The NSSE data indicate that the engineering persister group has proportionally fewer women and underrepresented racial/ethnic minority (URM) students in it than the engineering switcher group. Twenty-nine percent of persisters in engineering are women, whereas 36% of switchers out of engineering are women. There were 4% URM students in the persister group and 8% in the switcher group. We also found that persisters are less likely to be first-generation college-goers (24%) than are switchers (32%). Only the gender difference is statistically significant ($p < 0.05$), but these findings suggest that persisters are more likely to be male and white and less likely to be first-generation college-goers than switchers are. Although Figure 2.2-B indicates that engineering overall has persistence levels comparable to other majors, the issue of persistence remains particularly salient in that women and URM students are more likely to switch out of engineering than white males are.

Definition

switcher (or non-persister): a student who began college in engineering and has switched into a different major area (e.g., the sciences, arts & humanities) by senior year

Twenty-nine percent of persisters are women, whereas 36% of switchers are women.

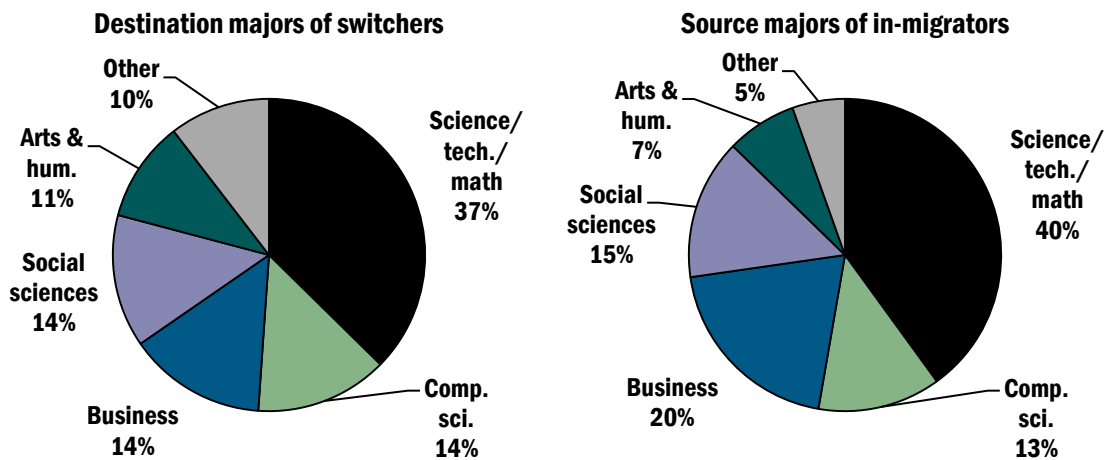
Women are more likely to migrate into engineering.

Another insight from the NSSE data is that, when compared to persisters, a larger proportion of migrators into engineering (*i.e.*, students who started in a non-engineering field and were majoring in engineering by their senior year) are women (42% of in-migrators vs. 29% of persisters).

Where do the switchers go? Where do engineering in-migrators come from?

Figure 2.2-E shows where those students who leave engineering go (left) and where those coming into engineering come from (right). Over a third of those switching out of an engineering major (the non-persisters) take up a science/technology/math major (e.g., biology, physics, chemistry, math), and about 14% each go to computer science and business. Combining the science/technology/math and computer science numbers, we see that over half of those who switch out of engineering stay in a major that is technical in nature.

Figure 2.2-E: Destination majors of those migrating out (switchers) of engineering (left) and source majors of those migrating into engineering (right)



Looking at those migrating into engineering, over 50% come from the combination of science/technology/math and computer science. However, because there are more than three times as many students switching out of engineering than are migrating in (182 and 55 students, respectively, in our NSSE sample of 11,812), there is a net loss from engineering to science/technology/math and computer science.

2.2.3 Persistence in the Engineering Major: Comparing College Experiences

Next we consider what we learned about students who matriculated and persisted in an engineering major (the 75% indicated by the leftmost bar in Figure 2.2-B), as compared to those who switched out of engineering (the other 25%).

On many measures, engineering persists and switchers are similar.

On many of the variables investigated through our Longitudinal Cohort work, the responses from persisters and switchers were indistinguishable during the students' first years in college. Moreover, as students progressed through their undergraduate education, the future persisters and switchers ascribed comparable *importance to* and *confidence in* professional and interpersonal skills. (These skills include leadership, communication, teamwork, and business ability.) They also reported similar levels of financial motivation to study engineering and knowledge of the engineering profession, comparable frequency of interaction with instructors, and similar satisfaction with these instructors, and they displayed similar

It might be difficult to differentiate between a student moving away from engineering and a student who is likely to persist.

confidence in solving open-ended problems. (Eriş et al. 2010) Adding to these Longitudinal Cohort findings, the NSSE data indicated other similarities between persisters and switchers. They reported comparable grades (McCormick et al. 2010), as well as comparable levels of study abroad, community service and volunteer work, participation in research with a faculty member, and membership in learning communities (Lichtenstein et al., forthcoming). Therefore, by these measures, it might be difficult to differentiate between a student moving away from engineering and a student who is likely to persist.

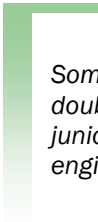
On some measures, persisters and switchers are different.

However, persisters and switchers were not similar when viewed through some other measures. We saw that switchers were more motivated to study engineering by parents than persisters were, whereas persisters seemed more motivated by a high school mentor (Eriş et al. 2010). In addition, switchers appeared to be less confident in their math and science skills. This finding should be interpreted in light of other findings from our study indicating that it may be interest and confidence in math and science that are drawing students into the engineering major to begin with (Kilgore, Chachra, et al. 2009). Switchers also had more concerns about financing college than did persisters. Fleming, Engerman, and Williams (2006) described the struggle of some Longitudinal Cohort students to remain in an engineering major with grade-dependent scholarships.

Other differences between persisters and switchers emerged during analysis of the NSSE data. Persisters were more likely to have a culminating senior experience or co-op and/or practicum experience than switchers. In contrast, switchers were more likely to be involved in independent study work or a self-designed major, and to have completed foreign language coursework (Lichtenstein et al. 2010).

Persisters and switchers differ in intention to complete an engineering major.

Even early in their college careers, persisters and switchers were strikingly different in their perceptions of whether they will graduate with an engineering degree or not. Figure 2.2-F shows the sharp decline (over successive survey administrations) in the intention to complete an engineering degree for switchers, compared to persisters. Early switchers (students who decide to leave engineering sooner than other switchers) were less firm in their intentions, even in the first year of college. What is not apparent in this figure, however, is that some persisters, despite their stronger average intention to complete an engineering major relative to switchers, expressed doubt as late as the end of junior year of college about continuing as engineering majors (Lichtenstein et al. 2007; Matusovich 2008; Matusovich et al. 2008).



Some persisters expressed doubt as late as the end of their junior year about continuing as engineering majors.

Commitment of persisters increases over the four years.

The significant and upward trend in intention to complete an engineering major among persisters shown in Figure 2.2-F was reflected in the structured interviews of these same students. In the interviews of students who ultimately persisted in engineering, less than half of them, as first-year students, reported being very committed to pursuing an engineering major. By the end of their second year, over 80% of them were very committed to completing their engineering major (McCain et al. 2007). This is consistent with Lichtenstein et al.'s (2007) observation that students frequently re-evaluate their commitment to engineering over the four years of college.

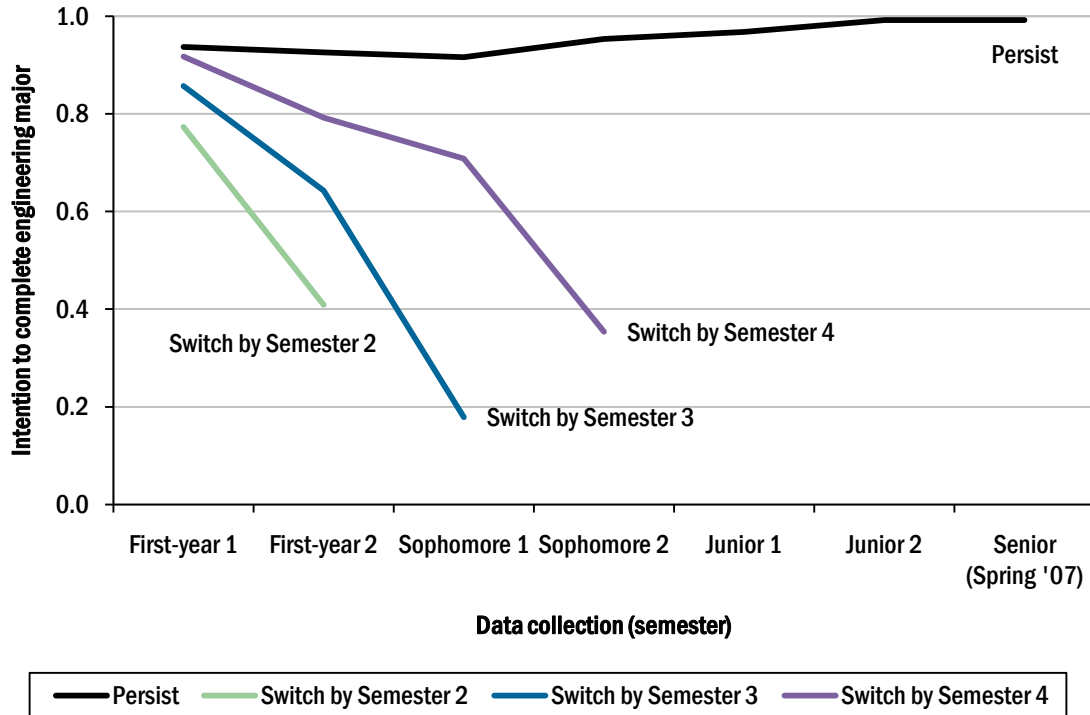
Figure 2.2-F: Strength of students' intention to complete an engineering major, with 1.0 being "Definitely Yes," 0.5 being "Unsure," and 0.0 being "Definitely Not." (Eriş et al. 2010)

Persist: students who had either graduated with an engineering degree or were still majoring in engineering (had an engineering major declared on their transcript) as of the summer of their fourth year of college ($n = 107$)

Switch by Semester 2: students who left engineering major by the end of their second semester ($n = 11$)

Switch by Semester 3: students who left engineering major by the end of their third semester ($n = 7$)

Switch by Semester 4: students who left engineering major by the end of their fourth semester ($n = 14$)



2.2.4 Factors of Knowledge and Identity that Relate to Persistence

Two interview-focused analyses explored the relationship between persistence and identification with and knowledge of engineering.

Entering students interested in engineering often have limited knowledge of engineering.

Many students interested in engineering matriculate college with limited knowledge of and exposure to engineering activities. In the sub-group of 32 students in this analysis, we frequently heard students describe their enjoyment of and success in high school math and science. However, we also frequently heard that students had little exposure to engineering. One sophomore told us that she had not really considered majoring in engineering until her senior year in high school. As few as 20% of these first-year engineering students had significant exposure to engineering activities (e.g., coursework in engineering during high school, engineering internships) prior to matriculating college. Low exposure to engineering

prior to college was much more common. Students might have engaged in engineering-like activities but had not been mentored by engineers. (Lichtenstein et al. 2007)

We also note that many switchers make the decision to leave an engineering major within the first two years, the period during which they are taking engineering prerequisites and before taking any (or many) engineering courses (Lichtenstein et al. 2007). One potential factor in this situation is that students are given little exposure to the many possibilities that an engineering career can offer in the first two years, while they are taking math and science courses taught outside of engineering departments (Garrison, forthcoming; Jocuns et al. 2008; Stevens et al. 2008; Stevens et al., Engineering student identities, 2005).

Range of intentions to complete an engineering major

In our Longitudinal Cohort semi-structured interviews, students revealed a broad range of exposure to engineering before and during college. Some students knew they wanted to be engineers before graduating high school, while others made an almost off-hand decision to enroll in an engineering major. As an example of one who had decided on engineering and his future college long before matriculation, Joe said,

I guess [I decided to become an engineer] about halfway through high school. I really decided that engineering was the thing for me. I took a couple of courses that were sort of Introduction to Engineering...and I decided that it was the field, and then, I sort of started lookin' around at different places. I was talking to one of my teachers who actually works, or interns, at a regional national laboratory, and he said they had a lot of good people come out of [my school].

Others were less sure as first-year students. Jane, a first-year student, described her prior lack of knowledge about the field and ambivalence toward the profession:

Honestly no, I had no idea what engineering was. I was just like, "Okay, math and science school; we got it," and then like somehow, that just kind of became synonymous with engineering—with that definition. They're like, "Oh you can be an engineer," and I'm like, "Okay, I guess so." And I only really got a feel for what I'd be doing after I got up here [at college]...I don't know what it [engineering] is.

Another student, Roger, was uncertain of his commitment to the engineering field and had even been interested in majoring in business at a prestigious, private, mid-western university prior to enrolling in college. Although his father is an electrical engineer, and although Roger had moderate exposure through extracurricular activities in high school, he really was not certain what engineers do on a daily basis—or if he wanted to find out. As he said,

I see my dad, he's an engineer. He sits in his cubicle, at his computer all day, typing up code and doing stuff. I don't really want to be doing that, but that's engineering for you. I haven't really thought about, "Well, after school, what am I gonna be doing?" I think it's sit in a cubicle all day, and I might be doing this, might be doing that, and I really don't know."

This work and these quotations suggest that few students—even those who have had some prior exposure to engineering—know what engineers do, and this affects their commitment to the major (Lichtenstein et al. 2007). As a result, programs that expose students to engineering experiences and/or projects early might have a greater chance of both enticing students to persist and interesting them in specific sub-fields of engineering.

Commitment to engineering depends on students' identification with engineering activities.

A student's reasons for choosing to pursue an engineering degree appear to be related to their persistence. Specifically, choosing to major because one identifies with engineering and the activities that engineers engage in is positively associated with commitment to majoring in engineering. The discussion and quotations in the next two paragraphs are drawn from a detailed analysis of interviews of 10 students at one Longitudinal Cohort institution that was part of one of the Ph.D. theses based on APS data (Matusovich 2008). (The thesis used a framework based on Eccles' expectancy-value model (Eccles 2005, Eccles et al. 1983) and Gee's (2000) conception of identity.)

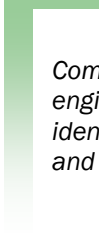
In this sample of 10 students, those with a strong connection between their identification with engineering and their perception of the activities that engineers engage in are more likely to show unwavering commitment to engineering. As third-year student Will said,

I have always liked building stuff. I think that's been the foundation of it. Legos were always my favorite toys when I was little. And I've always wanted some career where I could build stuff, and eventually found out that was called being an engineer.

In contrast, students with a weak connection between their engineering-related identity and the activities in which engineers engage showed continual renegotiation of their commitment to engineering. As fourth-year student Tim said,

Like the theory, what makes things work, taking things apart, and figuring all this stuff out, and all the intricacies, sometimes I just don't care about that. I'm like, "OK so these guys are engineers, that's what their thing is. Why am I an engineer?" And I look at like where I wanna go kind of with my career, and you see this shift away from engineering. And I ask myself, "Well so why did I get involved in engineering in the first place?"

Students like Tim demonstrate frequent re-evaluation of whether to stay in engineering (Matusovich 2008). Our data also suggest that many students' decisions about majoring in engineering are malleable and that this flexibility even continues up to the point of choosing a job (or other opportunity) after graduation (Lichtenstein et al. 2007).



Commitment to majoring in engineering is related to identification with engineering and engineering activities.

2.3 Motivation to Study Engineering

Motivation is an important factor in looking at the educational pathways of undergraduate engineering students. As one theory suggests, people act based on their motivation to fulfill basic human needs for autonomy, competence, and relatedness (Ryan and Deci 2000). Engineering students are no different. In this section, we examine the question, *What motivates them to study engineering?* The major themes of what we found are reported below.

2.3.1 A Wide Range of Motivational Factors, Most Constant Over Time

Through our APPLE Survey instrument, we explored six motivational factors, as summarized in Table 2.3-A. The first two of these factors—psychological and behavioral—are intrinsic, in that they originate within the individual and are related to enjoyment that is inherent in the task or activity itself. The other four—social good, financial, mentor influence, and parental influence—are extrinsic and come from outside of the individual. Except for the behavioral motivation factor, which was developed by the APPLIES research team, these factors and their constituent survey items were adapted from prior education research, as cited in Table 2.3-A.

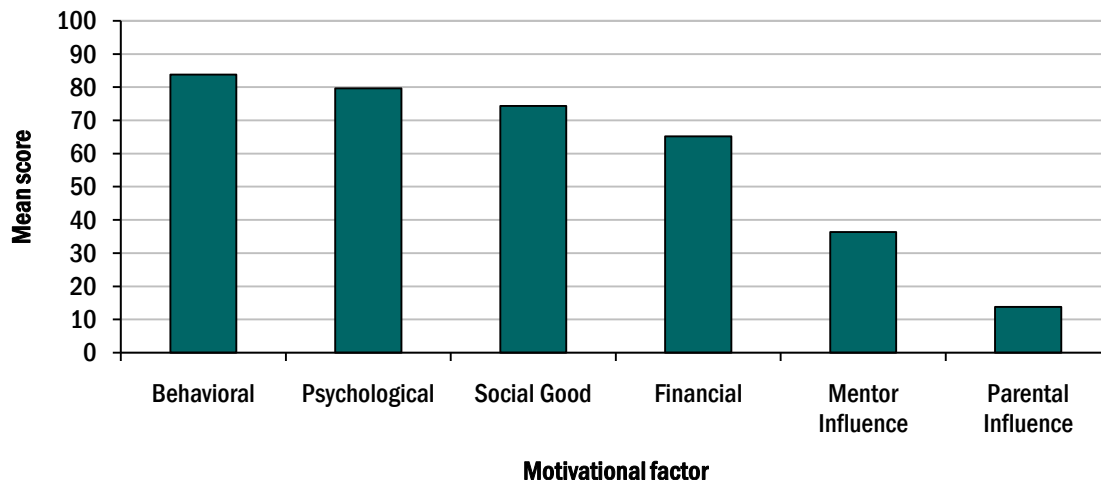
Top motivational factors are behavioral, psychological, social good, and financial.

The mean scores of seniors on the six motivation factors, as measured with the APPLE Survey instrument, are shown in Table 2.3-A. The data show that four factors, on average, provided moderate to major motivation for students to study engineering, with psychological and behavioral factors at the top. In other words, the top motivators are about how people feel when acting and thinking like an engineer. Semi-structured interview data suggest that, for some students, an important connection for intrinsic motivation may be pre-college behaviors/activities such as “tinkering.” Students in the Longitudinal Cohort talked about developing an interest in engineering based upon their childhood interests in tinkering with built objects, sometimes removing broken devices or appliances from the garbage and trying to fix them (Garrison, forthcoming).

Next on the motivation list were factors related to social good and financial security (also see Fleming, Engerman, and Griffin 2005). The Longitudinal Cohort interviews provide a rich portrait of students’ feelings about working for the social good. Some students talked about using engineering to effect positive change for underserved groups, or working on environmental and sustainability issues. As one senior said, “My inclination is that I’ll use engineering to try to do development work...kind of help the world rather than sit behind a desk...I have a real need to find a meaning in what I do with my life.” Another graduating student said, “I’m really interested in energy and the environment and sustainable design. I have a passion for service...I really like engineering” (Kilgore, Chachra, et al. 2009). These examples also suggest that social good motivation can be linked with intrinsic motivation.

Table 2.3-A: Motivational factors considered in APPLES

Motivational factor	Example
Psychological	Studying engineering for its own sake, to experience enjoyment that is inherent in the activity, e.g., “I think engineering is fun,” “I feel good when I am doing engineering.” This factor was based on the work of Guay <i>et al.</i> (2000).
Behavioral	Motivation related to practical and hands-on aspects of engineering, e.g., “I like to figure out how things work,” “I like to build stuff.” This factor was developed by the APPLES research team to capture the hands-on, action orientation of engineering.
Social Good	Belief that engineers improve the welfare of society, e.g., “Engineers have contributed greatly to fixing problems in the world,” “Technology plays an important role in solving society’s problems.” This factor was borrowed from the Pittsburgh Freshman Engineering Attitudes survey (Besterfield-Sacre <i>et al.</i> 1995, 1997, 2001).
Financial	Belief that engineering is a financially rewarding career, e.g., “Engineers are well paid,” “An engineering degree will guarantee me a job when I graduate.” This factor was borrowed from the Pittsburgh Freshman Engineering Attitudes survey (Besterfield-Sacre <i>et al.</i> 1995, 1997, 2001).
Mentor Influence	Influence of university and non-university affiliated mentors, e.g., “A faculty member, academic advisor, teaching assistant or other university affiliated person has encouraged and/or inspired me to study engineering,” “A mentor has introduced me to people and opportunities in engineering.” This factor was developed based on the work of Seymour and Hewitt (1997).
Parental Influence	Parental influences to study engineering, e.g., “My parents want me to be an engineer.” This factor was borrowed from the Pittsburgh Freshman Engineering Attitudes survey (Besterfield-Sacre <i>et al.</i> 1995, 1997, 2001).

Figure 2.3-A: Seniors’ motivation to study engineering on a scale of 0–100, where 100 indicates major motivator, 66 indicates moderate motivator, and 33 indicates minor motivator (Sheppard *et al.* 2010)

We also heard students talk about their perceptions of the financial security of an engineering job. (Note that these interviews were conducted before the economic downturn that began in 2008.) One senior reflected that “[engineering is] pretty good, like it guarantees your life, that you’re gonna have a good future” (Kilgore, Chachra, et al. 2009). Another student was very pragmatic at an early stage, saying, “I heard that the petroleum engineering school here is an excellent school, and they have like 100% job placement, and then petroleum engineering has the highest paid engineers of all the engineers, and so I figured uh why not take intro to petroleum engineering?” This same student separated his actions from parental influence and tied future financial security to a future lifestyle when indicating why he chose to major in engineering, offering, “My parents are gonna be happy with me and proud of me no matter what I do, so I’m not doing to it make them happy. I’m not doing it because society looks at engineers as cool people, ’cause they don’t. So basically—lifestyle, future lifestyle, and money” (Stevens et al. 2007).

A comparison of transfer and non-transfer students in the Single-School Cross-sectional Sample suggests that transfer students are less financially motivated to study engineering than non-transfer students (Korte and Smith 2007).

Mentors and parents are less salient motivators.

Relationships, such as with mentors and parents, are less salient motivators for engineering majors. We do note, however, that parental motivation may be tied to financial issues for some students (e.g., “I wanna take care of my parents like they—they’ve been really good to me and uh I wanna be really good to them.”). For others, parental motivation was tied to family pride: “I’m a first-generation college student, and because this [engineering] is a really hard major, graduating college is one thing—it would really be a very big accomplishment for me, myself and my family” (Kilgore, Chachra, et al. 2009).

Motivational factors are interrelated.

The six dimensions of motivation described in Table 2.3-A are interrelated. For example, seniors who pursued engineering for its intrinsic value (psychological and behavioral) also tended to be motivated by its potential social value. Mentor motivation was positively correlated with social good motivation and psychological motivation, which suggests an important (and subtle) role that mentors may play in helping to develop other motivational dimensions.

Mentors may play an important role in helping to develop other motivational dimensions.

Certain correlations were only observed by gender. Among senior men, parental motivation was correlated with mentor motivation. Among senior women, parental motivation and psychological motivation were negatively correlated.

Motivation remains essentially constant over the four undergraduate years.

The strength and order of the motivational factors in Figure 2.3-A are not appreciably different between first-year students and seniors (Sheppard et al. 2010; Korte and Smith 2008; Eriş et al. 2007, 2010). Furthermore, an examination of a subset of interview data found that the value of becoming an engineer for participants (because of identification with engineers) remained stable over the four years. This stability was independent of the extent to which the student identified with engineers and engineering. (Matusovich 2008). Overall, our findings suggest that students’ motivation to pursue engineering may take shape early on in their educational experience and that college reinforces their existing motivation.

Other aspects of motivation: status, portability, and “sticking it out”

In our interviews, students gave voice to other factors that are important in their decision to major in engineering. These factors include having a degree that was viewed as being highly valued and respected by other fields (Jocuns *et al.* 2008), working on cutting edge projects, having a degree that was potentially transferable to careers outside of the field of engineering, feeling that majoring in math or science would lead to a job with a perceived lower status (e.g., in teaching or lab work) when compared to an engineering career (Garrison, forthcoming), or believing that skills and confidence in math and/or science would directly translate into skills and confidence in engineering (Kilgore, Chachra, *et al.* 2009).

For a few students, the motivation to complete their engineering degree may be tied to “stubbornness” or “doggedness.” This was evidenced in interviews where students stated that “I’ve gone too far to turn back now,” and, “I’ve put in a lot of work, and there’s no reason to back out whatsoever right now” (McCain *et al.* 2007).

2.3.2 Differences Between Men and Women, Between Majors, and Across Years

Motivation varies with gender and major.

When we looked at gender differences in the results summarized in Figure 2.3-A, we found that behavioral motivation was greater among men, whereas mentor motivation was greater among women (Sheppard *et al.* 2010; Kilgore, Chachra, *et al.* 2009).

Looking at the effect of major, we saw that senior women majoring in BioX engineering (our grouping of all of the bioscience-related engineering fields), mechanical engineering (ME), electrical engineering (EE), and aerospace engineering (AE) exhibited comparable (and high) levels of psychological, behavioral, and social good motivation, followed by financial motivation. Men majoring in BioX engineering showed a similar pattern. In contrast, for men majoring in ME, EE, and AE, there was a clear hierarchy: behavioral, followed by psychological, followed by social good, followed by financial motivation.

Behavioral motivation was greater among men, whereas mentor motivation was greater among women.

The motivation profiles of women in other engineering majors varied with major. For women majoring in industrial engineering (IE) and chemical engineering (ChemE), psychological, social good, and financial motivation were of comparable (and high) strengths, followed by behavioral motivation. This contrasts with women in ME, EE, BioX, and AE, who had comparable (and high) behavioral, psychological, and social good motivation, followed by financial motivation. The IE women were much more financially motivated to study engineering than their BioX counterparts and much less behaviorally and psychologically motivated than their ME and EE counterparts. (Parikh *et al.* 2009)

Motivation is correlated with persistence and satisfaction.

Among first-year students who took the APPLE Survey, we see that intention to complete an engineering major is correlated with their level of psychological motivation. This suggests that students who choose to study engineering for its inherent enjoyment are more likely to persist in the major. However, psychological motivation is only one dimension of the persistence puzzle. Other motivational factors may play key roles in combination with psychological motivation. In addition, the individual’s ability to overcome barriers and take advantage of supports that occur along their academic pathway can be important.

For seniors, four of the six types of motivation shown in Figure 2.3-A—behavioral, psychological, social good, and mentors—are correlated with frequency of interaction and satisfaction with instructors. These same four types of motivation are also correlated with overall satisfaction with college. It may be that the motivated students seek out more frequent contact with instructors, or that more frequent and satisfying interaction with faculty strengthens motivation. It may also be that students who are motivated about a particular field and are able to become more skilled in that field (through their studies) are just generally more satisfied with college.

For seniors, behavioral, psychological, social good, and mentor motivation are correlated with frequency of interaction and satisfaction with instructors.

2.3.3 Identity, Motivation, and Sponsorship

We discussed above how different types of motivation are correlated in a variety of ways with the college experience and even with commitment to engineering for first-year and senior students, and for women and men.

Our data suggest that one way students' personal motivations develop into discipline-relevant interests may be through the processes of *sponsorship*, using Brandt's (1998) terminology. In this view, "intrinsic interest in engineering" is mutually constructed by the student and sponsors within the discipline. This concept of sponsorship is useful in looking at the development of an engineering identity. Sponsorship, which can be described as something ascribed and maintained by others (as in, "You are an engineer"), might come in a variety of forms—through faculty, mentors, peers, student support organizations, curricular and programmatic structures, or procedures and processes. Sponsorship of student interests can play a central role in how and under what circumstances students begin to develop an identity as an engineer, and enter, stay in, or leave engineering education. (Stevens et al. 2008; O'Connor et al. 2007)

Identity development as an engineer viewed within a framework of sponsorship

Aspects of sponsorship in developing (or discouraging) an engineering identity are illustrated in two case studies from the Longitudinal Cohort. Adam was initially drawn to engineering because of his abilities at math and was successful in his early studies because of these skills. As he said, "I like the immediate reward of math, of the black and white. It's like, if it's wrong, 'OK, I'll try it again.' And then I get it right and it's like, 'Yes, I got it right!'" However, he began to founder when he encountered more open-ended engineering problems. As he said in his third year,

That's like, what the real world is. There's not a right and a wrong. Whereas a lot of my life, it seems, basically can be broken down into that. You get the right answers or you do well in class and then you can go to the right college or you can get into the right major and stuff. But, I mean, that still applies somewhat, that if you do everything right, do everything good, then you get a promotion and stuff. But the real world isn't as right and wrong...Instead of me getting it right or getting it wrong and reworking it, it's like it might work out and it might not. You're not going to know right away. So it's scary...I might be nearing the end of black and white, right and wrong phase.

As Adam engaged in his identity development (which has been dramatically transformed in a "scary" way by the unexpected ambiguity of engineering work), he is doing so as a sponsored participant in the discipline. This sponsorship results in large part from his early academic

performance, which was motivated by interests that he now recognizes as being somewhat at odds with how he is coming to see engineering. (O'Connor et al. 2007)

An example of a lack of engineering sponsorship for a student's interests

Looking at the second case study, Bryn, a female student, found that her interest in considering multiple perspectives in her work was undermined by the competitive, individualistic nature of the curriculum. Towards the end of her sophomore year, she described her experiences in her pre-engineering classes:

It just seemed like there was just a different frame of mind and the whole "me succeeding," like, "me, me, me," and really not wanting to help people, and I didn't understand that, because if I know something, I'm gonna help you figure it out, and I would hope that if I didn't know something, it would be the same way.

Asked where this different frame of mind comes from, Bryn said,

Oh man. I don't know. I think that it just might be the atmosphere of this institution, that it's so big and it's so competitive, and I think a lot of classes I was taking, people were going for some really competitive stuff...a lot of those were gonna be weeded out. It was always that pressure that, at the next level, someone's gonna be cut.

However, she found a different atmosphere in a graduate-level, non-engineering research methods class:

It was so helpful. The grad students were, of course, way more advanced than I was...We had to work with partners, and the grad student I worked with was just really helpful. I mean, like it was just a community more, and we were able to talk. There was never a feeling of, like, when you're in the other classes that are competitive, there's always this underlying feeling of tension, and there wasn't that in that class...So there was just, it was just a different community, a different feel. I felt a lot more supported. I felt like I could really get good feedback from other students.

In this case, the student describes finding the kinds of experience that she valued, but outside of the undergraduate engineering curriculum. In terms of sponsorship, the kinds of interests Bryn had do have sponsors, but the sponsors she found were not in engineering. (O'Connor et al. 2007)

These two examples illustrate how sponsorship plays out in students' lives in a variety of ways. Some forms of sponsorship are explicit and intentional, and others are not. Regardless, what is particularly important is that sponsorship, and how it serves to validate a student's presence in engineering, may be coming into play more often than we realize in drawing students into (or pushing them away from) engineering.

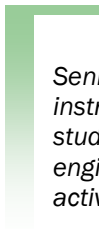
2.4 The Engineering College Experience

Subsection 2.2 compared college experiences of engineering undergraduates with non-engineering undergraduates. This subsection focuses more closely on the specific experiences of engineering students. We first examine differences between first-year and senior students and between male and female students. We then look at issues of students' identification with engineering and highlight some initial findings about transfer students and the effects of socioeconomic status. Next, we present some initial thoughts on the relationship between motivation and certain confidence measures in defining the engineering student's college experience. The subsection closes with a qualitative examination of graduating students' perspectives on significant learning experiences in engineering.

2.4.1 The College Experience across the Years and As Affected by Gender

Positive differences between seniors and first-years

Seniors interacted more with instructors than did first-year students, and their courses utilized more project-based learning and working in teams. This trend also held in the sophomore and junior years (Eriş et al. 2010) and included a shift from individual work (in Years 1 and 2) to group work (Years 3 and 4) (Stevens et al. 2008). Not surprisingly, more seniors had research, co-op, and internship experiences. They were also more active in engineering extracurricular activities than were first-years.



Seniors interact more with their instructors than do first-year students and are more active in engineering extracurricular activities.

Whereas participation in engineering extracurricular activities was greater among seniors than among first-year students, participation in non-engineering extracurricular activities was comparable between the academic levels.

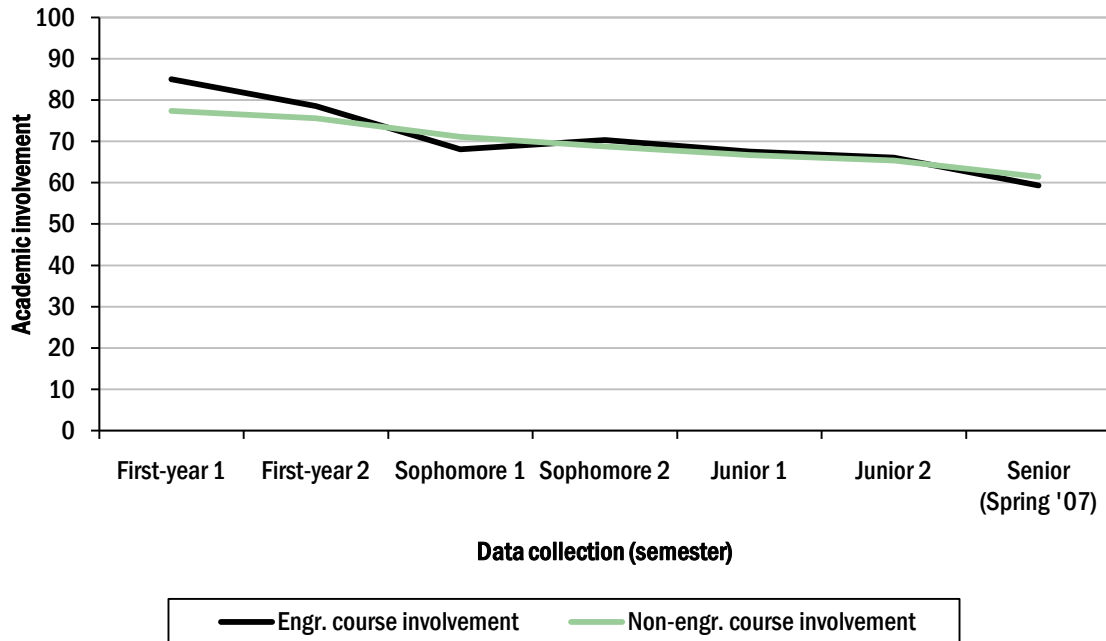
Negative differences between seniors and first-years

As a group, seniors were less satisfied than are first-years with their overall college experience. Also, seniors were less satisfied than first-years with their instructors, though they report interacting with them more.

Furthermore, seniors were less academically involved in their courses than were first-year students. *I.e.*, they reported being absent or late for class or turning in assignments that did not reflect their best work. This was true for both engineering and liberal arts courses and took place as a gradual change from the first-year to the senior year, as shown in Figure 2.4-A. Perhaps we should interpret this apparent decline in academic involvement in light of increased extracurricular participation in engineering activities and research, and even increased interaction with instructors. Are students, as they progress through their academic career, expanding their ways of learning about engineering at the expense of high levels of curricular participation? Are they learning to optimize their time? Have they learned what is needed to “do school,” as their self-reported GPAs are not dropping, in general?

While seniors may be more efficient and effective in balancing the complex demands of school and “non-school,” we also note that senior men reported a greater sense of curricular overload and, specifically, more difficulty in balancing their personal and academic lives than

Figure 2.4-A: Academic involvement in engineering and liberal arts courses (Eriş et al. 2010)



do first-year men. This difference was not present among women; however, women's sense of overload and difficulty with balance exceeded those of men at both the first-year and senior levels.

We note that students can have a desire for more balance (*i.e.*, pursuits aside from engineering studies) than their prescribed program of study will allow (Stevens *et al.*, Engineering Student Identities, 2005; Loshbaugh *et al.* 2006). As an example, one student at a technical university in the Longitudinal Cohort viewed the inability to pursue her interests in art as a cost or sacrifice associated with being an engineering student (Matusovich 2008).

Women and men, alike...and different

In the APS studies, many of the college experiences of women and men majoring in engineering were similar. They reported similar levels of interaction and satisfaction with instructors, similar levels of academic involvement, as well as exposure to engineering through co-ops, internships, and research. They also reported similar GPAs. However, we observed several noteworthy features of women's experiences in engineering:

- Both at the first-year and senior levels, women reported more frequent involvement in engineering and non-engineering extracurricular activities than did men. In the case of non-engineering activities, women attributed more importance to these activities. These differences were statistically significant ($p < 0.05$). It appears that activities outside of the classroom may play a more important role in the lives of undergraduate engineering women than of men. (Chachra *et al.* 2009)
- Both at the first-year and senior levels, women reported a greater sense of curricular overload than did men. In addition, they reported greater pressure to balance their

social and academic lives. These differences were statistically significant ($p < 0.05$). However, overload did not seem to be a direct result of extracurricular activities; we note that, for both women and men, there was no simple correlation between overload and extracurricular activities.

- Female study participants on several campuses spoke of the importance of doing well to favorably represent their gender (Garrison *et al.*, Cultural models, 2007; Fleming *et al.* 2008). A fear of representing one's gender poorly led some women to avoid asking for help or to limit from whom they sought help—seeking help from other women only. Additionally, some women reported being worried that they would have to prove themselves to the men in their classes; they would have to demonstrate their knowledge before their ideas were considered equal to their male classmates (Garrison *et al.*, Cultural models, 2007; Garrison, Stevens, and Jocuns 2008).
- Even women who appear to be succeeding as engineering students can be prone to self-doubts. In a series of interviews at a technical university participating in the Longitudinal Cohort, we saw that women with consistently high grades can still doubt their engineering ability and be uncertain about practicing engineering. Some women redefined what it means to be an engineer to match their perceived abilities. (Matusovich *et al.*, Competence in engineering, 2009)

Compared to men, women report more frequent involvement in extracurricular activities and a greater sense of curricular overload.

Identification with engineering:

Variations in perceptions of personal cost, enjoyment, and future usefulness

Some of the college experience may depend on how closely a student identifies with engineering. In an analysis of semi-structured interviews at one of the Longitudinal Cohort campuses, we saw that students who valued becoming an engineer because it was consistent with their sense of self did not see being in engineering school (“learning engineering”) as having a high personal cost, in terms of their time and effort. In addition, their enjoyment of engineering work stayed the same or increased over their four years of college studies.

Perhaps surprisingly, these students' perceptions of the future usefulness of what they were learning in school stayed the same (and relatively low) or decreased over the four years. In contrast, among students on one APS campus who identified less with engineering, perceptions of usefulness of engineering studies tended to be higher, perceived costs of earning an engineering degree higher, and enjoyment of engineering studies lower. (Matusovich 2008)

2.4.2 Other Intriguing and Important Demographic Factors

Two of the APS data sets generated some intriguing findings relating to the experiences of transfer students and the effects of socio-economic status. Although the APS research only touched the surface of these fundamental and important areas in American higher education, we feel that our initial findings are of broad interest. We include a brief summary of the key points below.

Transfer students' experiences

An analysis of survey and focus group data from transfer and non-transfer students who were part of the Single-School Cross-sectional Sample showed that the two groups were comparable with respect to their college experiences. However, we did find significant differences in other measures: student motivations to study engineering; confidence in personal, interpersonal, and problem-solving skills; engagement in non-engineering coursework; and satisfaction with their college experience.

Transfer students reported significantly lower levels of motivation to study engineering for financial reasons than non-transfer students. In addition, compared to non-transfer students, transfer students reported lower levels of academic involvement for liberal arts classes and lower levels of overall satisfaction with their collegiate experience. Transfer students also reported lower levels of confidence in personal and interpersonal skills (non-engineering skills) and higher levels of confidence in open-ended problem solving than non-transfer students.

Qualitatively, transfer students also spoke highly about their experiences taking classes in smaller community colleges before transferring to the larger university. They appreciated the smaller class sizes, along with more frequent interaction with faculty, in the community college setting. However, they also reported that missing the first year or two at the university contributed to the difficulties they encountered integrating into the university experience. This probably contributed to their higher levels of dissatisfaction with their experiences at the university. (Korte and Smith 2007)

Socioeconomic status

Using the survey data from the Broader Core Sample ($N = 842$), we explored how socioeconomic status (SES) might be related to the engineering college experience. SES in this preliminary exploration was operationalized to include parental education level and perceived family income.

We found that students in the highest and lowest SES quartiles were indistinguishable from one another on the measures of frequency of interaction with instructors, academic involvement in engineering and non-engineering classes, motivation to study engineering for social good and mentor reasons, and strength of intention to complete their engineering degree.

In contrast, students in the lowest quartile expressed a greater sense of curriculum overload, were less satisfied with college and instructors, were less involved in non-engineering extracurricular activities, and were less confident in technical skill sets. These same students were more motivated to study engineering for financial and family reasons, were more involved in engineering extracurricular activities, ascribed more importance to professional and interpersonal skills in the practice of engineering, and expressed greater intention to continue in engineering after graduation. (Donaldson, Lichtenstein, *et al.* 2008)

2.4.3 The College Experience As Influenced by Motivation and Confidence

Psychological motivation (motivation to study engineering for its own sake and for the enjoyment of it; detailed in Subsection 2.3) and confidence in professional and interpersonal skills (self-rated ability in leadership, communication, teamwork, business ability, social self-confidence, etc.) were significant predictors of students' post-graduation plans. These two variables are discussed in Subsection 2.7 in the context of students' future plans, but their importance prompted us to also explore what (if any) influence they might have on students' college experience.

Table 2.4-A: Definitions of groups of seniors based on levels of psychological motivation (M) and confidence in professional/interpersonal skills (C). For the m/c notation, bold capital letters indicate “above mean” and lowercase letters indicate “below mean” for the relevant measure.

Group label	Psychological motivation (M)	Confidence in professional/interpersonal skills (C)	Group characterization
M/C	At or above mean	At or above mean	High involvement
M/c	At or above mean	Below mean	Average involvement: engineering focused
m/C	Below mean	At or above mean	Average involvement: non-engineering focused
m/c	Below mean	Below mean	Low involvement

Focusing only on APPLES seniors ($n = 1098$), we defined four distinct groups using the mean for each of the two variables as the cut-off between the groupings. The four groups are defined in Table 2.4-A, and roughly a quarter of seniors fell into each of the groups. Groups are also labeled with an abbreviated “m/c” notation, where M stands for psychological motivation and C stands for confidence in professional and interpersonal skills. Bold capital letters indicate “above mean” and lowercase letters indicate “below mean” for the relevant measure.

On some measures, the groups are the same.

On a few measures, there were no significant differences among the four groups. For example, self-reported GPA, sense of curriculum overload, and motivation to study engineering for financial or parental reasons did not vary by group.

Synthesizing the differences to characterize each group

We next consider differences in college experiences and motivational factors by group. Within each group, we look at how variable scores compared with the average across all seniors. We also note when scores were at the extremes of a variable's range, referring to “top” or “bottom scores.”

High psychological motivation, high professional/interpersonal confidence (M/C)

The seniors in this group were consistently at the top in extracurricular participation and self-reported knowledge of engineering. Extracurricular participation includes both engineering and non-engineering activities, as well as co-op, internship, and research experience. That students in this group were at the top in these measures suggests that these students developed a more complete picture of the nature of engineering work. These students were also among the most motivated, with top scores on the behavioral, social good, and mentor motivation factors. Also noteworthy is that these students were top in interacting with faculty. Given this high level of participation in multiple ways, we refer to these students as the **High Involvement Group**.

Low psychological motivation, low professional/interpersonal confidence (m/c)

The seniors in this group were consistently at the bottom in self-reported extracurricular participation and knowledge of engineering. These students were among the least motivated, with scores on behavioral, social good, and mentor motivation variables at the bottom. Further, these students reported interacting less with faculty than did students in the other groups. Given this low level of participation in multiple ways, we refer to these students as the **Low Involvement Group**.

High psychological motivation, low professional/interpersonal confidence (M/c)

The seniors in this group were near the mean in self-reported extracurricular participation and knowledge of engineering. They reported interacting with faculty at the average level. These students were among the most motivated, with high scores on behavioral, social good, and mentor motivation variables, on par with the High Involvement Group. Given their average level of participation and high level of motivation to study engineering, we refer to these students as the **Average Involvement: Engineering-focused Group**.

Low psychological motivation, high professional/interpersonal confidence (m/C)

The seniors in this group were near the mean in extracurricular participation, except non-engineering extracurricular activities, where they were at the top. They also reported average knowledge of engineering and interaction with faculty. These students were among the least motivated to study engineering, and as such were similar to students in the Low Involvement Group. Given their average level of overall participation, high level of participation on non-engineering activities, and low level of motivation to study engineering, we refer to these students as the **Average Involvement: Non-Engineering-focused Group**.

Demographics by group

The proportion of women varied little by group with one exception: women comprised a greater proportion of students in the group with below-mean psychological motivation and interpersonal and professional confidence group (the m/c group). In addition, there were proportionally more underrepresented racial/ethnic minority men and women in the two groups with high psychological motivation, as compared to the two groups with below-mean psychological motivation.

On average, students in the m/C group reported higher family income (suggesting higher SES in this group), as compared to students in the two groups with lower confidence in interpersonal/professional skills (M/c, m/c). Students in the M/C group fell in the middle of the family income spectrum.

An emerging picture of involvement

The picture that starts to emerge is that students in the High Involvement and Low Involvement Groups are “opposites” on many measures. Students in the High Involvement Group were highly engaged with engineering and non-engineering activities, both inside and outside of the classroom, more motivated to study engineering, and more confident in their math/science skills (in addition to professional/interpersonal skills). In contrast, students in the Low Involvement Group were far less involved with engineering and non-engineering activities and were less motivated, less confident, and less satisfied with the overall college experience. We note however that students in these two groups were the same on key course-related measures: self-reported GPA, academic involvement in engineering classes, and sense of curricular overload. Thus, students in the Low Involvement Group, relative to those in the High Involvement Group, may be hard for faculty to spot, as they do not differentiate themselves by these course measures (whereas they do by out-of-class measures).

Students in the Average Involvement Groups were between students in the High and Low Involvement Groups on many measures. They reported average involvement in their engineering courses and interaction with instructors. However they were different from one another in several important ways. First, the students in the Engineering-focused Group focused more of their extracurricular involvement on engineering activities, whereas those in Non-Engineering-focused Group focused more on non-engineering activities. Secondly, the students in the Engineering-focused Group were highly motivated to study engineering for social good reasons (in addition to psychological motivation), whereas those in the Non-Engineering-focused Group indicated far less social good motivation.

2.4.4 Qualities of Significant Learning Experiences: Student Perspectives

When asked during interviews to talk about their most significant learning experiences while in college, graduating seniors at the large, public research university identified several qualities that made a difference in their learning (Kilgore, Jocuns, and Atman, Significant learning experiences, forthcoming):

- Encouraged or even required self-directed learning
- Hands-on and/or clearly applicable to the “real world”
- Enabled students to integrate a lot of diverse knowledge, to see the “big picture”
- Provided intrinsic motivation by empowering students to “own” the experience
- Challenged students

For example, Kara, a mechanical engineering student, described how her senior design project incorporated all of the above qualities. First, the project demanded a great deal of self-direction from Kara and her teammates, who were “left to our own devices a lot.” Directing their own learning and progress on the project entailed “incorporating everything that we had learned up until that point,” and also learning some facets of engineering project management. Kara felt that the complexity of the “logistics and the running around and the getting people together and...keeping people on task” added realism to the project, and thus prepared her for future employment. Furthermore, Kara reflected how the project “incorporated everything that we had learned up until that point” and thus was both a challenge and an opportunity. The team “would have liked a little more direction,” but Kara also acknowledged that the self-directed learning required by the senior project also

empowered them to own the project, as “in the end, it was good for us to have that experience of trying to make it on our own and make the decisions by ourselves.”

In addition to describing the qualities discussed above, several students explained that these learning experiences were significant to them because they entailed a *transformation* in how students thought about themselves, engineering, and/or the world. Kara’s senior design project caused her to broaden her conception of engineering work and thus transformed her vision of herself in her future profession.

Kara’s reflections on significant learning were not unique. All 15 seniors whom we interviewed at the large, public research university identified some or all of above qualities in describing what made a learning experience significant for them. Three of these students cited an excellent teacher or mentor who cultivated their interests and abilities by incorporating some of the above qualities into learning experiences. These students’ stories suggest that learning experiences can be designed to encourage self-directedness, applicability, knowledge integration, student ownership of the experience, and challenge, and that teachers can play a role in creating environments in which significant learning takes place.

2.5 Engineering Knowledge, Conceptions, and Confidence

This section discusses a wide range of findings concerning undergraduate engineering students' understanding of, conceptions of, and confidence in engineering in general. (Note that Subsection 2.6 separately focuses on design as a specific aspect of engineering.) We begin with a discussion of disciplinary knowledge and a description of students' increasing use of engineering language, followed by findings about how and where APS students report learning about engineering. Then, we describe student confidence levels for several key engineering skills and how they change over students' college years. We finish with some challenges: results from one of our studies revealing seniors' difficulties in understanding certain fundamental engineering concepts.

2.5.1 What Counts as Engineering: Accountable Disciplinary Knowledge

Students' understanding of engineering disciplinary knowledge changes over time.

In our analyses of semi-structured interviews and field observations with Longitudinal Cohort students, we described disciplinary knowledge as an important dimension of engineering undergraduate development (Stevens *et al.* 2008). Our study of disciplinary knowledge employed an ethnographic approach and examined how context and interpretation affect an individual's notions of what counts as disciplinary knowledge. This approach recognizes that different people conceive of engineering in different ways, and that these conceptions change over time. We use the term *accountable disciplinary knowledge* to refer to phenomena that are interpreted as counting as engineering knowledge. For instance, students enrolled in an introductory engineering course might interpret the presence of design problems and teamwork as indications that both design and collaboration are important skills in engineering.

Some students struggle with the shift from "book problems" to open-ended problems.

For some undergraduate engineering majors, accountable disciplinary knowledge and images of engineering shift substantially during their four years of study. Emphasis on solving formulaic, well-defined problems with single correct answers in lecture-based, first-year courses is replaced by a focus on open-ended problems without clear, "black-and-white" answers in upper-level project courses. Some students struggled with this shift in problem-solving style. In addition, early courses rarely conveyed the range of possibilities offered by an engineering career (Stevens *et al.* 2008; Garrison, forthcoming). Students reported differences between their engineering experiences in courses vs. during internships and co-ops (Stevens *et al.* 2008).

Use of engineering-specific language increases during the undergraduate years.

Multiple data sets collected from the APS Longitudinal Cohort reflect a shift in engineering students' use of language as they progress in their undergraduate studies. The Longitudinal Cohort survey findings discussed in more detail in Subsection 2.6 describe a shift in vocabulary, specifically pertaining to design. This analysis showed that senior and first-year students associated different activities with engineering design, with seniors tending more toward engineering-specific activities, such as identifying constraints and iterating. In contrast, first-year students were more likely to associate design with more general activities, such as communicating, planning, and visualizing (Atman, Kilgore, and McKenna 2008).

Jocuns and Stevens' detailed case study of one Longitudinal Cohort student's four-year experience describes how he grew to use more technical, engineering-specific vocabulary. Beyond vocabulary, he also became more fluent with different processes and techniques for communicating in engineering, e.g., use of diagrams, theories, and design. (Jocuns *et al.* 2008)

The remainder of this section focuses more directly on findings concerning students' conceptions of engineering and the kinds of experiences that affect these conceptions. Many of these findings are based on survey data and detail the skills and knowledge that students consider important in engineering practice.

2.5.2 How Students Learn about Engineering

Students' knowledge of engineering does grow from first to senior year.

As expected, seniors reported having learned more about engineering work since starting college than do first-year students. Students' knowledge of engineering is low at first and then increases over time, but their knowledge of engineering can be limited by a lack of exposure to the profession. As mentioned above, students encounter different images of engineering knowledge over time and must adjust to these changing images (Stevens *et al.* 2007, 2008; Korte & Smith 2008; Jocuns *et al.* 2008).

When asked about their knowledge of engineering prior to college, seniors reported lower levels than did first-year students. This might partly reflect the knowledge of engineering that seniors have gained since starting college; compared with first-years, seniors might more easily recognize (in retrospect) what they did not know about engineering before college.

Co-ops and internships build knowledge of engineering.

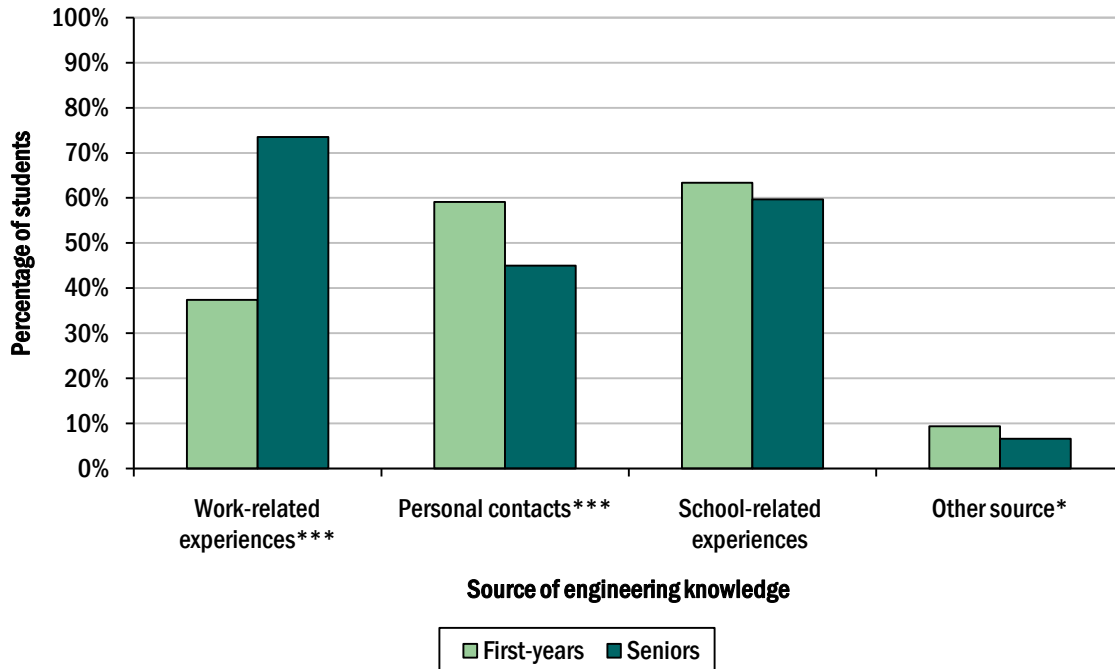
Students attributed gains in knowledge of engineering practice to a number of sources, and seniors cited more sources than did first-years. Seniors, more so than first-years, reported this knowledge coming from co-op and internship experiences ("work-related experiences" in Figure 2.5-A). For seniors, co-op and internship experience was the most commonly reported source, followed by school-related experiences. School-related experiences (e.g., professor, class) were cited by approximately 60% of first-year and senior students. Looking at one particular school-based practice, we found that, for first-year students (but not for seniors), team-based project work was correlated with gains in engineering knowledge.

Many seniors did not perceive gaining knowledge of engineering from school-related experiences.

That 40% of seniors did not identify their school-related experiences as adding to their knowledge of engineering practice is perhaps surprising, particularly given the increase in team-based project learning happening at the senior level (as described in Section 2.4). It may be that co-op and internship assignments make engineering in the academic setting seem just that: academic, relative to their co-op and internship work (Stevens *et al.*, Engineering Student Identities, 2005). This interpretation is consistent with what Matusovich (2008) found among students at one of the Longitudinal Cohort campuses. These seniors valued becoming an engineer because it was

40% of seniors do not identify their school-related experiences as adding to their knowledge of engineering practice.

Figure 2.5-A: Percentages of students who report gaining knowledge about engineering from various sources, with asterisks indicating statistically significant differences between first-years and seniors ($*p < 0.05$, $***p < 0.001$; 869 first-years, 1130 seniors)



consistent with their sense of self; their perceptions of the future usefulness of what they were learning stayed the same (and relatively low) or decreased over the four undergraduate years.

Are capstone projects not realistic and too late in the curriculum?

Furthermore, we note that most of the students we studied completed capstone or senior design project courses in their last year of school. Many students felt unprepared for the kind of work involved in these capstone projects, which were designed to be culminating senior-year experiences. Many felt they had not done enough design work prior to the capstone. Some students felt that their projects were not representative of work they would ever do in industry and consequently viewed their capstone experiences as inauthentic. In addition, they wished the capstone had occurred earlier in their respective programs or had been introduced into the curriculum in a more progressive manner. (Garrison, forthcoming; Adams *et al.*, forthcoming) We saw that more intentional bridging might be required to connect students' work experiences with in-class experiences (a point we will return to in Subsection 2.10).

Students recognize different skills as important in engineering.

Both first-years and seniors perceive math and science skills as being more important in engineering practice than professional and interpersonal skills (e.g., leadership, communication, teamwork). This finding is not surprising, given the central role that interest

and skill in math and science play in recruiting students to engineering in the first place, not to mention their prominent and early placement in a typical engineering curriculum.

Comparing first-years and seniors, we see that seniors rated math and science skills as being less important than did first-year students. There may be several reasons for this difference. Based on experience with larger projects (e.g., in capstones or internships/co-ops), seniors may be seeing math and science as just one of many skill sets needed in engineering practice. First-year students, whose perceptions might largely be based on high school advising, may believe that math and science are more central in engineering. In addition, the difference might reflect the tendency for engineering students to take more math and science courses in the first year, relative to senior year. The decrease in importance might also reflect differences in how math and science are practiced in school and how they are practiced in the workplace. In a workplace context, seniors might not recognize math and science as they learned it in school, resulting in a lower rating of importance, at least among seniors with industry exposure.

We also see seniors reporting the importance of professional and interpersonal skills at a level comparable with (if not slightly less than) what first-year students reported. It was surprising to us that seniors did not rate professional and interpersonal skills more highly, given their significantly greater participation in co-op, internship, project-based learning experiences, and engineering extracurricular activities, *i.e.*, all activities with a considerable amount of social interaction.

Learning about engineering is mostly similar among women and men.

Women and men report similar gains in learning about engineering from their first to senior year, and cite similar sources for these gains. However, we observed one noteworthy gender difference: Women report professional and interpersonal skills as being more important than do men (and this gender difference is greater among seniors than among first-years).

Importance of and preparedness with engineering skills and knowledge

When surveyed during their senior year, engineering students in the Longitudinal Cohort were asked two additional questions concerning engineering skills and knowledge. The first question provided the respondents with a list of engineering skills and knowledge items and asked them to select the five most important (Figure 2.5-B, with an alternative visualization in Figure 2.5-C). The list drew items from the ABET Criterion 3 program outcomes list (ABET 2009) and the National Academy of Engineering report, *The Engineer of 2020* (NAE 2004). The second question asked students to rate their level of preparedness (in the context of engineering practice) with each of the ABET/2020 items.

Seniors were most likely to identify *Problem solving*, *Communication*, *Teamwork*, and *Engineering analysis* as important items, with at least 50% of them including each of these in their list of five most important items. The least selected items included *Contemporary issues*, *Societal context*, *Global context*, and *Conducting experiments*. Less than 5% of seniors selected each of these items. Students' self-rated preparedness responses mostly mirrored their importance responses. Most seniors reported higher preparedness with items *Teamwork*, *Problem solving*, and *Communication*. On average, seniors reported the lowest levels of preparedness with items *Contemporary issues*, *Business knowledge*, *Global context*, and *Societal context*. (Yasuhara, Perceived importance and preparedness, 2008)

Figure 2.5-B: Engineering skills and knowledge items and the percentage of Longitudinal Cohort seniors who selected each among their set of five most important items ($n = 109$)

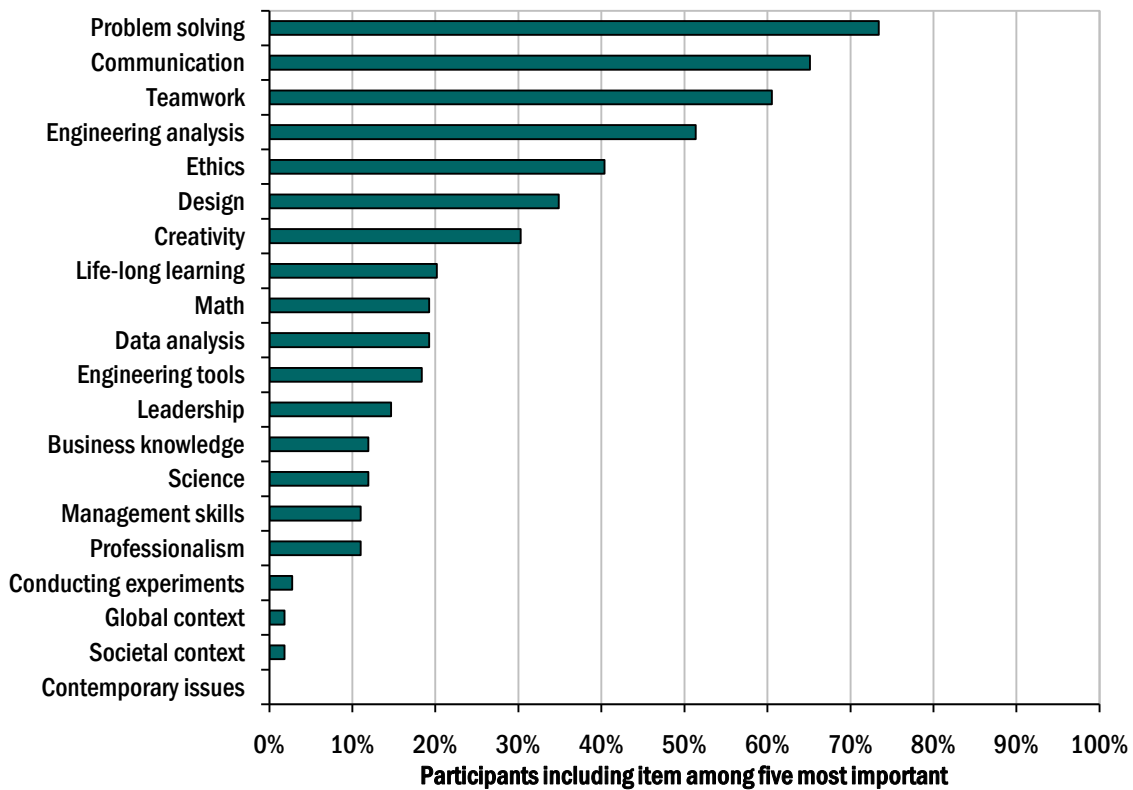


Figure 2.5-C: Word cloud (created at <http://www.wordle.net/>) of engineering skills and knowledge items, with larger items being more frequently selected by Longitudinal Cohort seniors as one of the five most important items ($n = 109$). Differences in darkness are arbitrary and serve only to clarify separation among adjacent items.



On the one hand, these ABET/2020 findings suggest that graduating engineering students appreciate and feel prepared in certain professional skills like communication and teamwork. In contrast, low prioritization and feelings of preparedness with contextual knowledge seem at odds with the global and complex nature of modern engineering work. This interpretation is moderated by the possibility that students considered the importance of contextual knowledge as part of another item, *Ethics*, which 40% of seniors included in their lists of five most important items.

There were important differences in the phrasing and format of the APPLES and Longitudinal Cohort ABET/2020 survey questions concerning the importance of certain skills. These differences precluded direct comparison of responses, but the findings are qualitatively similar in that students in both samples placed high importance on both math/science and professional skills. As for the APPLES finding that seniors rate math/science skills as more important than professional/interpersonal skills, the ABET/2020 findings might simply reflect that certain professional/interpersonal skills (communication and teamwork) are considered important, but others (e.g., leadership and business knowledge) are considered less important. (The Longitudinal Cohort ABET/2020 questions asked about each of these specific professional/interpersonal skills.)

2.5.3 What Does Confidence Look Like? What Contributes to It?

Through the APPLE Survey instrument, we explored three aspects of students' confidence: confidence in their math and science skills, in their professional and interpersonal skills, and in open-ended problem solving. This subsection describes differences between seniors and first-year students in these aspects of confidence, as well as the factors that seem to contribute to their development.

Not all confidence levels are equal; women's confidence lags in some areas.

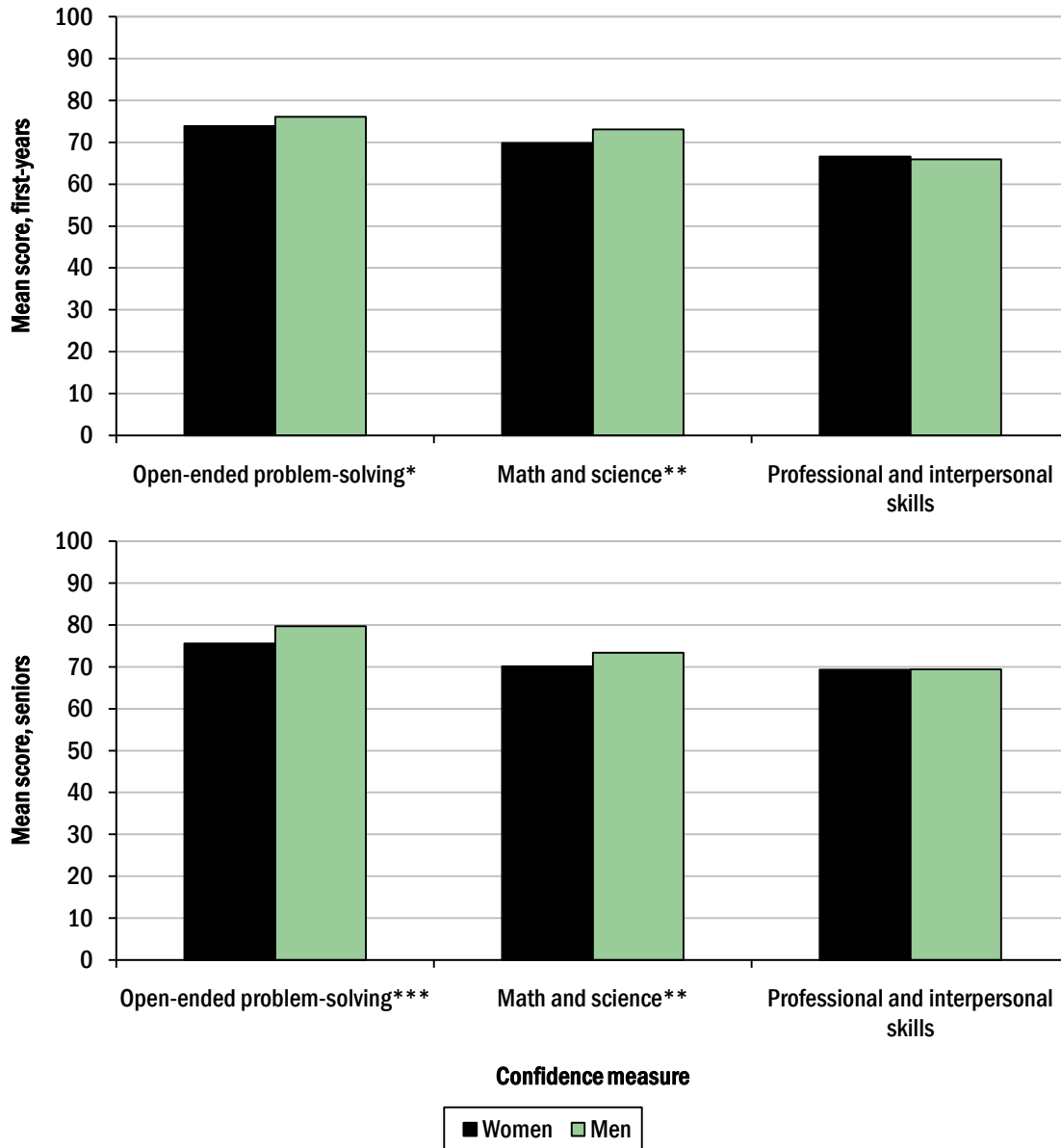
The APPLES engineering majors generally have an above-average level of confidence (relative to their non-engineering peers) in their open-ended problem solving skills, math and science skills, and professional and interpersonal skills, though confidence in open-ended problem solving is greatest (Figure 2.5-D). Among seniors, confidence levels in professional and interpersonal skills were comparable among women and men. At the same time, women were less confident than men in their open-ended problem solving and math and science skills. Noteworthy is that the confidence gap in open-ended problem solving among senior women and men was greater than the gap among first-years, suggesting that college experiences are affecting the development of confidence differently for women and men.

Students exhibit low confidence in professional and interpersonal skills.

Although students' confidence in these three measures was generally high, students rated themselves least confident in professional and interpersonal skills. This was true regardless of gender, cohort or underrepresented racial/ethnic minority (URM) status. Seniors' lower confidence in the critical area of professional and interpersonal skills (when compared to open-ended problem solving and math and science skills) may strengthen the argument that engineering is not doing a particularly good job in this domain. As we will see in Subsection 2.7, which describes students' plans for the future, we may be losing some top students to non-engineering paths as a result of this relative lack of confidence.

Students rate themselves least confident in professional and interpersonal skills.

Figure 2.5-D: Confidence levels of first-year (top) and senior (bottom) engineering majors in the Broader National Sample (APPLES), by gender, with asterisks indicating statistically significant gender differences (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; 311 and 557 first-year women and men, 326 and 795 senior women and men, respectively)



Confidence in math and science skills remains constant.

Confidence in math/science skills (relative to peers) remained constant at an above-average level for men and women when first-year and seniors were compared. One possible explanation for this lack of growth in confidence is that seniors realize there is more math to learn. Another is that they are seeing that, relative to their peers, their math skills remain

comparable. Alternatively, students might realize that the math they have learned in school may not be the math needed in practice.

Confidence in math and science skills was predicted by self-reported GPA. We cautiously interpret this relationship as indicating that this confidence is grounded in school-measured academic performance. The finding that being female is a predictor of lower confidence in math and science skills is consistent with another segment of APS research at one of the Longitudinal Cohort institutions, where women with high grades could still doubt their engineering ability and revise their positive beliefs about their competence in engineering (Matusovich *et al.*, *Competence in Engineering*, 2009).

That gender and self-reported family income (one indicator of socioeconomic status) were predictors of confidence in math and science skills is of concern. At the same time, that race/ethnicity does not seem to have influenced confidence in these key skills is noteworthy. Frequency of interaction with faculty, involvement in research, engineering extracurricular activities, and exposure to engineering through co-ops, internships, and work experience all had no predictive power with respect to confidence in math and science skills. Future work might address the question of why confidence in a set of skills that are so central to engineering was not positively predicted by any of the components of an engineering education that one might expect would contribute to the development of a student's confidence.

Gender and self-reported family income, but not race/ethnicity, predicted math/science confidence.

Non-engineering factors largely contribute to confidence in interpersonal skills.

As many educators would hope, confidence in professional and interpersonal skills was greater among seniors than first-year students. At the same time, students' perceived importance of these skills was *not* greater among seniors than among first-year students. We are left to wonder why these skills were not deemed to be more important, given seniors' greater co-op, internship and research experiences and increased project-based learning courses.

Confidence in professional and interpersonal skills among seniors was predicted by family income, one indicator of socioeconomic status (SES). Therefore, all things being equal, a senior from a higher family income will be more confident than a senior from a lower income. Family income was also a predictor of confidence in professional and interpersonal skills in the first-year model, albeit a weaker predictor than in the senior-year model.

We also found that confidence in professional and interpersonal skills was predicted by involvement in non-engineering extracurricular activities. The regression model for first-year students suggests that frequency of interaction with faculty is important in addition to participation in non-engineering extracurricular activities.

Confidence in professional and interpersonal skills was weakly predicted by involvement in engineering research or engineering extracurricular activities, and was not predicted by exposure to engineering through co-op, internship or work experience. Our findings suggest that these engineering-focused activities are not engendering the same types or level of professional and interpersonal confidence that involvement in non-engineering activities is. This weak effect might be because more socially confident students are drawn to non-engineering activities to a greater extent than are less socially confident students. Additionally, engineering-focused extracurricular activities might not contribute to development of social skills concurrently with technical expertise, suggesting room for improvement of these activities.

Possible explanations for differences in perceived importance and confidence in key skills

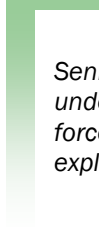
At the very least, the differences described above with respect to confidence in and perceived importance of key engineering-related skills (by gender, race, and class standing) reinforce that “the college experience” is complex and heterogeneous, affecting a variety of perception and confidence outcomes. We expect that the following (or some combination) may be happening as part of these college experiences: (1) various groups experience *different curricular and extracurricular activities* with which to build their understanding and confidence; (2) various groups experience the same curricular and extracurricular activities but *internalize them in different ways*; and/or (3) various groups come to college with *different pre-college experiences* on which to overlay their college experience. Teasing apart and testing these “candidate hypotheses” on differences may be useful in gaining a more fundamental understanding of how college affects students in different ways and how education can be improved for all students.

2.5.4 Misunderstanding Key Concepts

Mastering key technical concepts in ways that can be brought to bear in engineering analysis is critical to becoming an engineer. The Difficult Concepts Study employed specially developed interview protocols to investigate student learning of various key concepts in engineering mechanics and electrical circuits.

Even graduating seniors misunderstand some key engineering concepts.

During hour-long interviews at one of the Longitudinal Cohort institutions, two groups of graduating seniors (with majors in electrical and civil/mechanical engineering, respectively) did not understand concepts such as force and voltage well enough to explain them. Students typically thought of phenomena like force and voltage as *substances* instead of as *processes* or *interactions*. For example, students responding to a question about a free body diagram might say that tension is “a force inside a rope,” seeing force as a property of the rope, rather than the interaction between two or more bodies. Electrical engineering students would talk about voltage as being the property of a particular location, not the difference in electrical charge between two points. (Streveler *et al.*, Identifying and investigating difficult concepts, 2006)

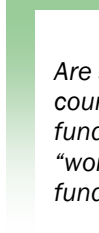


Seniors [in ME and EE] did not understand concepts such as force and voltage well enough to explain them.

Other ongoing work in thermal science, particularly heat transfer, suggests that chemical and mechanical engineering students are also misapplying the process vs. substance schema by confusing rate with amount (Streveler *et al.* 2008). Taken together with the APS investigations, these studies suggest that some students from chemical, mechanical, and electrical engineering use substance-based models for processes. Thus, helping students to create more accurate mental models that represent processes correctly (not as substances) may help greatly in many areas of engineering education. (Streveler *et al.*, Identifying and investigating difficult concepts, 2006)

Faculty are often unaware of misunderstandings and the difficulty of these concepts.

During interviews with faculty to develop the Difficult Concepts interview protocols, we observed that engineering faculty often thought that graduating students *did* understand these concepts. Furthermore, faculty typically did *not* rate these concepts as difficult for students to understand at all. (Streveler et al., Identifying and investigating difficult concepts, 2006) Further research could illuminate what makes these ideas conceptually so hard to master. Thinking further about engineering practice, we need to examine the extent to which students are able to pass courses in engineering fundamentals without a “working” knowledge of fundamental concepts.



Are students able to pass courses in engineering fundamentals without a “working” knowledge of fundamental concepts?

2.6 Engineering Design Knowledge, Conceptions, and Confidence

A variety of qualitative and quantitative data were collected from the Longitudinal Cohort to examine engineering design from multiple perspectives. The findings discussed in this section cover conceptions of design, confidence in design ability, experience with design activity, and approaches to open-ended design problems. Longitudinal analyses provide an understanding of how engineering students change with respect to these topics during the course of four years of undergraduate education. As discussed later in this subsection, comparative analyses of the Longitudinal Cohort data sets listed in Table 2.6-A show gender differences in a variety of design-related measures.

Table 2.6-A: Data sets whose analyses are discussed in this subsection, with year of collection (Longitudinal Cohort)

Data set	First year	Sophomore year	Junior year	Senior year
Most important design activities survey question	✓			✓
Confidence, experience, and preparation with design survey questions		✓		✓
Midwest floods design task	✓		✓	
Street crossing design task		✓		✓
Playground design survey question	✓			✓
Microchip factory design task				✓

2.6.1 Conceptions of Engineering Design

Conceptions of engineering design shift during the undergraduate years.

In first- and senior-year surveys, students were asked to identify the six design activities they considered most important, selecting from a comprehensive list of 23 items (Figure 2.6-A and Figure 2.6-B). Overall, most students selected *Understanding the problem* in both their first and senior years of study. In the first year, other more frequently selected items included *Communicating*, *Planning*, and *Brainstorming*, all of which were selected by at least 40% of participants. By their senior year, student conceptions of engineering design appear to have shifted. More seniors selected *Identifying constraints* and *Iterating* as important design activities than as first-year students. Conversely, fewer students selected *Planning*, *Visualizing*, and *Communicating* in their senior year, compared to their first year. These findings might reflect a shift toward thinking about design in terms of more engineering-specific language. (Atman, Kilgore, and McKenna 2008)

Figure 2.6-A: Percentage of seniors selecting design activities as one of the six most important, all APS respondents in longitudinal subsample ($n = 89$)

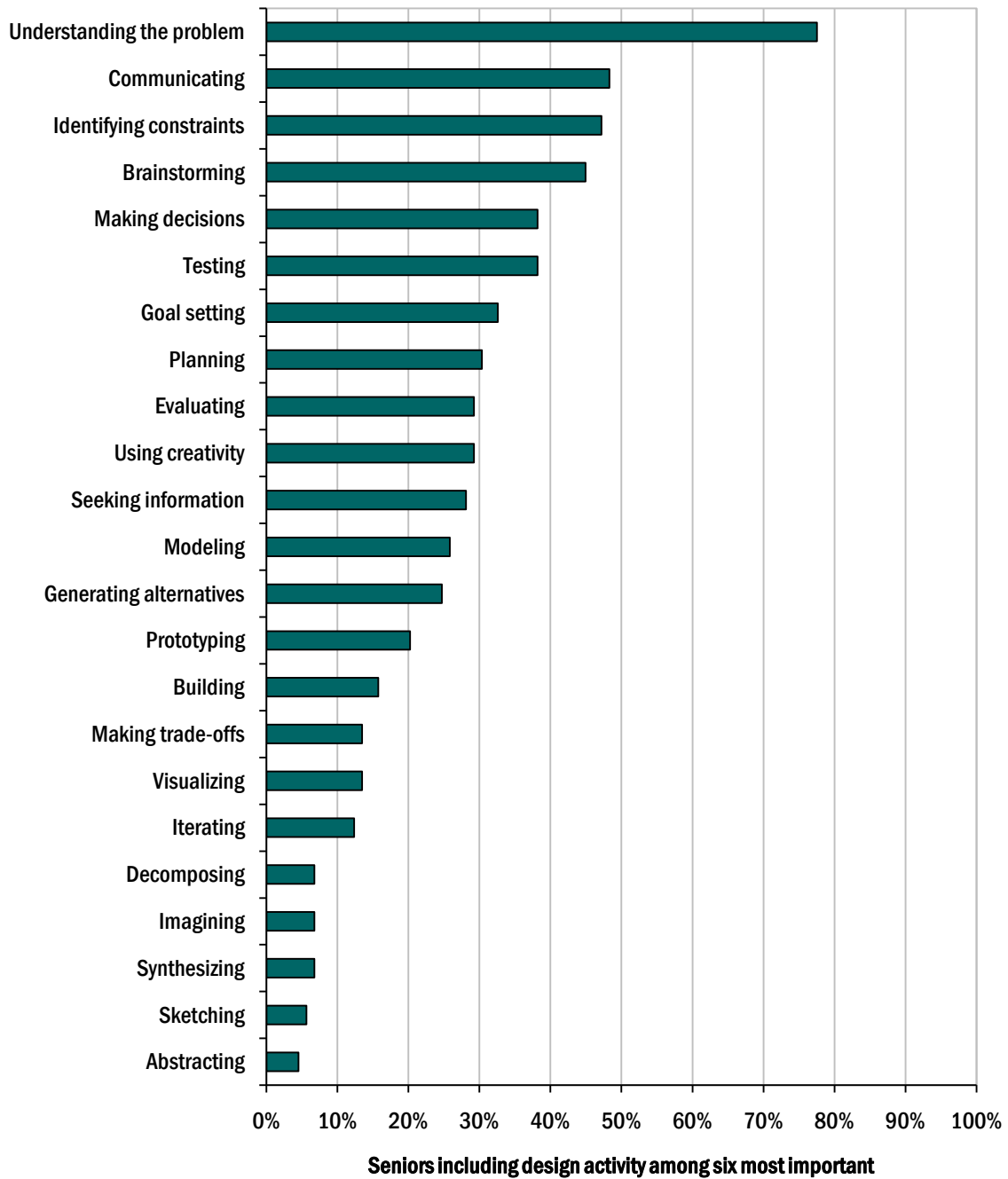
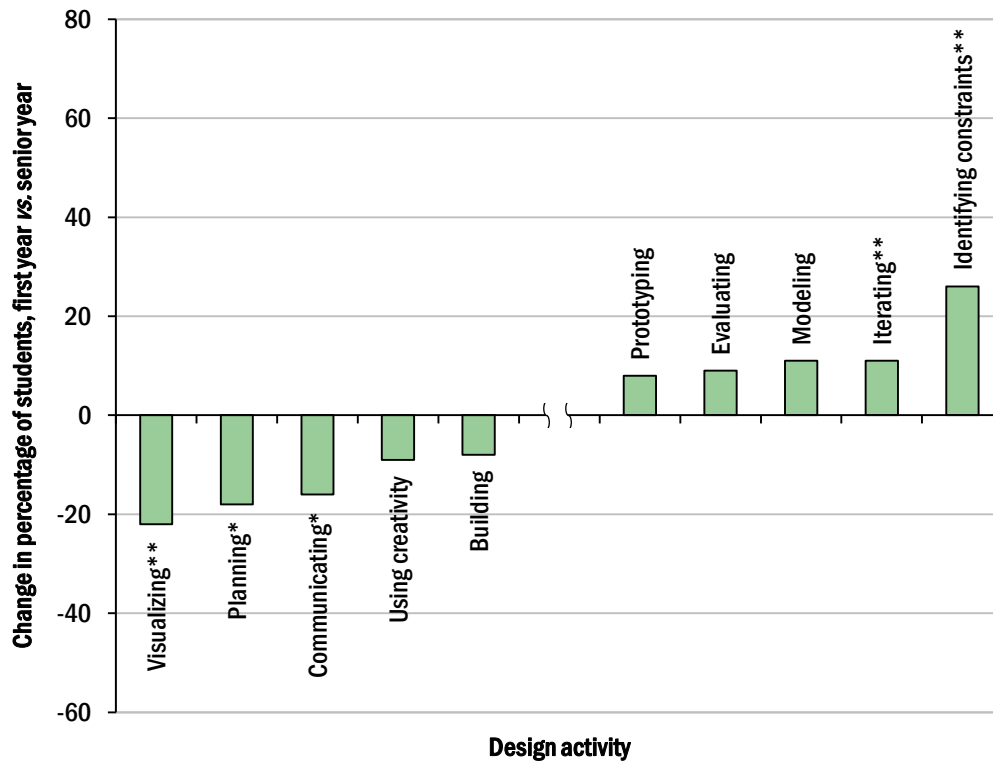


Figure 2.6-B: Change in percentage between first and senior year of participants selecting design activities as one of the six most important, all APS respondents in longitudinal subsample ($n = 89$; $*p < 0.05$, $**p < 0.01$)



Conceptions of engineering design vary with gender and institution.

Comparisons of women's and men's responses to the same survey questions reveal some gender differences in conceptions of engineering design. As first-years, women were more likely to select *Seeking information* and less likely to select *Building* and *Prototyping*. Gender differences in the students' senior-year responses were similar, with women more likely to select *Goal setting* and less likely to select *Building*. (Chachra et al. 2008)

While students at the Longitudinal Cohort institutions were largely similar in their conceptions of engineering design, seniors' responses exhibited some institutional variation for items *Communicating* and *Prototyping*. Among the four Longitudinal Cohort institutions, students at the public research university devoted to engineering and applied science were the most likely to select *Communicating* (75%, compared with as low as 30% at the private research university). Students at the private research university, however, were the most likely to select *Prototyping* (48%, compared with no more than 13% at each of the other three institutions). These differences might reflect the curricular and cultural emphases particular to the respective institutions. (Atman, Kilgore, and McKenna 2008)

2.6.2 Confidence, Experience, and Preparation with Design

Another set of survey questions, administered in the sophomore and senior years, examined student confidence, experience, and preparation with respect to a set of eight specific design activities:

- Defining what the problem really is
- Searching for and collecting information needed to solve the problem
- Thinking up potential solutions to the problem
- Detailing how to build the solution to the problem
- Assessing and passing judgment on a possible or planned solution to the problem
- Comparing and contrasting two solutions to the problem on a particular dimension such as cost
- Selecting one idea or solution to the problem from among those considered
- Communicating elements of the design in sketches, diagrams, lists, and written or oral reports

For each of the above activities, we asked Longitudinal Cohort students to (a) rate their confidence in their ability to engage in the activity, (b) indicate the frequency of their engagement with the activity in their courses, and (c) rate how well they believe their courses are preparing them to engage in the activity.

In both the sophomore and senior years, students on average described their confidence to do each of the design activities as *Good* or *Very good*. Students on average also reported that they engaged in each design activity as part of their coursework approximately 2–3 times per week to 1–2 times per month. Finally, students rated as *Good* to *Very good* the preparation from their classes to do each of the design activities. (Morozov *et al.* 2008)

Students reported engaging in design activities as part of their coursework approximately 2–3 times per week to 1–2 times per month.

Men report higher confidence and course preparation with design than women.

Both as sophomores and seniors, men generally indicated higher levels of confidence and course preparation than women for engaging in engineering design activities. Gender gaps were more pronounced in sophomores' responses. Compared to women, men reported significantly higher confidence with problem definition, generating ideas, and modeling as sophomores and modeling again as seniors. Findings for course preparation were similar, and men also reported significantly better course preparation with modeling, evaluation, and decision-making in the sophomore year and decision-making again in the senior year. These gender gaps are especially notable in light of the absence of gender differences in the frequency of engagement with the design activities in coursework (in either year). Taken together, these findings suggest that there was a gender difference in the *quality* of design education (if not quantity) that students in this sample received. (Morozov *et al.* 2008)

2.6.3 Consideration of Context During Design

We explored the extent to which APS students consider contextual issues while engaged in engineering design by presenting them with a variety of open-ended design problems over the course of their undergraduate education. Examples of contextual issues include

environmental, economic, and social factors relevant to a design problem. Two of the problems were presented in alternating years as 10- to 15-minute *design tasks*, in which students provided written responses to questions concerning the design of a retaining wall to contain river flooding (first and junior years) and the design of a pedestrian crossing at a busy intersection (sophomore and senior years). A third design problem concerning the design of a playground took the form of a forced-choice survey question administered in the first and senior years. These longitudinally collected design task and survey responses were analyzed to examine how much students consider various aspects of design problem context and the extent to which this changes during the four years of undergraduate engineering education.

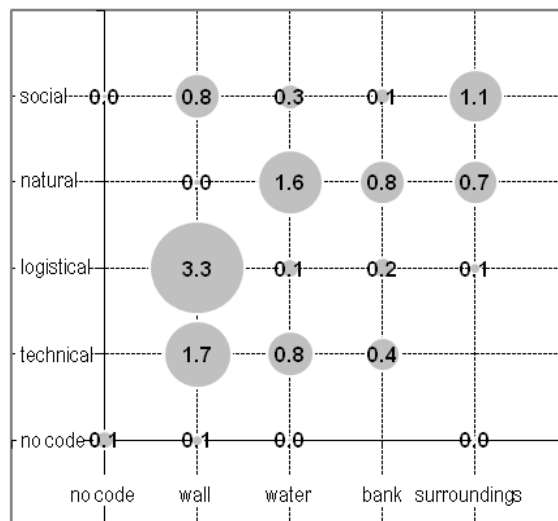
APS explored the extent to which students consider contextual issues during design (e.g., environmental, economic, and social factors).

First-year students consider design problem context.

Analyses of first-year students’ responses to the design task (referred to as the “Midwest Floods” design task) and the playground design survey question suggest that beginning engineering students did take into account the broader context of design problems. Examples of broader contextual factors considered include the natural environment, specific groups of users or stakeholders, and economic impacts.

The Midwest Floods task was administered once in the longitudinal cohort’s first year and again in their junior year, with a total of 79 students participating in both years. In this design task, students were given 10 minutes to list as many factors as they could think of that would be relevant to the design of a retaining wall to contain flooding on the Mississippi

Figure 2.6-C: Emphasis on various aspects of problem context as reflected in APS students’ responses to a problem concerning the design of a retaining wall to contain river flooding. Chart shows average results of coding responses of first-year students ($n = 79$), with physical location codes on the horizontal axis and frame of reference codes on the vertical axis. Area of the circle for each code pair is proportional to the average number of factors matching the code pair.



River. Students' written responses were segmented into distinct ideas (each representing one factor), and then the ideas were interpreted and categorized in terms of the physical location to which a particular factor referred (e.g., the wall itself or the bank on which it would be built) and the frame of reference of the factor (e.g., a technical consideration like the height of the wall or the rate at which the river flows would be coded *technical*; a concern for the environmental impact would be coded *natural*). Figure 2.6-C shows how students' ideas were interpreted and categorized along each of these two dimensions, with physical location on the horizontal axis and frame of reference on the vertical axis (Kilgore, Atman, et al., in *Journal of Engineering Education*, 2007; Atman, Kilgore, et al., at Research on Engineering Education Symposium, 2008). For instance, the figure shows that first-years' responded with an average of 3.3 wall-related, logistical factors and 1.6 water-related natural factors.

To facilitate interpretation, factors referring to the wall itself or the water surrounding it and representing a technical or logistical frame of reference were labeled *close context* factors. In the two-dimensional coding diagrams, close context factors are in the lower left corner; examples include costs, budget, and technical specifications. In contrast, *broad context* factors referred to the bank or surrounding area, or focused on the natural/environmental or social context issues relevant to the design problem. Examples of broad context factors include weather patterns, natural environmental impact, economic impacts, and effects on the people, businesses and communities surrounding the proposed retaining wall. The coded responses of first-year students, represented in Figure 2.6-C, show roughly equal emphasis on broad and close context, in terms of average number of factors of each kind considered.

As with the Midwest Floods design task, first-year student responses on the playground design survey question indicate consideration of both the close and broad context of a design problem. Students were given a list of 17 kinds of information and asked to choose the five that they would most likely need to design a playground. As first-year students, at least 80% included *Budget* and *Safety* among their choices. Other frequently chosen items were related to materials and included their cost, availability, and specifications. As with the Midwest Floods design task, these responses indicate consideration of both the close and broad context of a design problem. (Kilgore, Atman, et al. 2007)

Many sophomores do not consider design problems in temporal context.

The analyses described above examine consideration of physical, environmental, societal, and other dimensions of design problem context. Extending context to include the dimension of time, we also examined whether students place design problems in a *temporal context*. Data for these analyses came from the Street Crossing design task, administered to 58 Longitudinal Cohort students in their sophomore and senior years. Students were given 15 minutes to answer a sequence of four free-response questions about designing a pedestrian crossing at a busy intersection. Two of the questions concerned proposal and evaluation of potential solutions, and responses to these questions were coded using a scheme based on *life cycle analysis*, a technique commonly used to assess the sustainability of a designed artifact or process. Our coding scheme utilized four stages of a designed solution's lifetime, listed in chronological order: current state, design/construction, solution in place, and maintenance/disposal.

Consideration of temporal context was analyzed using a coding scheme based on life cycle analysis.

When students completed the Street Crossing design task in their sophomore year, most considered at least two points in time: the current state (manifesting the problem to be solved) and the solution in place (with the solution implemented as designed). In contrast,

only about a quarter of the sophomores considered the design/construction process, and less than a fifth thought about the future of the solution by considering its maintenance/disposal stage. (Kilgore et al. 2010; Yasuhara et al. 2009)

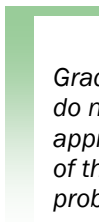
2.6.4 Development of Consideration of Context During Design

With multiple longitudinal data sets examining the consideration of context, we examined how two or more years of undergraduate engineering education influenced the ways in which students approach design problems. The findings suggest that, while engineering education is helping students develop as designers, graduating engineering majors do not exhibit a greater appreciation of the importance of the broad context of a design problem.

Students do not consider broad context more as juniors and seniors than as first-years.

Comparing the Midwest Floods responses of the Longitudinal Cohort students as first-years and juniors, the junior-year responses, on average, reflected consideration of more factors than the first-year responses. However, this increase was largely limited to consideration of close context factors, not broad context. The average number of close context factors increased from 6.0 to 8.3 ($p < 0.001$), but there was no significant increase in the number of broad context factors ($\alpha = 0.05$). (Atman, Kilgore, et al. 2008)

This increased consideration of close context might be a result of students' increased engineering-specific knowledge. This growth in engineering-specific knowledge also was reflected in students' shifting conceptions of engineering design (Subsection 2.6.1). Also consistent with increased gains in engineering-specific knowledge, APS students' senior-year responses to the playground design survey question were more similar to those of practicing, professional engineers' responses (data collected as part of another study) than the students' first-year responses were (Atman, Kilgore, and McKenna 2008). Finally, initial analyses of the Microchip Factory design task showed that very few seniors consider ecological factors when selecting a site for a microchip fabrication facility (Atman, Kilgore, et al. 2008). Collectively, these findings suggest that engineering curricula could be improved by emphasizing broad context in teaching design.



Graduating engineering majors do not exhibit a greater appreciation of the importance of the broad context of a design problem.

Consideration of temporal context does not develop significantly by senior year.

Comparing Street Crossing design task responses of the Longitudinal Cohort students as sophomores and seniors, we observed a similar pattern, with most students failing to consider design/construction or maintenance/disposal when proposing and evaluating potential solutions. More generally, between the sophomore and senior years, there were no statistically significant changes ($\alpha = 0.05$, $n = 58$) in the proportions of students considering the four life cycle stages we coded for. (Kilgore et al. 2010; Yasuhara et al. 2009)

2.6.5 Gender Differences in Consideration of Context

Women are more likely to consider certain aspects of broad context during design.

Earlier, we observed some differences in the ways in which women and men conceptualized engineering design (Subsection 2.6.1). In addition to these differences in how women think about design, we observed that women were more likely to consider certain aspects of a design problem's broad context. In the Midwest Floods design task, women responded with

more broad context factors than men in both their first and junior years ($p < 0.05$). (Notably, women and men responded with about the same number of close context factors.) (Atman, Kilgore, et al. 2008)

There were similar gender differences in first-year responses to the playground design survey question. When asked to select the kinds of information they would most likely need to design a playground, women were more likely to select items associated with broad context: *Neighborhood demographics*, *Handicapped accessibility*, and *Utilities* ($p < 0.05$). Conversely, they were less likely to select items associated with close context: *Budget*, *Material costs*, and *Labor availability and cost* ($p < 0.05$). (Note that, unlike in the Midwest Floods design task, which consisted of a free-response question, the fixed number of selections in the playground design survey question enforced a zero-sum game in selecting broad vs. close context items.) (Kilgore, Atman, et al. 2007)

Findings from the Midwest floods design task and the playground design survey question suggest that the women gave more attention than men did to the respective design problems' geographical, natural, and/or societal context. When it came to the inclusion of temporal context in the Street Crossing design task, however, there were no significant gender differences. Women and men were comparably likely (or unlikely) to consider each of the coded life cycle stages. These design task and survey findings suggest that women and men can take different approaches to engineering design, at least with respect to certain aspects of problem context.

2.7 Looking Beyond Graduation: Student Plans

Although the Academic Pathways Study focused primarily on students' undergraduate years, several components of the research examined seniors' post-graduation plans. This section describes aspects of students' plans upon graduation. We also consider how these vary by gender and underrepresented racial/ethnic minority (URM) status, and what other factors come into play in students thinking about their next steps.

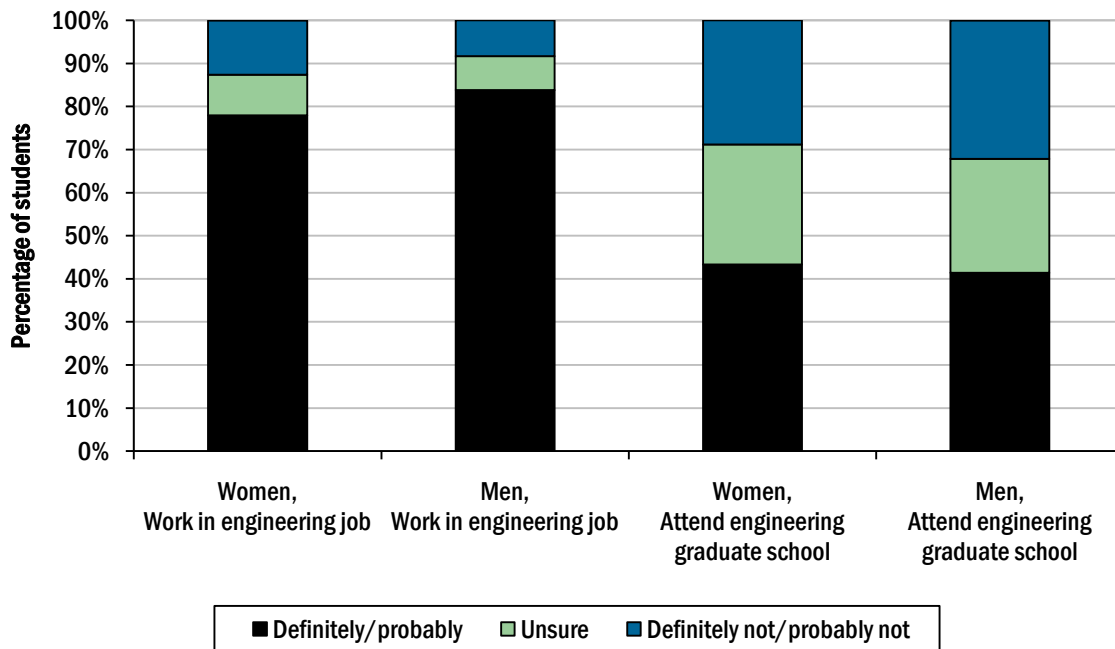
2.7.1 What Do Students' Post-Graduation Plans Look Like?

One aim of the APPLES study was to explore engineering students' post-graduation plans—how many students are planning on engineering work, how many are thinking about non-engineering graduate school, whether they are considering multiple options, what factors help indicate a student's direction, etc.

Key findings are summarized below, drawing from descriptive statistics on students' post-graduation plans. Four regression models of senior-level, post-graduation engineering and non-engineering school and work plans allowed us to identify and explore relationships between motivation, college experiences, demographics, and these plans. Two models of first-year student plans towards engineering graduate school and/or engineering work were also built. The regression models are described in detail by Sheppard *et al.* (2010).

Figure 2.7-A shows that women's and men's post-graduation engineering work and engineering graduate school plans are similar.

Figure 2.7-A: Intentions of senior men and women to study and practice engineering post-graduation (Gender differences are *not* statistically significant.)



Nearly 80% said “yes” to engineering work, and 20% were unsure or leaning away.

That a high percentage of seniors reported plans to enter into the work that their degree aims to prepare them for is consistent with what we saw with the Longitudinal Cohort, where the commitment to practicing engineering after graduation for those who persisted in an engineering major increased over their college years (Eriş et al. 2010).

At the same time, it seems surprising that 20% of seniors intending to finish an engineering degree were either turning away from a future in engineering or remained unsure. It is possible that some of them may have long had plans that included engineering as a stepping stone into another field, such as medicine, law, or business. It is also possible that some have been “turned off” by engineering along the way but decided to finish anyway (also see Subsection 2.3.1 and discussion on doggedness), or were not able to obtain an engineering job offer that they were excited about. Additionally, students who indicated they were “unsure” two months before graduation might have been waiting for job offers to become finalized.

Twenty percent of seniors do not plan to pursue engineering options after graduation or are unsure.

That a significant number of engineering graduates were leaning away from engineering work was also seen in our Longitudinal Cohort studies. These data also indicated that students completing a major in engineering were not necessarily committed to careers in engineering. In an analysis of data from the senior year (spring) administration of the PIE survey at two of the campuses, approximately 26% were either *Probably* or *Definitely Not* planning to pursue careers in engineering (Lichtenstein et al. 2009).

Co-ops, internships influence post-graduation plans to pursue engineering.

The regression models indicate one particular college experience that may influence students’ job direction. Among seniors, the top predictor of engineering job plans was exposure to engineering experiences such as co-ops and internships. This same variable was a negative predictor for plans for non-engineering employment. While those who are disinclined towards engineering employment may avoid exposure to co-op and internship experiences, we should also consider the possibility that their employment decision-making might have been influenced, if these students had had those experiences.

Forty percent considering engineering graduate school

The percentage of students planning on engineering graduate school remained constant at over 40% between first-years and seniors. In contrast, a significant number of students seem to have ruled out engineering graduate school between first year and senior year. The percentage of students *not* planning on engineering graduate school increased from 19% in their first year to 31% in their senior year.

We found that the top predictors among seniors of engineering graduate school plans were GPA and psychological motivation (e.g., thinking engineering is fun), and the top negative predictor was confidence in professional and interpersonal skills (e.g., skills in written and oral communications, teamwork, leadership). That is, students with greater confidence in professional and interpersonal skills were less likely to indicate interest in graduate school (See Subsection 2.7.3).

Finally, undergraduate research experience only weakly predicted engineering graduate school plans, and there was no predictive power to exposure to the profession, academic

involvement, or frequency of interaction with instructors. Some students, by the time they were seniors, might have developed a more realistic view of themselves in relationship to engineering graduate school and their probability of admission and success. Additionally, it could be expected that many students were excited to leave school, enter into the engineering work world, and begin to make an income, rather than continue studies as graduate students. (Note that this data was collected prior to the economic downturn that began in 2008.)

Seniors still unsure about their plans

While only 8% of seniors were unsure about their plans to enter into engineering work, approximately one-quarter were unsure about their plans related to a non-engineering job or graduate school (either engineering or non-engineering). In other words, one in four seniors was considering how non-engineering options might fit into their future. This is perhaps to be expected of students who were entering a period of exploration that frequently occurs between adolescence and adulthood.

In thinking about these results, we also need to recognize that current students (the so-called Generation Net or the Millennials) engage differently not only in their education when compared to prior generations (Chubin *et al.* 2008) but also with respect to their futures. As seniors, many are still figuring out their interests, what job opportunities are out there, and what new opportunities might emerge. Some are graduating from an engineering program and have little idea about the kind of work they will do on a daily basis, despite having completed internships or co-ops. This uncertainty about what is in store for them might also make students hesitant about engineering work or graduate school (Jocuns 2008).

Longitudinal Cohort analyses also reflected uncertainty in seniors about their post-graduate engineering plans. In addition, they suggest that the APPLE survey findings on students' plans as reported in late winter through early spring of their senior year may have over-reported the level of certainty in these plans. Of 28 Longitudinal Cohort seniors we interviewed at two of the study schools, 15 fell into the *Unsure* category. These students were still vacillating between different post-graduate options late into the senior year, even into summer. To be clear, these students were not vacillating between different *job* options within engineering; they were wrestling with a range of career choices. As one student said,

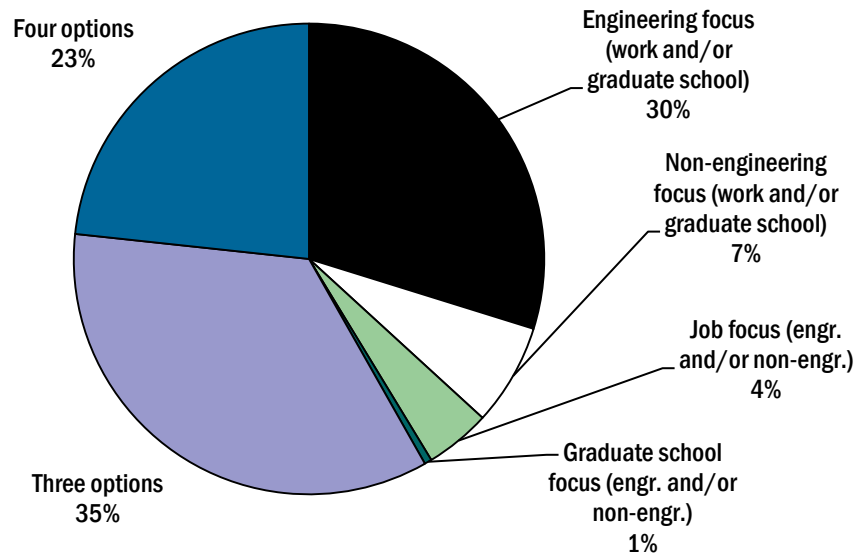
Ten years from now, I still plan on being in business for myself, doing consulting, either in education, or, possibly, in engineering. But the focus will be on education, science education stuff. I might have to do the engineering to, you know, actually make some money, but the focus is hopefully going to be in science education.
(Lichtenstein *et al.* 2009)

More than 60% of engineering graduates had a combination of plans.

As seen in Figure 2.7-B, about one-third of seniors saw themselves as focused on "engineering only." Upwards of 60% of seniors were considering some combination of engineering and non-engineering jobs and/or graduate school. This may have been because some were still defining their path and were leaving options open, whereas some might have had a defined path with different segments that incorporate work inside and outside of engineering.

We note that seniors, as a group, relative to first year students, were broadening their career interests. This may reflect today's professional reality—students may perceive that they no longer have the option of setting their sights on one thing and one thing only. Even though students' career trajectories were becoming more defined by their senior year, there was still

Figure 2.7-B: Combinations of options being considered by seniors. (Note: Students were able to select from four, non-mutually exclusive options: the likelihood of pursuing engineering work, non-engineering work, engineering graduate school, and non-engineering work.)



a fair degree of uncertainty as to their paths. Alternately, we could interpret this uncertainty as a result of the fact that students' career trajectories were still being formed.

An engineering degree can provide a basis for many future options.

Our Longitudinal Cohort studies reinforce that many students do not think of their future in terms of a single job or even one career, but rather as one that consists of many possibilities and includes non-engineering endeavors. Participants felt that their engineering education and the problem-solving skills they had learned would provide a good basis for exploring different options after graduation (Lichtenstein *et al.* 2009).

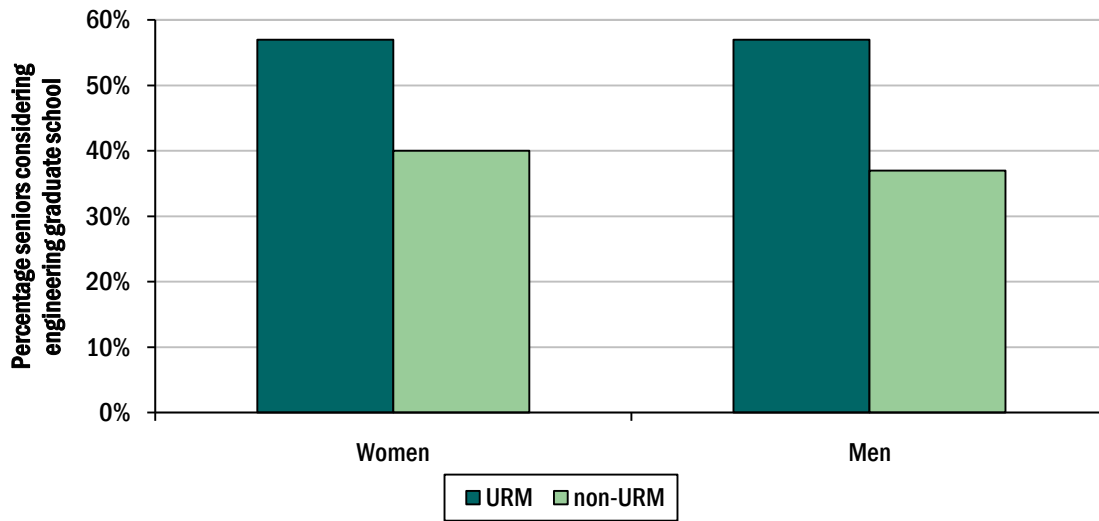
2.7.2 The Demographics of Tomorrow's Professionals

URM students were initially more interested in engineering graduate school.

Engineering graduate school plans differed notably between URM (underrepresented racial/ethnic minority) and non-URM students. Particularly in the first year, URM students expressed significantly more interest in attending engineering graduate school than did non-URM students (65% vs. 38%), and URM status was a predictor of engineering graduate school plans among first-year students.

By the senior year, URM status was no longer a predictor, when controlling for other factors. However, when we look at the actual percentages, one-and-a-half as many URM seniors expressed plans to attend engineering graduate school (Figure 2.7-C). One might expect that this stronger interest in engineering graduate school among seniors would translate into actual graduate school enrollment, but a gap remains between URM student representation

Figure 2.7-C: Seniors in the APPLES sample who are considering engineering graduate school, by gender and URM status



in engineering graduate programs relative to their representation in bachelor's degree programs.

URM women and men think differently about post-graduation options.

We note two other observations with respect to student diversity. First, senior URM women reported the highest mean level of professional and interpersonal confidence and the lowest mean self-reported GPA, relative to their senior peers. In the model of seniors' engineering graduate school plans, GPA was a positive predictor, and confidence in professional/interpersonal skills was a negative predictor. It could be that we are losing some women before engineering graduate school because they believe that a lower GPA precludes graduate studies. Alternatively, they might not see how their professional and interpersonal skills can be utilized in engineering graduate work.

A second issue is that more senior URM students were considering multiple options that span engineering and non-engineering than were non-URM students (67% vs. 56%). This could suggest that URM students may have broader interests, and also that engineering as a profession may need to work harder to retain these individuals among its ranks.

Women's plans similar to men's, but...

Similar percentages of women and men were planning on engineering and non-engineering work and graduate school. However, men were slightly more likely to focus on engineering only, and women slightly more on both engineering and non-engineering options.

2.7.3 Key Factors in Plans

We saw a mix of factors in looking at students' plans for the future. Three of the most noteworthy were students' psychological motivation, the level of confidence they expressed in their professional/interpersonal skills, and aspects of the institutional setting.

Psychological motivation/interest an important factor

The psychological motivation factor loaded heavily on all four of our senior regression models. It positively predicted heading toward post-graduate engineering options and negatively predicted heading toward non-engineering options. This makes sense in that individuals who are excited by engineering want to keep doing engineering. However, one question that we did not investigate is, where does psychological interest and motivation come from? Thinking of the experiences of students beyond the campus and even before they enroll in college, could K–12 education, families and communities, and society do more to promote enjoyment in engineering thinking, through more exposure, more opportunities, and more support in general? Additionally, engineering might be conceptualized in ways that invite a more diverse student population by highlighting the broad range of problems that engineers address.

Psychological Motivation/ Interest strongly predicts seniors' intention to pursue engineering options after graduation

Confidence in professional and interpersonal skills an important factor

Confidence in professional and interpersonal skills also showed up as being important in all senior models, but in the opposite direction to that of psychological motivation. We found that heading towards engineering options was predicted by lower professional/interpersonal confidence (all other factors being equal), whereas heading towards non-engineering options was predicted by higher professional/interpersonal confidence. However, employers increasingly say that these skills are critical for success in today's engineering workplace, as the practice of engineering is a social, as well as technical, activity.

Confidence in Professional & Interpersonal skills strongly predicts seniors' intention to pursue non-engineering options after graduation

Institutional differences can have strong influences on student pathways.

The responses of engineering seniors at two of the four APS campuses from the Longitudinal Cohort were examined in greater detail with respect to their thoughts and intentions to follow an engineering pathway after graduation. The PIE survey and semi-structured interview data from 74 students on the two campuses were analyzed, and four major themes emerged that create a richer portrait that adds to the cross-sectional APPLE survey results of student intentions to pursue (or not) an engineering career after graduation.

The seniors on the two campuses represented in this subset of APS data showed different response patterns when asked about whether they planned to pursue careers in engineering. These different response patterns were likely a function of programmatic differences at the two campuses. One campus was focused primarily on the education of engineering, science, and technology majors, and the other larger university offered a broader range of majors, including the humanities and social sciences. At the technical campus, only 14% of seniors indicated they were *unlikely* to pursue an engineering related activity after graduation (either a job or graduate school). On the other campus, 36% of engineering seniors reported that they were *unlikely* to pursue an engineering related activity. These differences emphasize the potential for different institutions to attract different kinds of students and/or for institutional factors to shape post-graduation plans. (Lichtenstein et al. 2009).

2.8 Looking Beyond Graduation: Experiences in the Work World

As the previous subsection described, approximately 80% of engineering undergraduates in our sample were planning to seek employment in an engineering field. Although the APS focused primarily on students' undergraduate years, several components of the research examined the experiences of recent graduates' entry into the engineering workforce.

In a series of studies during 2006–2009, we interviewed over 100 engineering graduates who were in the first or second year of an engineering job and 15 of their managers. Fourteen companies were represented, and the studies generated six distinct data sets.

The major themes that emerged about the engineering experiences of early career engineers are presented below. This work has been situated in multiple theoretical frames looking at the transition from school to work—specifically, the ways in which new engineers make sense of their career choices and learn to navigate their first job experiences. Theoretical frames used for analysis were Social Cognitive Career Theory (Lent and Brown 2008), Social Cognitive Theory (Bandura 1986, 2001), Social Exchange Theory (Blau 1986, Lawler 2001), and theories of relationships (Villard and Whipple 1976).

In these studies of new engineers entering the workplace, there were two predominant topics studied: the experiences of new engineers applying their technical expertise (what they learned in school) to engineering problems, and their experiences learning to navigate the organizational and social systems of the workplace.

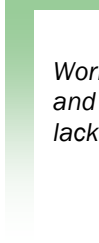
2.8.1 The Work World, as Compared to the School World: The Nature of Engineering Problems

Technical problems are more complex and ambiguous in the work world.

Some newly hired engineers remarked that the technical problems they faced on the job were different from those they encountered in school. Work problems were ambiguous and more complex and often lacked complete data. Frequently, a necessary initial task was to define the problem in terms of the preferences of the group, thereby deciding on the appropriate scope and what information was key to the solution. It was important to understand the larger work group's expectations about what constituted an appropriate approach and an acceptable solution. New engineers consistently reported that the work of engineering they encountered on their first jobs was significantly different from their experiences in school.

(Korte, Sheppard, and Jordan, 2008) New hires reported encountering a steep learning curve, initially, and this was sometimes associated with a probationary period. Recent hires also reported a change in their sense of time, in that problems could pop up suddenly and that deadlines were less under their control than when they were in school. (Jocuns and Stevens 2009)

For example, talking about the differences between work and school problems, one of the new engineers said,



Work problems were ambiguous and more complex and often lacked complete data.

I mean, in school, it's very textbook. They always try and model everything in a mathematical sense in school. And in the real world, it's a lot more difficult to model things. It's just there's a lot more variables involved, and there's the [uncertainty] too of whether or not you're modeling it right. Are you following the right procedures and principles? And stuff like that. (Korte, Sheppard, and Jordan, 2008)

Another new hire had a similar feeling, saying,

I guess in school, you've got your specific material you're learning, and you have your specific problem that goes with that material. In real life, you never have anything that specific, at least with my experience so far. I'm sure there are some people that do, but then they'll only have those kinds of specific problems. Mine, I have to combine that with 500 other specific problems that we might have done in school. It's never just that one focus. (Korte, Sheppard, and Jordan 2008)

Another new engineer described this difference between school and the work world:

Whereas in real life, right, you're not going to just bend the thing, see what happens, and explain it, and then move on to your next assignment. You're going to bend that thing, see what happens, explain it, and try and fix it. Whereas in school, you explain it and get a result, and then no follow-up. (Korte, Sheppard, and Jordan 2008)

We note that the type of assignment given to a new hire could determine how strongly linked they felt the activity was to their schooling. Tasks that involved problem definition and resolution were felt to be more strongly linked to what they had learned in school. Many referred to learning a “way of thinking” that typified engineering expertise. Other tasks that were focused on project or data management seemed less relevant to their education and less like “real engineering.”

Many different players and processes can affect decisions.

New hires found that there were many people who could influence decisions, including those who might not be directly involved with a team. Data that had been regarded as objective and the primary basis for decisions in school might not, in the workplace, have this objective status or the same top priority in reaching a decision. In many cases, priorities were based on the relationships between the engineer and others in the organization. In addition, company processes were sometimes perceived as a constraint to effectiveness or efficiency. New hires needed to learn skills to navigate the more nuanced decision-making process in their place of employment. (Korte, Sheppard, and Jordan 2008)

Company processes were sometimes perceived as a constraint to effectiveness or efficiency.

2.8.2 The Work World, as Compared to the School World: Managers, Co-Workers and Teamwork

Support from managers and coworkers is very important and can vary greatly.

There was great variability in the degree to which the new hire's manager provided direct assistance. For some, their manager was actively involved in providing information, answering questions, or pointing new hires towards resources. For others, managers provided little assistance, and this was often because they were too busy in balancing project

assignments and other managerial duties. In some cases, the manager was not even available to greet the newly hired engineer on their first day. Another frequent cause for lack of support was that the manager was relatively new to the company or manager's role and therefore still learning the ropes. (Korte 2009)

The experiences of new hires ranged from good...

Well, [company]'s a big organization, and I think I was very fortunate, because, when I started the position, my initial supervisor was very—they were very good at throwing things at you that you might not even know why you need them.

...to less satisfactory:

My manager wasn't there to greet me, or nobody was there to be like, "Hey, welcome aboard," blah, blah, blah. There was like one random dude that happened...They were like, "Do you know where [manager] is?" "No, I don't know where he is." And now I know why they don't know where he is, because he's busy as hell, and he's never at his desk. (Brunhaver et al. 2010)

Compared to managers, co-workers were the most significant source of information in this process, both in terms of understanding work tasks and the culture of the work group. New hires were often given assignments that had been formulated by more senior engineers. New hires often had to build good relationships in the group to access sources of technical information, as well as for learning the context and social systems of the workplace. (Korte, Sheppard, and Jordan 2008; Korte 2009, 2010)

As one study participant reported,

It's like, around here, you're going to run into a lot of people that are very laid back, and if they don't think you're priority or your work's priority, you'll be on the back burner for a year on something. And so you'll learn that you've really got to network and really learn people around here and really, really get to know them on a personal level and earn their respect. (Korte, Sheppard, and Jordan 2008)

The assistance new hires were able to get from their coworkers also varied greatly. Similar to the situation with managers, some coworkers were very supportive in mentoring the new hire and orienting them to the job. In other cases, coworkers were too busy or new at the job themselves to offer much assistance. (Brunhaver et al. 2010, Korte 2009)

Differences in age or outside interests can impede camaraderie.

With respect to forming relationships with coworkers ("bonding"), there was a broad range of experiences for new graduates, from developing a strong feeling of camaraderie with a majority of their coworkers to feeling little or no camaraderie. A frequent cause of the latter situation was a significant difference in age or outside interests. As one former student said of his successful bonding with coworkers,

It was much easier because I think we were all in the same age group, so integrating with the group was really easy. I think we got to know them, they got to know you. And it's like I was here for maybe ten years, I mean it just—you just have that type of feeling to it, you know? (Brunhaver et al. 2010)

Rotation of new engineers can inhibit forming strong relationships with coworkers.

The practice of rotating new engineers through different positions as part of orientation was a program at several of the companies we studied. This practice can have an impact on how well new hires learn the business of the organization and develop relationships in a work

group. Rotating around the company afforded new hires experiences with the range of activities that comprised the business. Rotations would often last three to six months, and new hires sometimes felt that, despite the importance of learning from coworkers, it was not worth the effort for some of their coworkers to befriend a new engineer who was unlikely to stay beyond the duration of the rotation. As one new hire who had negative feelings about a rotation experience said,

You're only going to be there for four months. So you could understand where people are, like, well, I'm not going to take the time to really get to know you, 'cause you're going to be gone in three months. And so you don't really take it personally, but you do kind of. (Brunhaver et al. 2010)

Teamwork was much different in the workplace than in school.

In many cases, new hires started working on teams well after the project had started and sometimes never saw the finish of the project. This view of teamwork was different than school projects, in which the members typically started and finished a project together. (Korte, Sheppard, and Jordan 2008)

Teamwork can be much more complex in the workplace compared to school: joining or leaving a project mid-stream; working with non-engineers...

Teams in the workplace were usually much larger and more diverse than those that students experienced in school. Workplace teams often included members from other engineering disciplines, others who were non-engineers, and occasionally people from outside the company. New engineers could sometimes be the sole engineering (or company) representative on these teams and, as a result, had a greater sense of responsibility. (Jocuns 2009)

2.8.3 Finding One's Role or Place

Understanding one's role

A theme running through many of the interviews was the importance to new hires of understanding what their role was in the company. This could be a source of concern, since we heard only a few examples in our interviews of managers who made the effort to provide this sort of context to their new employees. Engineering work was often a complex, long-term project. Individual engineers contributed small pieces of the project, and it was difficult for new hires to understand how the whole process worked. (Korte, Sheppard, and Jordan 2008)

Getting a sense of the bigger picture

A key part of understanding one's role was learning the reasoning behind decisions, as well as the goals and priorities of the larger organization. Understanding the priorities of the organization allowed new hires to formulate ideas about the value of their work and how it fit into the larger picture. (Korte, Sheppard, and Jordan 2008)

Some new hires expressed feeling a bit lost navigating in a large organization. In the words of one, "I had a hard time just trying to understand how the system actually worked. Even now, I'm still a little iffy on a lot of details and whatnot." Another stated, "One of the first things is kind of like to get oriented into the actual whole system, because the system is just like absolutely, ridiculously huge." (Korte, Sheppard, and Jordan 2008)

Company education efforts could be insufficient

All companies offered some type of education for the new employee to varying degrees, and in some cases this effort was quite extensive. In spite of this, new engineers typically indicated that they felt their company's efforts in training and new employee orientation did not seem sufficient. This often was expressed as a lack of exposure to "the big picture" and an incomplete (or non-existent) description of where the individual fit in the corporate structure.

New hires often felt the lack of exposure to the "big picture" and were unsure of where they fit into the organization.

As one study participant who was hungry for a view of the "bigger picture" said,

I wanted always more overview, more overview. Tell me about how the whole company process and procedures work. How does this person fit in with that person? I was getting into too much depth of information on specifics without getting an overview. So I was constantly asking people, especially my first two, three weeks, give me an overview. (Brunhaver et al. 2010)

2.8.4 Communication Matters

The importance of communication and documentation

New hires reported becoming aware of the importance of effective communication and documentation in the workplace. This could be routine reporting to a manager and the team, as well as sharing results with other interested groups in the company who might not have been directly involved in their project. In some cases, new hires began projects that had little documentation or background material and had to fill in the gaps for themselves. Finding information was a major task for new hires and included finding out who knew what, what information existed, and where this information was. Navigating myriad databases and learning who to ask for what information was important to getting grounded in the job. (Korte, Sheppard, and Jordan 2008)

One new engineer felt the challenge of having to pick up the pieces from someone else, stating, "The person in charge of this system, he already had a test procedure that he had started writing, but he had written that, and it wasn't really complete, like two, three years ago. So it's kind of like he handed that over to me, and I had to update it and make changes and kind of get it up to date with the new spec that was in the system now." (Korte, Sheppard, and Jordan 2008)

Communicating with non-engineers

One significant aspect of the job for many newcomers was the importance of communicating with non-engineers. As part of this, new hires had to learn to anticipate how different interests in the organization might interpret data in different ways, and this was a new experience for many (Korte, Sheppard, and Jordan 2008). An important and necessary skill was learning how to communicate effectively with audiences that included clients and others who were not engineers (Jocuns 2009).

New hires had to learn how to communicate effectively with audiences that included clients and others who were not engineers.

One participant described learning the importance of understanding the audience when presenting results: "[I am] definitely learning more about how to present my data to people...

It's a huge difference in how people perceive your data depending on how much they know" (Korte, Sheppard, and Jordan 2008).

Learning to use a new language

Many new hires had to learn both company- and industry-specific language. In addition to learning entirely new terminology, new hires had to learn ways of referring to things that were different from vocabulary used in school. Mastering this new language required learning how to use the terminology in different contexts. (Jocuns 2009) This acquisition of terminology can be seen as a continuation of learning the language of engineering that began during the undergraduate years, as discussed in Subsection 2.5.1.

2.9 Summarizing Results about Diversity

The percentage of engineering degrees received by women and underrepresented minorities (URM) has remained markedly flat for the past decade—about 20% for women and 5% and 7% for African American and Hispanic students, respectively (NSF 2009). An important goal of the Academic Pathways Study was to assist efforts to increase diversity in engineering education by providing greater insight into the variety of experiences diverse engineering students may have. Therefore, we oversampled for gender and race/ethnicity in our longitudinal and cross-sectional studies to ensure the inclusion of underrepresented voices. Having sufficient numbers of women and URM (underrepresented racial/ethnic minority) students enabled us to examine how gender and URM status are related to the various student trajectories we observed.

In the prior subsections, we described learning, developmental, and professional pathways of engineering students as indicated by APS findings. In this subsection, we summarize findings with respect to gender and URM status from across the other subsections. We follow the order of previous subsections, discussing findings about engineering students' overall college experience; motivation and interest in engineering; experiences within the engineering college; development of engineering and design knowledge, conceptions, and confidence; and post-graduation plans.

2.9.1 The College Experience

As discussed in Subsection 2.2, the engineering major is less diverse than other majors with respect to gender, URM status, and first-generation college students. Within the NSSE Comparative, Longitudinal data set (247 institutions, 11,812 participants), we found that a larger proportion of in-migrators than persisters in engineering were women, URM students, and first-generation college students. (Recall that in-migrators are students who start college in a non-engineering major but subsequently switch into engineering. Persisters are students who start and stay in engineering.) In other words, the group of students who migrated into engineering was a source of increased diversity. Unfortunately, engineering does not appear to invite in-migration, relative to other college majors. Only 7% of engineering persisters in their eighth college semester came from majors outside engineering, compared with other majors in which in-migrators comprised 30–65% of students at this stage (Ohland *et al.* 2008). Below, we discuss some of the areas where differences in perceptions, perspectives, and experiences may provide some explanations for continuing underrepresentation, as well as suggesting opportunities for addressing this issue.

2.9.2 Motivation to Study Engineering

We recall from Subsection 2.3 that we found *psychological motivation* (the enjoyment of engineering inherent in the activity) and *behavioral motivation* (related to the practical, hands-on aspects of engineering) were the strongest sources of motivation to study engineering, with motivation to do social good and financial motivation not far behind. All of the above sources of motivation were very strong in comparison to mentor or parental influence, but, nonetheless, these additional sources of motivation were also important to some of the students in our sample.

Gender, motivation, and approaches to engineering

Some motivators have different significance for men and women. In the Broader National Sample, behavioral motivation was greater among men than women, whereas mentor motivation was greater among women. The greater behavioral motivation of men is consistent with how they prioritized engineering design activities, with men significantly more likely to have included “building” among those activities they consider most important in engineering design (Subsection 2.6). The perceived importance of the practical, hands-on aspects of engineering work was reflected in many students’ comments in interviews. For example, Austin, a mechanical engineering major at the large, public university, described his motivation to study engineering: “I’ve always been interested in, I don’t know if—not mechanical systems, but just like putting stuff together.” He went on to describe his work as an engineering student: “Basically all the design work we do is to assemble something so, yeah, it’s always—the more stuff you’ve built the better, and I think—I don’t know, just a lot of what I’ve done has paid off that way.” (Kilgore, unpublished)

In contrast, Lauren, a chemical engineering major at the large, public university, described men’s and women’s different approaches to project work:

When we’re working on projects and stuff, [men] have like a one-track mind where it’s like, let’s just get through this and then we can go...When I’m in a group, then I sort of have to pay attention to the little details surrounding it, like, oh, what about this, what about this, and maybe we have done this—maybe not get through everything in one sitting as they would like, but then consider more of the big picture sometimes. (Chachra et al. 2008)

Gender, motivation, and major

Students’ majors also seemed to factor into differences in motivation in the Broader National Sample. For senior women majoring in mechanical engineering (ME), electrical engineering (EE), or aerospace engineering (AE), psychological motivation, behavioral motivation, and social good motivation were of comparable (and high) strength (Parikh et al. 2009). In contrast, for men in these same three fields, there was a clear hierarchy: behavioral, followed by psychological, followed by social good. Both men and women majoring in bioscience-related engineering fields (BioX) exhibited comparable (high) levels of psychological, behavioral, and social good motivation, followed by financial motivation—the same pattern as for women in ME, EE, and AE. Nationally, BioX enrolls a significantly higher percentage of women than ME, EE, or AE, so the motivation profiles observed in BioX might reflect the critical mass of women in these majors. Alternatively, students with this motivational profile might be differentially attracted to BioX majors because of content or values reflected in the BioX fields.

Women majoring in industrial engineering (IE) and chemical engineering (ChemE) had a distinctly different pattern than women in other engineering majors. For these women, psychological, social good, and financial motivation were of comparable (and high) strength, followed by behavioral motivation. These women were more financially motivated to study engineering than their AE and BioX counterparts, and less behaviorally motivated than their AE and EE counterparts. Again, in the case of IE and ChemE, certain characteristics of the major may reflect the greater number of women involved in it or, alternatively, may attract a greater number of women, or some combination of the two.

Gender, URM, and mentor influence

In both the Longitudinal Cohort and Broader National Sample, women reported that mentor influence was a greater factor in their decision to study engineering than did men. Although

mentor influence was not the strongest factor for engineering students as a whole, it did figure prominently for some women. For example, Elizabeth, a computer engineering student at the large, public university, was offered continued support by a company hoping to hire her upon graduation. In addition to matching her with a mentor when she was interning for them, mentors continued to visit her when she returned to school. Elizabeth described having periodic conversations over coffee with female mentors who offered practical career advice as well as social support. We also recall from the NSSE data analysis that women represented a higher percentage of in-migrators than persisters in our sample. It may be that mentors serve an important role in encouraging diverse college students who are still searching for the right major to consider engineering.

Indeed, a few URM students at one APS institution were drawn to study engineering because they were given a high-paying summer internship in engineering before their first year of college, and were offered additional advising and extra tutorials for prerequisite coursework. Before their internships, these students had not considered engineering as a potential career. Women learned from the experience that one could do many different kinds of work with an engineering degree, and not all of them planned to become practicing professional engineers. Some were going to use their engineering degrees to do non-engineering work. (Garrison, forthcoming)

2.9.3 The Engineering College Experience

As discussed in Subsection 2.4, many of the college experiences of women and men majoring in engineering were similar, as reflected in the Broader National Sample. They had similar levels of interaction and satisfaction with instructors, and reported similar levels of academic involvement, as well as exposure to engineering through co-ops, internships, and research. They also reported similar GPAs. However, we have noted some differences in their experiences. First, women and men exhibited differences in levels of participation in extracurricular activities, with women reporting higher participation. Women also reported greater feelings of curricular overload and difficulty balancing school and social life.

Gender and extracurricular activities

It appears that activities outside the classroom may play a more important role in the lives of undergraduate engineering women than of men (Chachra *et al.* 2009). As in the Broader National Sample, women in the Longitudinal Cohort reported more frequent involvement in engineering and non-engineering extracurricular activities than did men, and in the case of non-engineering activities, attributed more importance to these activities. We also saw an interesting gendered pattern of participation emerging in a small sample of graduating seniors ($n = 15$) reflecting on their extracurricular participation in their senior year. Women in this sample described their participation in professional and networking organizations, while men were more often engaged in hands-on, engineering-related extracurricular activities. Also, women more often described taking on administrative leadership roles. Finally, among seniors who reported high levels of participation in extracurricular activities, women more often described activities in more than one organization, while men more often were focused on one intensive activity.

Gender and curricular overload

Both in the first and senior years, women in the Broader National Sample reported a greater sense of curricular overload (difficulty in coping with the pace and load demands of engineering-related courses) than did men. In addition, they reported greater pressure to balance their social and academic lives. This sense of overload is unlikely to be a *direct*

result of greater participation in extracurricular activities, as we noted that, for both women and men, there was no simple correlation between curricular overload and extracurricular activities.

Gender and race/ethnicity in the classroom

Elizabeth, the computer engineering major in her last year at the large, public university, observed that her contributions to in-class discussions were ignored in favor of men's:

Let's say...there are three people in the group and there's one guy and, you know, one girl talking to another person, and then let's say I'm the girl and there's another guy trying to explain the same thing to another person. That person turns to listen to the guy rather than the girl. That happened to me a lot... (Chachra et al. 2008)

Perceptions like this may have led some women at this institution to believe that they would have to prove themselves to the men in their classes before their ideas were considered as valuable as those of their male classmates (Garrison et al., Cultural models, 2007). Such a perception also goes hand in hand with a sense of the importance of representing their gender positively. Some women at the comprehensive, historically Black, private university spoke of the importance of doing well to favorably represent their gender (Fleming et al. 2008). Similarly, at the large, public university, both women and men majoring in engineering said in interviews that they believed women were held to lower standards for admission to the college than men (Garrison et al., Cultural models, 2007). One male student was rather blunt, musing, "I always kind of wonder like, hmm, when girls get something, I wonder if it's because they're a girl or because they deserved it" (Chachra and Kilgore 2009). Among Longitudinal Cohort students who participated in the structured interviews, white women in particular seemed to hold this opinion, describing the novelty and advantages of being in the minority for the first time, perceiving that they had more support and opportunities available to them (Fleming et al. 2008).

At the large, public university, after admission to engineering (typically occurring at the end of the sophomore year), women reported reluctance to seek help on work from men in their classes to avoid being perceived as not having earned a spot in the college. Women felt the need to maintain the appearance that they knew "what was going on," so they went "underground" for help and tried to work with other women whenever they could (Garrison, Stevens, and Jocuns 2008). Some also reported wanting to stay in engineering despite negative feelings about the major, because they wanted to make things better for those who would follow them (Garrison et al., Cultural models, 2007).

This concern about others' perceptions was shared by some URM students, though only 19% of students in the Longitudinal Cohort said race plays a part in their becoming an engineer. William, an African-American student at the comprehensive, private university, explained his own complex perspective: "I feel like sometimes African-Americans...aren't...considered to be as...capable...as far as doing course work and everything it takes to become an engineer." William appeared not to have internalized the external negative messages that he perceived as he went on to distinguish this external issue from his own beliefs: "I don't personally feel like that's the truth..." (Fleming et al. 2008). This stands in contrast to Kara, a white student who diminished the importance of an award for best female engineer that she received from the Society of Women Engineers, saying, "There's probably only 20 girls in my class" (Chachra et al. 2008). These findings appear consistent with those concerning relationships between gender and URM status with self-confidence in math and science skills, as elaborated below.

2.9.4 Engineering Knowledge, Conceptions, and Confidence

Women and men reported similar gains in learning about engineering and cited similar sources of these gains, as we discussed in Subsection 2.5. We see two noteworthy gender differences in the Broader National Sample. First, women reported professional and interpersonal skills as being more important for engineers than did men. Second, more dimensions of the college experience (interactions with instructors, and “out-of-classroom” experiences) correlated with gains in engineering knowledge for men than for women. At the same time, women in the Broader National Sample reported lower confidence in math and science skills than did men.

Gender and professional and interpersonal skills

In the Broader National Sample, first-year and senior women reported professional and interpersonal skills as being more important than did men (and this gender difference was greater among seniors than among first-years). This is surprising, considering that with increasing time in college, students are more likely to have been involved in engineering-related summer jobs, internships, and co-ops, as well as team-based design projects where these skills would be used. Consider Kara’s reflections on her senior design capstone at the large, public university, which she described as “90%...logistics and the running around and the getting people together and making—or just, you know, keeping people on task and together and so forth” (Kilgore, Jocuns, and Atman, *School gets in the way*, forthcoming). If women and men tend to take different kinds of roles in collaborative learning settings, this might help explain gender differences in how these settings are experienced. It might be the case, for instance, that women take on more of the project management-oriented tasks and men take on more of the technical tasks in a team-based design project.

Gender and engineering knowledge gain

In the Broader National Sample, men’s reported gains in engineering knowledge correlated with frequency of interactions with instructors and “out-of-classroom” experiences, while women’s gains in engineering knowledge did not. As discussed previously, at least on one APS campus, women’s desire to appear as strong engineering students drove them to seek academic assistance from other women, often outside the classroom. This reluctance to publicly admit weakness could offer an explanation as to why we saw no correlation between an increase in engineering knowledge and women’s interactions with their instructors in the larger sample. Also, we observed different patterns of participation in extracurricular activities, with women more likely than men to report taking administrative leadership positions in student organizations. Although most students acknowledged the importance of the professional and interpersonal skills that would have been developed in such roles, students rated these kinds of skills secondary to math and science skills. These out-of-classroom experiences may not have been as closely connected to the development of engineering knowledge (as reported by students) as other experiences that seemed more directly linked.

Confidence in math and science skills

In the Broader National Sample, confidence in math and science skills was predicted by self-reported GPA (for both women and men). We cautiously interpret this as indicating that this confidence was grounded in school-measured academic performance. Female gender and lower perceived family income were weak predictors of lower self-confidence in math and science skills, whereas URM status was not a predictor at all. However, in some cases, gender seemed to be a more significant factor than self-reported GPA, as even some women with high GPAs expressed self-doubts. In a series of interviews at the public, technically-

focused research university, we saw that some women with consistently high grades can still doubt their engineering ability and be uncertain about practicing engineering. Despite her high GPA, Leslie doubted she had all the skills she needed to be an engineer and grew to define her career goal in terms of taking a support rather than primary role. “[I] visualize myself not really actually doing the engineering itself. But, being the support to someone else who does it.” In Leslie’s case, though confidence did not deter her from attaining an engineering degree, it may have been a factor in the formation of her professional identity. (Matusovich *et al.*, *Competence in Engineering*, 2009)

In general, engineering is achieving relative success with respect to persistence in the major, as discussed in Subsection 2.2. However, Leslie’s case demonstrates one striking consequence of lower confidence in math and science skills that may be more prominent among women and may perpetuate gaps in professional achievement beyond the college years.

At the same time, our finding that race/ethnicity seemed not to influence confidence in these key skills is noteworthy. We recall that students were more likely to say gender rather than race/ethnicity played a role in their development as engineers. We also are reminded of William at the comprehensive, private university, who acknowledged that others may perceive his race to be a factor in his abilities as an engineer, but he did not internalize this message (see Subsection 2.9.3).

In the Broader National Sample, frequency of interaction with faculty, involvement in research, participation in engineering extracurricular activities, and exposure to engineering through co-ops, internships, and work experience all had no predictive power when it came to confidence in math and science skills. In addition, in the Longitudinal Cohort, we found no changes overall in the self-confidence measures we took over time. However, we did see the same gender gap in math and science skills confidence, as well as in confidence in open-ended problem-solving (Chachra and Kilgore 2009). What is it about the experiences of women that results in their continuing to have lower levels of self-confidence in math and science skills throughout the college years?

2.9.5 Engineering Design Knowledge, Conceptions, and Confidence

One explanation for the persistent gender gap in self-confidence may lie in women’s and men’s different conceptions of and approaches to engineering design work, as discussed in Subsection 2.6. Below, we discuss gender differences in these conceptions of and approaches to design, including potential links between these trends and the gender gap in self-confidence.

Gender and conceptions of design

When asked to identify the six most important design activities from a list of 23, first-year women in the Longitudinal Cohort were more likely than their male counterparts to include *Seeking information*, while less likely to select *Building* and *Prototyping*. Gender differences in the students’ fourth-year responses to the same question were similar, with women more likely to select *Goal setting* and less likely to select *Building*. (Chachra *et al.* 2008)

We recall that the opportunity to engage in hands-on activities in engineering was a stronger motivator for men than for women in the Broader National Sample. This finding is consistent with the tendency for men in the Longitudinal Cohort to think of engineering design in terms of hands-on activities, with women tending to consider management and planning activities as more important than men did. It may be that both women and men perceive engineering as a practical, hands-on endeavor, yet the work that is most valued by women is outside this dominant image.

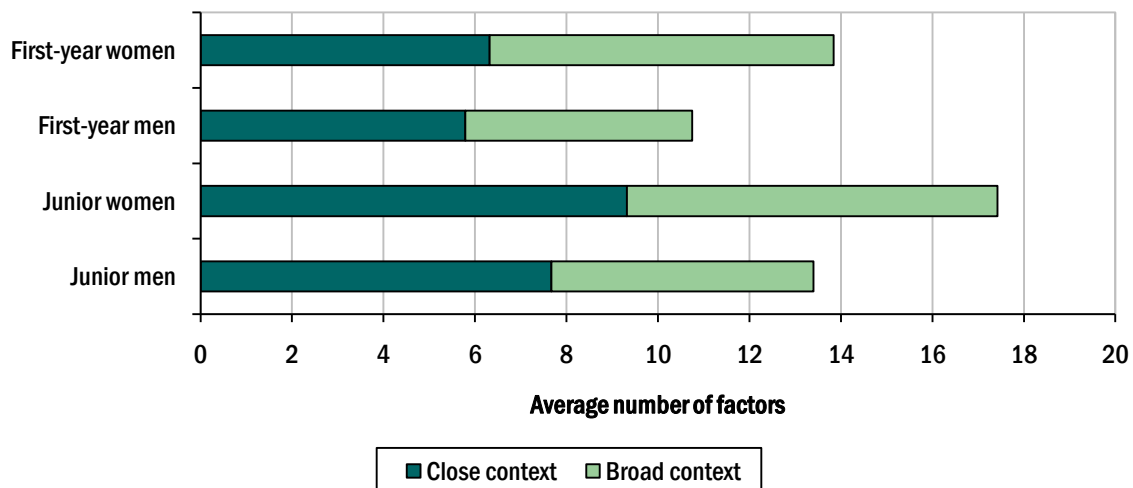
Gender and confidence in design abilities

In the Longitudinal Cohort, men reported higher confidence and course preparation to do design work than women in both the second and fourth years. These gender gaps are notable in light of the absence of gender differences in the reported frequency of engagement with the design activities in coursework (in either year). Taken together, these findings may suggest that there was a gender difference in the quality (if not quantity) of design education that students in this sample received. As discussed earlier in this subsection, it may be the case that women and men tend to take different kinds of roles in team assignments, similar to what we observed with women in administrative leadership roles in extracurricular activities. If indeed men tend to engage in the hands-on (and more directly visible) activities and women taking the less visible planning and project management activities—this could result in qualitatively different course experiences for men and women. An alternative interpretation of the confidence gaps is that women may hold themselves to higher standards than men when they consider their level of preparation. This interpretation is complemented by findings discussed previously in this subsection about women in the Longitudinal Cohort being especially concerned about representing their gender positively.

Gender and approaches to design

Above, we observed some differences in the ways in which women and men conceptualized engineering design. In addition to these differences in how women think about design, we observed that women were more likely than men to consider certain aspects of a design problem's broader context. When asked to list as many factors as they could think of that would be important in designing a retaining wall system to prevent flooding of the Mississippi River, women in the Longitudinal Cohort responded with more broad context factors than men in both their first and junior years (Figure 2.9-A; Atman, Kilgore, *et al.*, at Research on Engineering Education Symposium, 2008).

Figure 2.9-A: Average number of close and broad context factors in responses to the longitudinally administered Midwest floods engineering design task, by gender and year ($n = 79$). In both the first ($p < 0.01$) and junior year ($p < 0.05$), women's responses included more broad context factors.



There were similar gender differences in at least the first-year responses to another design task administered to the Longitudinal Cohort. When asked to select the kinds of information they would most likely need to design a playground from a specific list, women were more likely than men to select items associated with broad context: *Neighborhood demographics*, *Handicapped accessibility*, and *Utilities*. Conversely, they were less likely to select items associated with close context: *Budget*, *Material costs*, and *Labor availability and cost*. (Kilgore, Atman, et al., in *Journal of Engineering Education*, 2007)

Findings from the Midwest floods design task and the playground design survey question suggest that the women gave more attention than men did to the respective design problems' geographic, natural, and/or societal contexts. When it came to temporal context in the Street Crossing design task, however, there were no significant gender differences. Women and men were equally likely (or unlikely) to consider each of the life cycle stages that responses were coded for (Kilgore et al. 2010).

2.9.6 Post-Graduation Plans

There were two notable trends in post-graduation plans in the Broader National Sample. The first was that URM students were more likely to express an intention to attend engineering graduate school. Second, while similar percentages of women and men expressed an intention to get a job, men were more likely to focus on engineering jobs, while women were more open to non-engineering jobs as well.

Graduate school

Notably, engineering graduate school plans differed between URM and non-URM students. Among first-year students in the Broader National Sample, URM students expressed significantly more interest in attending engineering graduate school than did non-URM students (65% vs. 38%), and URM status was also a predictor of engineering graduate school plans among first-year students.

Among seniors, URM status was not a predictor when other factors were controlled, though a substantially larger proportion of URM seniors expressed plans to attend engineering graduate school, relative to non-URM students. What is feeding these differences in students' interest in engineering graduate school? How is the higher professional and interpersonal confidence and lower self-reported GPA of senior URM women coming into play? And why does the increased interest in engineering graduate school among seniors not translate into actual graduate school enrollment, as a gap remains between URM student representation in engineering graduate programs relative representation in bachelor's degrees? How can we better capitalize on high levels of interest among prospective URM majors in the first college year?

We note three other important points with respect to student diversity. First, senior URM women reported the highest mean level of professional and interpersonal confidence and the lowest mean self-reported GPA, relative to their senior peers. In the model of seniors' engineering graduate school plans, self-reported GPA was a positive predictor and professional and interpersonal confidence was a negative predictor of engineering graduate school plans. Are we losing some of these female prospective graduate students, because they believe that a lower GPA precludes graduate studies? Do they not see the value of social skills in engineering work, or, conversely, do they believe their social skills will have greater value in other disciplines?

A second important point is that senior URM students were more likely to consider multiple options that span engineering and non-engineering than were non-URM students (67% vs.

56%). This result could suggest that URM students have broader interests, and also that engineering as a profession may need to work to retain these individuals among its ranks (see Subsection 2.7).

Finally, our analyses suggest complex interactions between gender and race/ethnicity. Issues affecting women are not necessarily the same as those affecting URM students, although both demographic groups are underrepresented in engineering. More specifically, issues affecting majority (non-URM) women are not necessarily the same as those affecting URM women. Given the small number of URM women with advanced engineering degrees, these are questions that need to be addressed. They are particularly important as we work to diversify engineering faculty.

Engineering work

Similar percentages of women and men were planning on engineering and non-engineering work and graduate school. However, men were slightly more likely to focus on engineering only, while women were more likely to consider both engineering and non-engineering options. Further work is needed to understand not only how students conceptualize their future careers, but how conceptualizations may vary by gender, particularly given the underrepresentation of women in engineering careers.

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 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

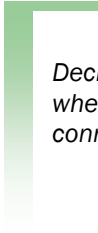
We hope the new insights about engineering student pathways gained through APS research, coupled with practice-related questions above, will facilitate reflection, stimulate discussion, and eventually inform action on your campus. The APS team has already engaged multiple communities in productive discussions 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.

3 Faculty Approaches to Teaching: Studies of Engineering Educator Decisions

In the Studies of Engineering Educator Decisions (SEED) thread of CAEE, we explored engineering teaching through a decision-making lens. Emphasizing decision making represents a relatively novel approach to studying teaching. Existing approaches for studying teaching include research to identify, validate, and promote effective teaching practices, as well as research on educator concerns and beliefs about teaching, and the types of knowledge involved in teaching. Our focus on educator decisions complements such work.

A decision represents the point where educator thinking connects with educator action, and the decision-making process represents a context in which educators can apply research findings about students (Turns *et al.* 2007). Decisions are also a site of professional responsibility. Conversations within the engineering education community about research-informed teaching can be understood as an assertion about one professionally responsible way to make decisions. Finally, decisions represent a cross-cutting approach to studying how engineering students are taught: Decisions that affect students are made not only at the classroom level but also in individual interactions with students, at the policy level, and in informal contexts (Huang, Eliot, *et al.* 2006).



Decisions represent the point where educator thinking connects with educator action.

In this work, we focused on educators' decisions by collecting and analyzing educator-provided narratives about specific decisions they had made and the processes they used to make the decisions. We then analyzed these narratives (hereafter referred to as decision narratives) to answer the research questions listed below.

- RQ1: How do engineering educators commit to action in teaching?
- RQ2: To what extent and in what ways do engineering educators enact effective teaching practices?
- RQ3: What are strengths and limitations in how engineering educators conceptualize students?

Below, we report on the analyses of the decision narrative data we collected from 31 engineering educators to answer these three questions. In each case, we provide rationale for the question, present our approach for addressing the question, share findings from the analysis, and discuss implications of the findings. In presenting results, we provide both an overall sense of the findings and additional detail (spotlight) on findings of particular interest. In discussing implications, we highlight (1) opportunities to *recognize* educators for what they are already doing and to *encourage* educators to try new things, (2) areas of *additional research* that are suggested by the results, and (3) opportunities for *critical reflection* associated with the results (Brookfield 1995).

In this section, we also address a fourth question that emerged as we were engaged in the work on the first three research questions. We address this research question using data that emerged from our efforts to address RQ1–RQ3 and a related synergistic project.

- RQ4: How can a focus on decisions and decision narratives be used in teacher professional development?

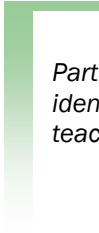
Our closing comments, which build on all of these analyses, focus on the use of decision narratives as a tool for research *and* professional development.

3.1 Approach

This work involved the collection of a data set that was analyzed in multiple ways. In this section, we describe how we collected the data, characterize the set of study participants, and provide overarching comments concerning the data analyses. Details on the analysis procedure for each question are located in the section devoted to the question.

3.1.1 Data Collection

We collected data through open-ended interviews with practicing engineering educators. The core of the interviews involved inviting participants to identify and then discuss two recent, relatively challenging teaching decisions. We specifically asked them to identify and discuss one planning decision (*i.e.*, a decision made in advance of meeting with students) and one interactive decision (*i.e.*, a decision made while in the act of teaching). The logic of the interview questions was guided by work on the Critical Decision Method (CDM) (Klein, Calderwood, and MacGregor 1989). CDM represents a method for acquiring information on the ephemeral process of decision-making. A main premise of CDM is that the decision-making process reported by a participant for a decision that is recent, memorable, and potentially difficult will reflect the actual process to a reasonable degree. Our emphasis on planning and interactive decisions was inspired by the work of Shavelson and Stern (1981). Asking participants to discuss decisions represented, for us, a way to get the educators to talk about their teaching in a specific and detailed way, rather than in general abstractions.



Participants were asked to identify and discuss two teaching decisions.

Because of a lack of precedent in the use of such interviews with engineering educators, we used a pilot study to gauge the reactions of engineering educators to our interview questions (Huang, Yellin, and Turns 2006). This pilot work confirmed the feasibility of asking educators about teaching decisions, but also demonstrated the need to include warm-up questions to help the educators think about their teaching in advance of being asked to select and then report on two specific decisions. To address this issue, the interviews also included questions about participants' teaching responsibilities in general. Information on the protocol is available in Subsection 6.2.2.

3.1.2 Participants

Thirty-one engineering educators at a large public institution in the Northwest participated in the research study. These participants volunteered to be in the study by responding to a solicitation e-mail that was sent to all engineering faculty in the College of Engineering. Participants represented 12 engineering departments at the institution, making up about 15% of the engineering faculty, collectively. In terms of rank, 12 of the participants were full professors with tenure, 7 were associate professors with tenure, 7 were assistant professors on a tenure track, and 5 were non-tenure track faculty. Four of the participants had high-

level administrative roles within the university in addition to their faculty appointments. Nine of the participants were female. All names used in this report are pseudonyms in order to protect the identity of the participants. Table 3-A provides detailed demographic information on the participants.

3.1.3 Data Analysis

Our primary unit of analysis was the participant, and we looked generally at what topics, issues, and themes were prevalent across the participants. The specific frameworks used for each analysis are presented in subsequent sections along with the findings.

Clearly, our research was tightly tied to (and limited by) the data we collected. First, because the data represented volunteer participants from one educational institution, treating the results as a starting point seems appropriate. Second, because the educators were asked to select teaching decisions without constraint, our analyses involved necessarily broad questions. A final consideration in interpreting the data is the nature of the relationship between what was said in an interview and what was “true” (*i.e.*, what they *said* they believed and what they *actually* believed, what they *said* they did and what they *actually* did).

Table 3-A: Demographics of educators who participated in SEED.

Gender	Position	Department
female	Assistant	Aeronautics & Astronautics
male	Assistant	Aeronautics & Astronautics
female	Assistant	Bioengineering
male	Full	Chemical Engineering
male	Full	Chemical Engineering
male	Full	Chemical Engineering
male	Full	Chemical Engineering
female	Assistant	Civil & Environmental Engineering
male	Assistant	Civil & Environmental Engineering
male	Associate	Civil & Environmental Engineering
male	Associate	Civil & Environmental Engineering
male	Associate	Civil & Environmental Engineering
male	Research Assistant	Civil & Environmental Engineering
male	Full	Computer Science & Engineering
male	Full	Computer Science & Engineering
male	Lecturer	Computer Science & Engineering
female	Assistant	Construction Engineering
male	Associate	Electrical Engineering
male	Associate	Electrical Engineering
female	Full	Electrical Engineering
female	Full	Electrical Engineering
male	Full	Electrical Engineering
male	Senior Lecturer	Electrical Engineering
male	Full	Industrial Engineering
female	Associate	Mechanical Engineering
male	Full	Mechanical Engineering
female	Assistant	Statistics
male	Associate	Technical Communication
male	Full	Technical Communication
female	Senior Lecturer	Technical Communication
male	Lecturer	Transportation

3.2 RQ1: Decisions and Commitment to Action

Our general interest in how engineering educators commit to action in their teaching was motivated by an interest in understanding how to help them make use of information from research, such as the information from the Academic Pathways Study (APS). Decisions, as points where educators commit to action, represent a context for making use of APS-like information or any other information available to educators.

In order to look broadly at the overall process of decision making (Turns, Huang, *et al.*, forthcoming), we analyzed the decision narratives in terms of how the educators did the following:

- **Reacting to decision making:** The educators' responses to the notion of decision making as a way to talk about teaching
- **Providing rationale:** The educators' abilities to provide a rationale for the decisions they identified
- **Collecting information:** The type of information the educators reported collecting in order to make decisions
- **Gauging satisfaction:** The level of satisfaction associated with the decisions

These dimensions are interesting in that it would be *easier* to support educators in improving their teaching practice if they recognized themselves as making decisions (because then they could be discussed), could externalize a rationale (because it could then be inspected, debated, extended, revised), engaged in more information gathering (because new information could be added), and were not completely satisfied with decision outcomes (because there would be a reason to iterate).

3.2.1 Results and Discussion

Below, we provide overall results concerning the decision making processes reported by the educators, followed by a spotlight on how the educators address "time" as a key element of their decision-making rationale.

Overall results

Reacting to decision making. The transition to the decision portion of the interview followed a series of warm-up questions concerning the educator's teaching responsibilities. Initially, most participants reacted to the transition to discussing decisions with a need for negotiation about what exactly was meant in order for them to recognize and focus on specific decisions. For example, one participant's initial reaction was, "That's really hard, because I don't know which type of decisions you're talking about," while another stated, "Well, that's a—that's a big, nebulous question." However, with clarification from the interviewer that we were interested in decisions broadly, all but one participant successfully transitioned to talking about a wide range of decisions. Three-quarters of the participants eventually committed to specific decisions that became the subject of the interview while the others identified a type of decision and talked about the type, but without reference to a specific instance. The one participant who was unable to make the transition to talking about decisions stands out because of his difficulty in mapping a language of decision-making to his teaching practice. Although he was willing to continue with the interview, he commented on multiple occasions about the dissonance between the language of decision-making and his own way of thinking about his activity. For example, early in the interview, in response to a question about

decisions, he stated, “I don’t view it [my teaching] that way.” At a later point, when asked whether a particular action could be considered a decision, he clarified, “It’s not a conscious decision.”

The decisions reported by participants were overwhelmingly decisions concerning a *group* of students in the context of a *specific teaching assignment*, mostly a class. At the same time, there were occasional references to decisions concerning interactions with individual students, as well as decisions concerning an approach to interacting with students across teaching assignments. Perhaps unsurprisingly, no participant reported decisions made outside of specific teaching assignments, such as decisions concerning admissions or curricular design. However, the absence of such decisions in the dataset is interesting. Does this lack of inclusion of decisions outside of specific teaching assignments suggest that such decisions are not considered “teaching” decisions, or is it that these types of decisions did not seem implied by the way the interview protocol was structured?

Providing rationale. All participants were able to provide some level of rationale for their decisions and mentioned a variety of factors as part of their rationale. Reassuringly, all participants alluded to student learning at some level. The types of additional factors mentioned by participants included time (31 of 31), departmental policies (25 of 31), interpersonal relationships (21 of 31), student ratings (18 of 31), physical space and facility support (17 of 31), funding for themselves (15 of 31), keeping themselves engaged (14 of 31), teaching assistants (14 of 31), promotion and tenure (14 of 31), financial resources for instruction (12 of 31), lack of knowledge about a topic (6 of 31), and failing to receive course materials from previous educators (4 of 31). There are many ways to organize these various factors. For example, while several of these factors could be represented as relatively neutral “resource constraints,” a large number of these factors were also very specific to the individual making the decision. This broad picture reminds us of the complexity of all decisions associated with teaching and how teaching decisions are not just about student learning.

All participants mentioned student learning as part of their rationale.

A striking feature of the rationale was the extent to which participants talked about prior, related decisions and the influence of those prior experiences on the current decision. Given the level of prior experience for most of the participants in our study, this feature of their rationale reminds us of the historically situated character of teaching decisions.

Gathering information. Participants mentioned a variety of sources of information as being useful to their decision making. For example, they talked about getting information from personal experience (31 of 31), colleagues (29 of 31), teaching centers (20 of 31), and student suggestions (16 of 31). While some did refer to making use of research (10 of 31), these references were vague. These counts represent instances where participants were specific about the source of their information. An interesting feature of the rationale provided by the participants was the number of assertions about students that were not linked to a specific information source.

Participants rarely mentioned educational research as a source of information for their teaching decisions.

Gauging satisfaction. When participants were asked about their level of satisfaction with their teaching decisions, five interesting patterns emerged. Participants spoke of not being

“optimally” satisfied but considering the outcome to be good enough (20 of 31), not being satisfied but also not having sufficient control to change the situation (19 of 31), not being satisfied but simply having to focus on something else (6 of 31), being satisfied but at personal expense (19 of 31), and being satisfied with no reason for additional change (16 of 31). Note that these five satisfaction categories are not mutually exclusive across participants since participants spoke of at least two decisions, and in some cases, spoke of more than two decisions. Evidence of emotion was a feature of the decision narratives that suggested underlying points of satisfaction and dissatisfaction. While the narratives overall had a neutral, detached quality, 28 participants spoke of positive emotions at some point, and 25 participants spoke of negative emotions at some point.

Dissatisfaction with decision outcomes was not always associated with a desire to improve the situation.

A noteworthy feature about their assessments of personal satisfaction was the limited information on which these satisfaction assessments were based. Participants reported basing their sense of satisfaction on some form of self-evaluation, such as their own sense of student engagement (27 of 31); feedback from students, such as direct feedback through student emails or discussions and indirect feedback through evaluating student performance on exams and assignments (25 of 31); and formal student evaluations, such as mid-term evaluations or end-of-term student ratings (21 of 31). Participants rarely mentioned peer teaching evaluations as a source of information for determining the satisfaction of specific teaching decisions (3 of 31). If dissatisfaction with outcomes can motivate change, perhaps the addition of information to create dissatisfaction could be a means for instigating change.

Spotlight: Time as an element of rationale

Time stands out as one of the elements of rationale mentioned by all participants. What makes time interesting, however, is the different ways that the educators in the study talked about time (Huang, Yellin, and Turns 2007). As expected, having limited time was frequently invoked as a constraint that precluded particular types of innovation, as in this example:

I think about the fact that people have different learning styles, and I don't believe in a single learning style...It would be great if you could teach every idea with every learning approach...but that's too time consuming.

As expected, having limited time was frequently talked about as a constraint on innovation.

However, time was also discussed in more nuanced ways. As we discuss below, participants in the study talked about time in terms of (1) specific time intervals that affect their teaching decisions, (2) types of time such as preparation time, (3) time as something that could be used more effectively through creative teaching decisions, and (4) time as a way to take students into account.

To elaborate, faculty characterized specific *time intervals* that function as parameters when thinking about teaching decisions. Examples of these time intervals included total number of hours in a term-long course, the minutes allocated to specific activities during a class session, the amount of time needed to grade or assess student work, and how much time faculty expected students to spend on specific activities. For example, in discussing how many group learning activities to include during the entire course, one participant stated, “I mean 50 minutes, one thing, you're done. And so you can't do that every week, you just can't.” Another participant, an assistant professor who was beginning his third year of

teaching at the university level, referred to the time interval of a *term* in his discussion of a new course that he was developing: “...something that you can teach in 10 weeks that’s worthwhile.”

Preparation time came up for some educators as a type of time of particular significance. For example, a full professor who carried a heavy administrative load in addition to research, teaching, and family responsibilities described a strategy for minimizing teaching preparation time, stating, “I’m sort of proud of myself. In 16 years I’ve only taught 3 different courses, which I think is a model of teaching efficiency in terms of prep time.” Another participant, an associate professor with eight years of teaching experience, echoed this strategy, describing the preparation time needed for a course he had taught several times as having “reached a steady state...that asymptotic area where my lectures are more or less under control. I can...show up an hour before lecture, organize my overheads...read my notes once, and show up, and I’m ready to give a good lecture.”

New faculty members in our study confirmed how some experienced faculty seemed to minimize the time they allocated to teaching preparation. For example, an assistant professor with two years of university teaching experience discussed the amount of time he spent preparing for his classes, compared with the amount of time that he thought more experienced colleagues spent preparing, stating,

I probably do more preparation for classes than a lot of instructors, at least the instructors I know, who are—some of them are experienced ones. Once you teach a class like 27 times, it’s really easy to wing it.

However, at least one experienced educator, a full professor with more than 10 years of teaching experience, reported spending a significant amount of time on preparation, saying, “You need to spend five hours at least to prepare for one good hour of teaching.”

While time was considered by many to be a significant constraint, some participants commented on ways in which they essentially *created more time* for their teaching. For example, some faculty members talked about blurring the boundaries between their teaching assignments and their research interests. Some talked about assigning class readings that would match their current research interest. A couple of participants talked about including classroom- and teaching-related issues into their research agenda (e.g., incorporating educational technology, new classroom assessment techniques). Others talked about teaching classes that only relate to their research interests, enabling them to optimize the time spent on both areas. In one specific example, an associate professor talked about choosing to teach classes that relate to his research interest and background:

...the courses I tend to choose to teach are courses that are related to my background, related to my interest, either laboratory or hands-on. The senior-level course is a new course that I had developed—the one I teach in spring—and that was based on my interests, started out as just materials, and gradually evolved toward the role of materials in construction and constructability, and so the senior course I teach is on reinforced concrete construction, and we talk about constructability issues—not just how materials affect it, but also understanding the whole process. But that I guess would be a decision. I decided to offer—to develop that course and offer it because it was kind of a continuation of my evolving interests.

Some participants talked about ways in which teaching decisions could be used to create more time.

On a different note, another participant, an assistant professor, talked about using alternative teaching approaches such as active learning activities to create time for herself during class periods. She then used the extra time to prepare and plan for the rest of the class sessions and to think of ways to steer students to the topic of the day:

Oh, it's a little bit funny, this active learning, because you—you give out the little assignments, and then you all of a sudden have nothing to do, you're waiting for them to think about it, and you want to kind of stay out of their way. And so I kind of step back, and sometimes I'll tidy up the classroom, or I'll look, you know, and see what's coming up and how I can organize the rest of the class, because sometimes—like on this topic, it's so condensed. I have a content issue with this particular topic, and so picking out some of the things that I think are most important. So I guess... I'm taking the time of active learning to actually then kind of formulate decisions for the remainder of the class.

Finally, in talking about time, faculty not only mentioned their own time, but also issues related to *students' time*. This involved being respectful of student time (e.g., whether to assign projects over major holidays, whether to assign field trips on weekends) and how time could be used to ensure student success (e.g., how educators in a department could work together to distribute exams over time in order to ensure students could adequately prepare for each exam, working to ensure there is enough time for students to “absorb” material). The following example from an associate professor not only illustrates an educator attempting to manage student time in order to promote success, but also suggests the amount of time that can be required for an educator who wishes to address such a concern:

Some participants considered issues related to students' time when making teaching decisions.

During the junior year, all of the students are taking the same sequence of classes, so there are 80 students in the same five classes, and I always tell them, I said, “You know, I'm going to work with all the teams that are teaching this quarter so that we don't all give you the midterm on the same day. You know, because that's like—that's a problem.” And they're like, “Okay, cool.” And so I send an e-mail to all the professors saying, okay, I'm going to give my midterm on the Wednesday of the fifth week or the fourth week or whatever. And some of them respond, some don't.

And so I had a case where like the professor announces two days before he was going to do his midterm on that same day, after I had already asked him, you know, to try to work with me on this. And so I communicated with him, and I said, “You know, I contacted you with the e-mail, I tried to sort this problem out, and then you end up assigning it on the same day.” And he says, “Well, when I was a graduate student”—of course, the guy is like 70 years old—“When I was a graduate student, we had to do all our tests on the same day. There's no reason why they can't do it,” blah, blah, blah, blah, blah, blah, blah. I'm like this is [...], because you know that if they do two midterms on the same day that they're going to be less prepared for one than the other, so, I mean why put them through that? We want them to do as best as they can in each class. It doesn't make any sense.

It's just like—kind of punish them, like a hazing ritual or something like that. And so—well, that's what it really is, you know. And so I went back to the students, and I said, “Okay, he changed his date to my date. I talked to him about it, he's inflexible, so I'm changing my date, at last second.” So then I turned mine from Wednesday to Friday.

And then I said, “Don’t tell him I did that, because he’ll change his to Friday, you know.” I was just pulling their leg, but, you know, the students appreciated the fact that I was willing to work with them, you know.

3.2.2 Implications

The educators we interviewed deserve *recognition* for being able to articulate a rationale for their decisions. It also seems useful to acknowledge that educators may not always be in a position to make changes to their teaching, even when they themselves are personally dissatisfied. At the same time, while the existence of rationale is a starting point, educators should be *encouraged* to think more critically about their rationale.

In terms of *research*, each of the four points of our analysis (reaction, rationale, information, and satisfaction) represents a point for further research. For example, what is the space of actions in teaching for which educators are aware of making decisions? What are the limits of this awareness? What specifically are desirable qualities of effective rationale? What does it mean for an educator to have the capacity to use research about students to inform teaching? How do we help educators develop the capacity to use research in this way? What would happen to educator decision making if there were more information on which educators could gauge their satisfaction with their decisions?

What does it mean for an educator to have the capacity to use research about students to inform teaching decisions?

In terms of *critical reflection*, we note that visions of expertise are often associated with experts having a great deal of knowledge and expert activity as often involving very little conscious reflection. As a result, perhaps expert teachers would be less aware of their decisions. From a critical reflection perspective, however, it is important to think about the types of assumptions that are embedded in a decision-making process that is tacit and fluid, as well as considering which students are benefitting from such a decision-making process.

3.3 RQ2: Decisions and Effective Teaching Practices

Our general interest in the use of effective teaching practices was motivated by the body of research that seeks to identify, validate, and share effective teaching practices. Information that benchmarks the use of such practices seems helpful to efforts to promote such practices. For example, understanding how much and in what ways a particular teaching practice (e.g., cooperative learning groups) is being used by educators can be helpful to faculty developers wishing to promote the practice, educators considering the practice or trying to make sense of their own activities, and researchers seeking to conduct research to better understand the practice. Work that focuses on such benchmarking is emerging—e.g., Pembrige and Paretti (2010) surveyed capstone instructors about their teaching practices, Cox and Courdray (2008) developed a tool for observing teaching practice—but such efforts are limited.

Our initial work in this area started with the observation that the interviewed educators, regardless of which decisions they were discussing, made reference to helping students connect topics to the “the real world” (Yellin *et al.* 2007). As we probed this observation, we became drawn to the general issue of the ways in which the educators might be positively influencing student motivation to learn. This thread led to a second phase of exploratory work, in which we sought to map ideas from both theoretical and empirical work on what

motivates students to the activities reported by the educators. This inductive analysis (in which undergraduate, masters, and Ph.D. students worked alongside research scientists and practicing educators) demonstrated the promising nature of looking at our data through a motivation lens (Turns, Gygi, and Prince 2009).

In transitioning to a comprehensive analysis of this issue, we identified the work of Wlodkowski and Ginsberg (1995) as offering a broad framework that not only links teacher activity to student motivation to learn but also embeds an emphasis on creating environments that help *all* students develop such intrinsic motivation to learn (Turns, Gygi, and Prince, forthcoming). Based on a synthesis of work on motivation, the Wlodkowski and Ginsberg framework asserts that educators can help all students feel intrinsically motivated to learn material by engaging in four practices:

- **Establishing inclusion:** Creating an inclusive environment through *respect* toward all students and *connectedness* with students
- **Developing attitude:** Helping students develop a positive attitude toward material through *relevance* and *choice*
- **Enhancing meaning:** Helping students to establish meaning of the material through *engagement* and *challenge*
- **Engendering competence:** Engendering student competence through *authentic* assessment procedures that help students see their growing *effectiveness* in doing something the students themselves find to be personally important.

Analyzing our data relative to this framework consisted of determining, for each practice, the number of educators who reported activity that can be mapped to the practice (the prevalence) and patterns in how the practice was addressed (e.g., specific approaches, reported challenges). Because we did not ask directly in the interviews about either the term “motivation” or any of the specific teaching practices listed above, the results may underestimate the extent to which these issues are present in educators’ teaching. While none of these items were explicitly requested in the interview protocol, the interviews were rich with information related to these issues.

3.3.1 Results and Discussion

Below, we provide overall results concerning how the educators engaged in teaching practices associated with enhancing student motivation. We then spotlight two aspects of these results: the ways the educators emphasized relevance (which is associated with the “attitude” practice) and the ways in which the educators emphasized connectedness (which is associated with the “inclusion” practice).

Overall results

The results revealed significant variation in the prevalence of the effective practices identified by Wlodkowski and Ginsberg:

- **Establishing inclusion:** *Connectedness* practices were prevalent (mentioned by a majority of participants), while *respect* practices were much less prevalent.
- **Developing attitude:** Practices concerning attitude were similarly unbalanced. All participants made at least one reference to *relevance* (an expected finding, given the earlier analyses concerning references to the “real world”), while few mentioned anything to do with *choice* or autonomy (with most allusions having to do with student choice in projects).

- **Enhancing meaning:** Most participants mentioned practices related to both challenging and engaging students. References to *challenging* students were frequently to the specific issue of choosing projects or the more general issue of knowing how hard to push students. Practices related to *engaging* students were described as serious activities but were also associated with making the class fun.
- **Engendering competence:** We found no allusions to authenticity and effectiveness as characterized by Wlodkowski and Ginsberg. In fact, there were few allusions to any type of effort to help students demonstrate their competence (i.e., few allusions to assessment). One might reason that such a finding was due to the fact that we did not explicitly ask participants about assessment. However, if assessment is a critical element of teaching, then one would expect such issues to have appeared in a data set about teaching.

Spotlight: *Relevance as a pervasive concern*

To illustrate the findings, we talk first about the practice of making instructional material relevant. The prevalence of actions related to *relevance* was not a particularly surprising finding. Engineering is widely considered an applied activity, and concerns about the relevance of material would be a logical component of the applied nature of engineering.

Relevance was raised by all of the participants in this study in some form. Strategies for making topics relevant included (a) thinking about real-world expectations, (b) using projects anchored in an actual example, (c) linking the topic being discussed to actual examples, (d) leveraging departmental core competencies or professional accreditation requirements, (e) basing decisions on what is believed to be important in the future and in engineering, and (f) considering issues of within-school relevance (e.g., this is relevant because it will be on the test).

One of the most frequent themes was how faculty emphasized real-world expectations for what engineers need to do in the workplace as a way to motivate students to become prepared. For example, one participant talked about telling students, “It’s a matter of what’s acceptable, professional conduct once you leave this institution, and it’s my job to prepare you for the real world.” Another participant’s concern for relevance was more behind-the-scenes: “I hope we can help students...making decision[s] in the face of imperfect or incomplete information, which is, you know, life as a professional anywhere.”

The educators in the study also focused on connecting to “real-world situations” as a means of establishing relevance. For example, one participant noted, “Well, I thought the fact there was this obvious case study that people were familiar with would also give it a little more immediacy.” Another stated this idea more generally: “I try and tie it in to very—and this is a term that is way overused in the universities, but—real-world situations. Our students, a lot of engineering students, tend to respond really well to that.”

Another dimension to helping students see relevance involved more direct connection of student performance with some aspect of the future activity, such as in this example:

So I said, “[Student name], that was a very nice solution. You’ll be pleased to know that’s exactly the way the problem was solved and that led to a patent...” So you want to build up in the students a confidence that they can solve problems.

All participants made at least one reference to helping students see the relevance of instructional material.

Spotlight: Connectedness as a surprising concern

Interestingly, practices related to establishing *connectedness* were (like relevance) raised by almost all participants in the study. Wlodkowski and Ginsberg (1995) explain connectedness in the following way: “Connectedness in a learning group is a sense of belonging for each individual and a felt awareness that one is cared for and one cares for others” (p. 63). Practices related to connectedness included those directly related to caring, as well as practices related to listening and responding to students.

Practices related to establishing connectedness were (like relevance) raised by almost all participants in the study.

Multiple participants spoke both directly and indirectly about caring for students. For example, one educator asserted directly that he cared about students, although he wondered whether students really understood that he cared. Other educators demonstrated a caring attitude by expressing concern for students’ emotional states (e.g., “distinguishing the students who have an actual difficulty”) and by expressing concern about fairness. Additional actions linked to caring and connectedness included learning students’ names, keeping in touch with them after the term ends, empathizing with students’ struggles (including making comparisons to the educator’s own experience), and being concerned about their mental states and stressors. The following passage is an example of an articulation of caring:

There’s no time. And so what am I going to do? But I think I learned from parenting that what to do with that is devote your full attention to that student’s problem, to the extent that you can, and really walk them through it, even though it’s not scalable. Because what they do, they show you a sort of really dependent, needy side of themselves, but if they get the message that you care and will be there to back them up, then they can sort of flip to this “I don’t need your help” state.

Participants also spoke of listening and responding: examples included attending to students’ level of attention, understanding, and engagement; being responsive to student requests for accommodations or extensions; and soliciting feedback through formal and informal means. Eliciting feedback and gauging the classroom environment in terms of students’ moods and other psychological characteristics and then adjusting the activity accordingly were frequently discussed activities.

A majority of participants spoke about listening to students by asking for feedback and making the elicitation of feedback a priority. They also spoke of different mechanisms for getting feedback. For example, Linda talked of getting feedback in a relatively expected way: by handing out index cards and asking students to provide information on the cards. Other efforts to get feedback were more informal, such as one participant’s comments about “reading body language, looking at eyeballs, just you can feel the class” to see if the students were continuing to follow the lecture. Another participant highlighted the importance of prioritizing the act of listening: “You have to be accessible to students, and you have to get them to come talk to you, because if they don’t come talk to you, you don’t know what you’re doing wrong, you don’t know where you’re failing them, and that’s frustrating to me.”

While listening can be considered an important part of connectedness, it is arguably the act of responding to what is heard that contributes to conditions of connectedness. Here again, the majority of participants spoke of ways that they responded to what they heard from students—such as stopping a lecture and providing an example, adjusting class activities based on student responses to quiz questions, and changing due dates for a project. One participant did express concern about the extent to which an educator can be responsive:

So, yeah, I am, too...to a fault, I'm much too responsive to my own...you know, it's not good for me. I mean I...you know, if you're sending [discussion forum posts] at 11:30 at night, and then you're up on the computer at 6:30 the next morning sending [posts], there's a little bit something wrong, but that's just how I did it.

3.3.2 Implications

It is encouraging that engineering educators are already addressing issues of relevance as part of attitude, connectedness as part of inclusion, and challenge and engagement as part of meaning. At the same time, this analysis suggests that engineering educators should be *encouraged* to think about issues of respect as part of inclusiveness, issues of autonomy as part of attitude, and issues of authenticity and effectiveness as part of competence, as these issues came up less frequently in the data set.

Researchers interested in building on this work could pursue the issue of autonomy in engineering education by exploring what exactly makes autonomy so challenging (e.g., the curriculum is too constrained, educators do not believe students are capable of autonomy). Similarly, researchers could further probe the findings concerning assessment by asking, for example, what is the prevalence of the types of assessment practices that Wlodkowski and Ginsberg highlight? More generally, how should the limited references to assessment in our data be interpreted?

Researchers interested in building on this work could pursue the issue of autonomy by exploring what exactly makes autonomy so challenging.

A key issue for *critical reflection* would start with the question of whether the educators' practices are actually having the intended effect on students (e.g., are students actually seeing relevance, are students actually engaged), and move to a more critical focus on the ways in which different groups of students are benefitting.

3.4 RQ3: Decisions and Conceptions of Students

Our general interest in how engineering educators conceptualize students has been motivated by the ideas of student-centered or learner-centered teaching as described in the teaching literature. Student-centered or learner-centered approaches to teaching are considered to be normatively desirable and characteristic of expert teacher activity. Connecting to our work, it seems that the ways in which an educator approaches being student-centered or learner-centered would be related to how that educator conceptualizes students.

In initial exploratory work, we focused on how a subset of the participants talked about students (Turns *et al.* 2008; Yellin, Turns, and Huang, 2008). Noting that much of the talk about students took the form of assertions, we explored the connection between this aspect of our data and published work on "personal practical theories" (Yellin, Huang, *et al.* 2008). As we progressed in these exploratory efforts, we were drawn to the prevalence of statements in which educators differentiated among students. Since the issue of how educators differentiated among students represented a broad topic with potential connection to diversity and inclusiveness in teaching, we decided to explore this further (Sattler, Turns, and Gygi 2009; Sattler and Turns, forthcoming).

In this analysis, we asked the question, *How do engineering educators differentiate among students in the context of talking about teaching decisions?* To address this question, we developed a conceptual framework consisting of four dimensions by which educators could differentiate among students:

- **Knowledge:** What students know (e.g., the extent and nature of prior knowledge, level of understanding of course content, whether students have misconceptions)
- **Behavior:** What students do (e.g., asking questions, coming to office hours)
- **Educational classification:** A grouping assumed to be relevant to the educational system (e.g., the visual learners, the juniors)
- **Demographic classification:** A grouping related to demographic categories (e.g., by gender, ethnicity)

This analysis involved filtering the data for places where the educators had differentiated among students (based on linguistic cues) and classifying the instances of differentiation according to the four dimensions of the above framework. We then summarized the data by determining the *prevalence* of differentiation based on each dimension (*i.e.*, the number of educators who had at least one instance of differentiating based on the dimension), as well as *patterns* in the instances of differentiation associated with each dimension. As with motivation, participants were not directly asked about how they differentiated students in the process of making their decisions or even how they took students into account in making the decisions. Our premise (again, following the Critical Decision Method) was that, if such issues were important parts of the process that educators had used to make their decisions, they would report on these issues. Indeed, we found that the interviews were rich with information related to differentiation.

3.4.1 Results and Discussion

All of the educators in the sample differentiated among students at some point in their decision narratives. Below, we provide overall results concerning *how* the educators differentiated students in the teaching narratives that they provided. We then spotlight two aspects of these results: the pervasive use of academic rank and disruptive behaviors as a means to differentiate students.

Overall results

The prevalence of differentiating based on each dimension varied.

- Eighteen out of 31 educators differentiated students based on knowledge. These differentiations often involved assertions structured as binaries (e.g., students knowing or not knowing something). An interesting feature of these differentiations was how generic they often were (e.g., students “getting it” or “not getting it”).
- Behavior was the most prevalent basis for differentiating among students; 27 out of 31 educators differentiated students based on behavior.
- Many of the educators also had at least one instance of differentiating among students based on some type of educational classification (22 of 31 educators). Much of this type of differentiation was based on class standing or academic rank (e.g., freshmen, graduate). Students were also differentiated based on their educational pathway and their discipline.

- Finally, 14 out of 31 educators differentiated based on demographic classification. The specific classifications varied (e.g., “naval officers,” “Chinese,” “Asian,” “ROTC,” “Mexican,” “American Blacks,” “foreign students,” and “women”). None of these classifications was particularly prevalent; in fact, many of these groups were each mentioned by only one educator in our sample. No educator differentiated based on socio-economic status.

Spotlight: Academic rank as a pervasive basis for differentiation

The prevalence of differentiation based on academic rank (15 participants), while not surprising, is arguably interesting. The specific basis of such differentiations did vary: non-majors vs. majors, advanced students vs. remedial students, lower classmen vs. upper classmen, and undergraduate vs. graduate. However, the most prominent differentiation was undergraduate vs. graduate.

As the educators compared and contrasted the similarities and differences between the various populations, they often made assumptions about what students are capable (or not) of doing. For example, one educator said, “I think graduate students are a little more flexible than undergraduates in terms of what they’re willing to do.”

Another educator further used academic rank to assess students’ abilities:

Yeah, their knowledge level and where they are in their degree program. So if I’m teaching an undergraduate course for students that are just coming into the program, they’re at a different level. They need, in my view, they need some stepping stones.

Similarly, another educator described differences between what students are capable of doing based on their academic rank—juniors and seniors versus freshmen and sophomores:

I expect that that there’s going to be a divide. There’s going to be the juniors and seniors who already have a lot of experience doing these type—doing this type of writing that are going to do fine at this, and then there’s probably going to be a couple students who are freshman and sophomores who struggle a little bit more with being able to do everything at once.

Spotlight: Disruptive behavior as a pervasive basis for differentiation

A somewhat surprising finding was the prevalence of differentiation based on disruptive behavior. In all, 18 educators made differentiations among students that involved disruptive student behavior. Further, when the educators started discussing these behaviors, they tended to focus on the event, returning to the issue multiple times throughout the interview. For example, educators described disruptive behaviors of “talking,” “giggling,” “being argumentative,” “being resistant,” as becoming or being a “distraction” and “disruption.” Most of the time, these assertions were quite general, without elaboration or further development (e.g., “argumentative”). Others were quite specific and descriptive in nature: “The things that distract from the flow are arguments about...‘I needed a half a more point on this,’ or ‘Why did you knock off this’...”

In all, 18 educators made differentiations among students that involved disruptive student behavior.

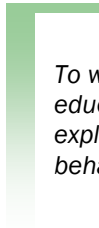
3.4.2 Implications

The results of this work suggest that faculty developers and others that work with engineering educators should *recognize* that engineering educators are sensitive to some ways in which students differ, since being aware of and responding to student differences represents a form of student-centeredness. At the same time, the results suggest that educators should be *encouraged* to think more about the ways in which differentiating among students based on student knowledge could be made a more central element of teaching practice.

This research suggests a variety of areas for future *research*, all of which are related to *critical reflection* issues of fairness and equity. For example, researchers could further explore the issue of what educators believe to be important characteristics of students at specific academic levels. Additional questions in this area could include the following: How aware are educators of their beliefs? How do educators take into account the idea that those beliefs do not apply to all students? To what extent do such beliefs create self-fulfilling prophecies, because educators make instructional decisions based on their beliefs? Also suggested by our data,

researchers could explore the extent to which educators consider a range of explanations for student behavior (e.g., why are students behaving in ways that are being labeled disruptive). This type of analysis could probe into what educators are assuming about student behavior when they are not explicitly seeking explanations, and how such assumptions might disproportionately impact some students.

Researchers could also explore a possible explanation for part of the pattern in our analysis: the possibility that educators differentiated among students based on what is most visible to them (e.g., behavior, academic rank). If visibility explains the pattern of differentiation we saw, then educators could be supported in more sophisticated differentiation efforts by data that makes visible the basis for other differentiations. Finally, another line of research could seek an explanation for the lower prevalence of differentiating based on knowledge. While one could sustain that the limited prevalence of differentiation based on knowledge was the result of our protocol (*i.e.*, we did not ask about differentiating based on knowledge, and perhaps the educators just identified decisions for which knowledge was not relevant), such a position seems, at minimum, worth closer examination, since student knowledge is arguably fundamental in all teaching.



To what extent do engineering educators consider a range of explanations for student behaviors?

3.5 RQ4: Decisions and Teacher Professional Development

In starting this work, we did not set out to document how the process of collecting and analyzing decision narratives could itself be a form of professional development. Nevertheless, information in this area emerged as we conducted the work. In this subsection, we identify three stakeholder groups who may have benefited from this research: the researchers who analyzed the data, the researchers who collected the data, and the educators who were interviewed. For each stakeholder group, we identified a data source that may contain insight, and we explored the data for links between the data and general issue of professional development concerning teaching.

3.5.1 Benefits to Those Individuals Who Analyze Data

We involved a number of people in our data analysis effort. In particular, at two points in the process, we organized a for-credit research group on the University of Washington campus in order to enlist the aid of various students (Larson *et al.* 2009; Gygi, forthcoming). As it turned out, this not only extended our capacity for analyzing the data, but also gave us a chance to think about how analyzing such data could help participants gain insights into teaching.

As a final assignment in the second for-credit research group, participants reflected on what they had learned as a result of participation in the group. Further, because the group had been advertised as a general opportunity to learn to analyze qualitative data, it was not expected that participants would talk about what they learned about teaching. However, six of the ten participants alluded to insights concerning teaching.

One of the three Ph.D. students, a student with a significant amount of teaching experience, included insights concerning teaching in her reflection. In particular, she reported that the process gave her a “new perspective on engineering educators.” She also reported that the opportunity gave her a chance to reflect: “I found myself often reflecting on my own teaching decisions as I read the transcripts and questioning how I motivated my students or considered their differences.”

“I found myself often reflecting on my own teaching decisions as I read the transcripts and questioning how I motivated my students or considered their differences.”

Two of the three masters students in the group included insights concerning teaching in their reflections. One reported that she now saw “educators as designers” and had become “more reflective about [her] own teaching practices.” The second student (a student with no teaching experience) reported on how the activity had caused him to recognize and reflect on a variety of his own assumptions about teaching and his own educational experiences. In his words,

To be honest, I just thought that there were good instructors and not so good instructors... I have always considered motivation, especially academic motivation, as an intrinsic quality that was either an advantage or disadvantage for individual students. Also, I never assumed that instructors and professors cared about student motivation... I was surprised in the way that the instructors in the transcripts discussed student motivation, even though the word was rarely mentioned directly. Student motivation was a deeper concept than I initially considered, and it made me think of some of the assignments, interactions, and decisions made by professors and instructors during my undergraduate days.

Three of the four undergraduate participants also made comments concerning teaching. In contrast to the experiences of the graduate students, which involved reflecting on their own experiences, the comments of the undergraduates emphasized simply being exposed to, and reassured by, the teachers’ perspectives. For example, one stated that “it is interesting to know that some really care about the students.” A second noted that

...as a student, I always had the opportunity to rate the teachers and just sit back and not know whether any of my suggestions were being implemented or not. However, by being a member of this research, this time, I got to sit back and read what the teachers said and whether any of the suggestions got implemented at all.

Finally, a third undergraduate noted that “the transcripts were a fascinating way to examine what teachers were doing, if anything, to motivate student learning.”

In follow-up interviews, Gygi (forthcoming) found that all of the doctoral students found the experience to provide an opportunity to reflect on teaching and also an opportunity to identify new practices to explore. In fact, two of the doctoral students participated in the group because they wanted to learn more about teaching. One commented that the interviews were an excellent source of teaching insight, and the opportunity to analyze the transcripts in a collaborative environment was a valuable professional development opportunity.

3.5.2 Benefits to Those Individuals Who Collect as Well as Analyze Data

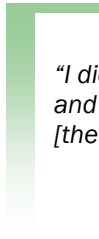
Given the emerging insights into how the analysis of decision narratives was helping participants gain insights into teaching, we decided to explore the feasibility of having graduate students collect such narratives. Thus, as part of a graduate course called “Advanced Studies in Design Thinking and Knowing” (taught by Dr. Jennifer Turns and Dr. Mark Zachry), we asked ten students to identify design educators who they admire and interview the educators about their approach to teaching design, including key decisions that they had made. As a class, we constructed an interview protocol and then helped class participants make decisions about who to interview. Then, each class member worked to arrange and conduct an interview, prepare and present a short report on what had been learned, and then participate in a discussion concerning the results.

All students successfully navigated the logistics of the activity: identifying educators, setting up interviews, and getting their respondents to talk about their teaching. In subsequent reflections on the activity, students reported not only on their enthusiasm for the activity (e.g., “I thought the discussion following our interviews was really interesting, and it’s too bad we can’t take those questions we all wrote up and discuss further.”), but also on the specific kinds of insights that they gained from their individual interviews and collective discussion. It appears that the interviews raised fundamental questions for the students such as the following: What counts as design? (“One of the ideas that stuck in my head was that of what constitutes design,” and “how hard of a time I had fitting [this educator]’s ideas of design into our reading—before the interview I expected this process to be simple.”) To what extent can design be taught? What are best practices for design education? Are tools and general techniques for design education separable or inseparable?

3.5.3 Benefits to Interviewee

If both conducting and analyzing the interviews can play a role in professional development concerning teaching, then it is valuable to consider the extent to which simply being interviewed can serve a professional development function.

Since we did not have this question in mind when we conducted our interviews, data to support this proposition are limited to statements volunteered by participants. A small amount of such data does exist. For example, one participant stated at the end of the interview that “it helps me think about my teaching to interact with someone like you.” Another participant was not as direct but did note, “I think it’s a very interesting interview, and the questions you raised are very key and very interesting.” Another participant, who also helped our recruiting by distributing our solicitation e-mail, added the following when she distributed the solicitation: “I did one of these interviews, and the opportunity to talk with [the interviewer] was invaluable.” More generally, it was interesting to see how many people volunteered to be in the study, and how generous they were with their time.



“I did one of these interviews, and the opportunity to talk with [the interviewer] was invaluable.”

While such evidence is clearly anecdotal, there is substantial theoretical reason to be interested in the benefit of such interviews to the participants themselves (e.g., Brookfield 1995). As a result, future researchers who engage in this type of research are encouraged to consider exploring this in greater detail.

3.6 Summary

Decision narratives collected with the Critical Decision Method are powerful tools for advancing teaching in engineering education. In this body of work, we used decision narratives to investigate multiple questions:

- In analyzing the decision narratives to better understand educator decision-making (see Subsection 3.2), we found that most of the educators we interviewed reacted positively to the emphasis on decisions and decision making, and that all were able to provide a rationale for their decisions (with both time and allusions to prior decisions as common features of their rationale). We also learned that the participants collectively mentioned a variety of sources of information as being useful in decision making (although research was infrequently mentioned as a source), and we identified five patterns in terms of satisfaction with their teaching decisions.
- Looking beyond their decision processes and towards what additional information the decision narratives could reveal, we analyzed the narratives to explore educators' use of teaching practices that are considered effective at helping students develop intrinsic motivation to learn (see Subsection 3.3). In this analysis, we found that engineering educators reported using a variety of teaching practices that are known to increase student motivation to learn, such as helping students see the relevance of material, helping students feel connected to the learning group, and helping students experience productive levels of engagement and challenge. We found less frequent mentions of providing students with opportunities for autonomy, enabling all students to feel respected, and providing students with opportunities to demonstrate their growing competence.
- Driven by the broad issue of how engineering educators conceptualize engineering students, we analyzed the decision narratives to learn more about how engineering educators differentiate among students (see Subsection 3.4). In this analysis, we found that all of the educators differentiated among students at some point, that student behaviors were the most prevalent basis for differentiating among students, and that differentiation based on other dimensions (what students know, their educational classifications, their demographic classifications) was also prevalent but less so.
- In addition to these analyses, we also investigated the benefits of engaging in research on teaching decisions (see Subsection 3.5). Here, we reported evidence to suggest that engaging in research on teaching decisions has professional development benefits for the individuals who analyzed the decision narratives, the individuals who collected the narratives, and even the educators who were asked to provide the narratives.

In our analyses, we focused on broad questions because we collected data on a broad set of teaching decisions. Innumerable variations of this work could focus on collecting decision narratives relative to a wide variety of specific constraints (e.g., decisions about assessment, decisions about student projects, decisions about working with first-years).

We propose that the outcomes of this research may be useful for faculty development personnel in helping them to better understand their faculty clients. Additionally, decision narratives themselves might be used by faculty developers to initiate fruitful discussions with faculty on problematic teaching issues.

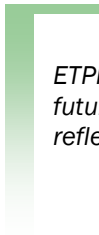
An exciting feature of the use of decision narratives in research is the idea that the process of doing the research is potentially significant for all parties involved (Subsection 3.5). Our tentative results about these benefits should be further validated.

In moving forward, there are opportunities to bring these ideas together—for projects featuring not only collection and analysis of decision narratives in specific domains but also active efforts to leverage (and document) the collection and analysis activities as professional development efforts.

4 *A Focus on Teaching: Engineering Teaching Portfolio Program*

The Engineering Teaching Portfolio Program (ETPP) was designed to assist future engineering faculty (primarily graduate students and post-doctoral researchers) in developing a teaching portfolio. The program was also designed to encourage participants to reflect on teaching, which could in turn increase their knowledge about teaching, alter their attitudes, and lead to changes in their current or future teaching practices.

This work was motivated by national interests in promoting effective teaching in engineering and in better preparing future faculty for teaching responsibilities. In addition, our emphasis on preparing graduate students for teaching responsibilities is similar to the emphasis of two other components of CAEE: preparation of future engineers (Academic Pathways Study) and the preparation of future researchers (Institute for Scholarship on Engineering Education). In developing ETPP, we sought to complement other means by which graduate students become prepared for teaching careers (e.g., actual teaching assignments, campus-level courses on teaching, workshops associated with professional meetings, how-to books). We also sought to develop an experience that would be valuable to all participants, regardless of their teaching experience.



ETPP was designed to encourage future engineering faculty to reflect on teaching.

This work consisted of an iterative, research-based design process; program offerings at two universities; and a formal program evaluation exploring impact on participants. The primary work with the Engineering Teaching Portfolio Program spanned the period from 2003 to 2006. Interest in this program (as measured by downloads of the materials from the CAEE web site) continues to this day.

4.1 The Program and Its Development

The Engineering Teaching Portfolio Program provides participants with the opportunity to examine, reflect, and revise their beliefs and goals as teachers through a series of eight weekly meetings consisting of portfolio development exercises and peer review of drafts of portfolio components. The exercises include identifying portfolio design specifications, developing and revising a teaching statement, identifying and annotating teaching artifacts, developing a diversity statement, compiling a complete draft portfolio, and outlining a professional development plan. The ETPP is designed to be peer-led and peer-focused. Participants rotate the leadership role for each session and facilitate the sessions without supervision by faculty or professional staff.

Key features of this program include the following: (a) a focus on graduate students, (b) a series of activities that collectively help students develop a teaching portfolio, and (c) a peer-led structure. The program contains these elements for three primary reasons. First, we have an interest in helping improve the flow of graduate students into faculty positions in engineering. The program content and products are designed to meet the needs of graduates entering the academy. Second, our goal is to develop a scalable model for working the pipeline issue nationally. The peer-facilitated structure is cost-effective, because it does not require significant institutional commitment of fiscal or human resources. Third, engineering graduate students are more likely to participate in a program that has been customized to engineering. Our program is product-oriented and designed to help prepare participants for the academic job search.

Two additional distinctive features of our program are the emphasis on peer review as a key program activity and the requirement that participants create a diversity statement. Concerning peer review, the program includes time for participants to engage in peer review of their teaching philosophy, their annotated artifacts, and their diversity statements. This emphasis on peer review is not simply a means to help participants improve their documents but also a context for participants to share experiences, a means to trigger meaningful discussion about experiences, and an opportunity for participants to question fundamental ideas related to teaching. The diversity statement is also a defining feature of the program. Participants are asked to discuss diversity in teaching, prepare a statement concerning how they address diversity in their teaching, and then engage in peer review of these statements. A review of teaching portfolio initiatives at other institutions around the nation suggested the distinctiveness of these program elements (Yellin *et al.* 2006).

4.1.1 Development Process

We used an iterative, research-informed process to develop the program's curriculum and supplemental materials. Data collected during program offerings provided the basis for case studies of the peer review processes and the activities related to the diversity statement. The data also allowed us to gain insight into participants' conceptions of central topics (*i.e.*, teaching and diversity). We used information from these analyses to refine the weekly guides and develop the supplemental materials. We also published the results of these analyses, so they would be available to others engaged in similar work. These studies are briefly summarized below:

- In (Turns, Yellin, *et al.* 2006), we presented a detailed analysis of the conversation of one ETPP group during the diversity statement components of the program (*i.e.*, the introduction of the diversity statement and the subsequent peer review of participants' draft diversity statements). In particular, we documented the content of their conversation concerning diversity, teaching, and the intersection of these issues.

Topics included diverse populations, diversity and activities in industry, diversity and activities in academia, attitudes about diversity, and strategies for and challenges of addressing diversity in teaching. We also presented evidence on the interweaving of these topics over time (e.g., interweaving of diversity in general, teaching in general, and diversity as related to teaching) and the inclusive, balanced nature of participant contributions over time (*i.e.*, all participated, no one dominated).

- In (Sattler, Yellin, *et al.* 2007), we discussed trends in how program participants talked (during post-program interviews) about diversity and their reactions to discussing diversity during ETPP. Through the analysis, we noted how participants' experiences about diversity were frequently related to critical incidents in their prior experience and how issues of "political correctness" manifested in the ETPP conversations about diversity.
- In (Turns, Yellin, *et al.* 2006), we presented a detailed analysis of the content of the peer-review conversations of two groups during the second and seventh weeks of the program. We found that participants discussed choices and assumptions about audience, negotiated understandings of the portfolio genre, shared general writing strategies, exchanged editorial feedback, shared specific ideas related to teaching, provided each other with positive reinforcement, grappled with issues of "stage fright" about their writing, and engaged in overall task negotiation. The content of these conversations provided evidence for claims that participants were gaining new or refined ideas related to teaching, as well as improved teaching portfolio documents, confidence in their documents, and general ideas about how to leverage feedback in writing activities.
- In (Huang, Yellin, and Turns 2005), we documented the broad range of ideas about teaching that were introduced through conversations during program sessions. These ideas—ideas about what constitutes teaching, what counts as "good" teaching, the role of decision making in teaching, and a variety of issues related to pedagogy and assessment—provided a basis for thinking about how ETPP could increase or refine a participant's teaching knowledge.

In addition to discussing portfolios and teaching, participants provided each other with positive reinforcement, grappled with "stage fright" about their writing, and engaged in overall task negotiation

4.1.2 Program Materials

The ETPP program materials (overviews, weekly guides, and supplemental materials) represent a significant product of the development of the program. The overviews and weekly guides describe the key activities, while the supplemental materials contain information to address issues that came up during initial offerings or were raised during discussions with our advisory board. These materials are available online (<http://www.engr.washington.edu/caee/etpp-sessions.html>).

4.2 Offerings at the University of Washington and Beyond

Over the period from 2003 to 2006, approximately 100 people voluntarily participated in offerings of the Engineering Teaching Portfolio Program (Table 4.2-A). These counts focus on active participants. The number of people expressing interest was much higher, as was the number of people attending initial sessions. The most common reason for not enrolling or actively participating was scheduling. These offerings were held at the University of Washington and the University of Florida. Additional spinoff activities expanded the number of people influenced by the ETPP effort.

University of Washington, 2003

The first offerings of ETPP took place in the summer of 2003. Graduate students from all ten departments in the College of Engineering at the University of Washington (UW) were invited to participate in the program. Participants were fifteen graduate students organized into two groups. This initial offering involved decentralized, peer-led facilitation, where participants each signed up to facilitate at least one of the eight sessions. To support formative evaluation, data collected during these sessions included field notes for each session for both groups (including real time information on who said what), a group interview with each of the two groups, interviews with individual participants, and surveys of individual participants.

Table 4.2-A: Iterations of ETPP, along with number of participants. These numbers represent those participants who completed the program. Initial enrollment numbers were higher (total of approximately 140).

Iteration	Number of active participants
University of Washington, Spring 2003	18
University of Florida, Fall 2005 or Spring 2005	9
University of Washington, Summer/Fall 2005	39
University of Washington, Summer 2006	28
Total	94

University of Florida, 2004–2005

ETPP was used at the University of Florida (UF) in the fall of 2004 and again in the spring of 2005. This adoption by another school was due primarily to the efforts of a postdoctoral researcher in aerospace engineering at UF who learned about the program through an ASEE paper reporting on the UW pilot program. Although ETPP was still being polished, the UF researcher began a recruiting effort that garnered an initial group of 35 interested students (nine completed the full eight-week program). Her willingness to implement a program that was essentially still in development enabled the ETPP team to fine-tune the program more rapidly. Details of these offerings were published at the 2005 ASEE conference (Rosca and Hickey 2005).

University of Washington, 2005

The 2005 offering of ETPP at the University of Washington featured a larger number of participants than the previous offerings, a curriculum that had been revised based on the formative evaluation efforts, and a collection of supplemental materials made available to provide participants with additional support. Twenty-five participants, divided into four groups, participated in the summer of 2005, and fourteen additional individuals participated in the fall of 2005. As in previous offerings, these offerings involved decentralized peer-led facilitation—participants each signed up to facilitate at least one of the eight sessions. To support additional formative evaluation of the program, we collected data during the summer 2005 offerings (field notes for each session, interviews with participants). No additional data was collected during the fall 2005 sessions.

University of Washington, 2006

The summer 2006 offering of ETPP featured small changes to the curriculum and supplemental materials, as well as a revised approach to facilitation. The 28 participants were organized into two groups. In response to challenges associated with the decentralized peer-facilitation approach used in previous offerings, these offerings featured a common facilitator. In keeping with the peer-led approach, the facilitator was another graduate student who had been hired on the basis that she would help the group proceed through the activities. There was, however, no expectation that she would or could provide expertise concerning teaching portfolios. Data collection for these offerings was limited to reflections made by the facilitator.

ETPP variation, University of Washington, 2005

In 2005, a variation of ETPP was used with undergraduate students who were being trained to be mentors for the Minority Science and Engineering Program at the University of Washington. This work, which involved four undergraduate students, was documented in an ASEE conference paper (Yellin *et al.* 2005). One finding from this work was that, like the graduate students and post-docs, undergraduates have strong ideas about teaching, even though they may not be able to express them using formal terminology.

4.3 Impact on Participants

An evaluation of ETPP was conducted by staff at the University of Washington's Office of Educational Assessment, with an internal report completed in 2008 (Maring). This subsection highlights the findings from that evaluation, specifically findings based on interviews with participants of the 2005 University of Washington offerings ($n = 28$) and a follow-up survey sent in 2007 to all ETPP participants. The evaluator invited participants of ETPP to take part in an online survey about longer-term impact of the ETPP experience. A total of 89 participants were successfully contacted, and 43 responded to the survey (48% response rate).

Table 4.3-A: Participants' ratings about ETPP overall on the follow-up survey

Survey item statement	% of participants who agreed or strongly agreed
As a whole, I enjoyed my ETPP experience	86%
In hindsight, I think my decision to take part in ETPP was a good one.	88%
At this point, I consider ETPP a good use of my time.	86%
I would recommend ETPP to other graduate students.	88%

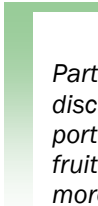
In general, participants were very positive about their overall ETPP experience. In the immediate post-interviews, participants praised the program, noting various ways in which it was valuable. On the follow-up survey, participants remained positive.

Table 4.3-A shows the percentage of participants who agreed or strongly agreed with positive evaluative statements about ETPP as a whole.

In terms of specific outcomes, the evaluation provided evidence that participants created a tangible product (*i.e.*, the portfolio) that they valued and, in some cases, used in job applications. They reported that building the teaching portfolio and peer discussions tied to the construction of the portfolio served as mechanisms for them to think more deeply about their teaching, to articulate the decisions they make while teaching, and to formalize these thoughts. Concerning the diversity elements, they were mixed on the benefits and impacts of talking about diversity. Ultimately, respondents indicated (in the interviews) that the ETPP had resulted in changes in their knowledge along a range of topics: about the design and use of portfolios, about conceptions of teaching, and about approaches to diversity. Reports of direct impacts on teaching were mixed, but this makes some sense, since most participants were graduate students who had little formal teaching experience. Nevertheless, many felt that the program had had or would have a positive impact on their teaching. Additional highlights of the evaluation are included below:

- The majority of participants indicated on the follow-up survey that they had used a part of their portfolio (73%) or looked at it (77%) at least once since they took part in the program. These findings indicate the long-term utility of the final ETPP products.

- In the immediate post-ETPP interviews, almost half of the participants (41%) noted that increased reflection about teaching was one of the most important effects of being in the program. More specifically, participants appreciated the opportunity to formalize thoughts about teaching that they had previously had in an informal or disorganized way (e.g., “while lying in bed”). In the follow-up survey, participants also made comments about ETPP making them “think more” in general about teaching, but with less frequency than participants in the immediate interviews.
- Both immediately after ETPP and at the follow-up survey, participants most frequently mentioned the discussions with their peers in the ETPP sessions as the most significant and/or valuable aspect of the program. One specific way in which the discussions were valuable was in gaining new perspectives on teaching. Participants commented that they appreciated hearing and reading about others’ decisions, strategies, and teaching methods in general. Seeing documented examples (via the teaching portfolios) of what others do in their teaching was noted as particularly valuable by some participants.
- Another aspect of discussion that was perceived as particularly valuable was receiving feedback about the components of the teaching portfolio. Both immediately after the program and at the follow-up, participants commented that they appreciated hearing how their teaching portfolio documents could be improved. In general, participants commented that these discussions were particularly fruitful, because they were with peers and not with more seasoned teachers or faculty members. This may be because the discussions gave participants the opportunity to practice expressing their ideas in a low-stakes environment.
- The majority of respondents (74%) indicated that the statement, “Whenever it is feasible, I try to document the things I do as an instructor,” was more true because of ETPP (ratings of 4 or 5). In the interviews conducted immediately after ETPP, increased documentation of teaching decisions and activities was the most frequently mentioned change to actual teaching practices.



Participants commented that discussions about improving portfolios were particularly fruitful for being with peers, vs. more seasoned teachers.

4.4 Summary

The Engineering Teaching Portfolio Program efforts resulted in a comprehensive set of curricular materials, research that not only informed the development of the curricular materials but is available to others interested in supporting graduate students, around 100 program “graduates,” and several small-scale spinoff efforts. ETPP is notable in the way it embeds opportunities to learn about teaching in the production of something inherently desirable to future faculty (the portfolio), features conversations about diversity, and involves a way of talking about teaching that supports participation by people with a wide range of prior experiences.

Potential future work with ETPP includes additional offerings at the University of Washington and beyond, integration of APS results into the curriculum and supplemental materials, and more extensive analysis of the data to fully understand how participants benefit from program participation. Concerning the issue of benefits, a promising hypothesis is that the educational power of portfolio construction comes from consideration of the *significant questions* that can be associated with portfolio construction (e.g., who am I talking to, what exactly do I want to say about my teaching, who judges teaching, how do I provide evidence of my strengths as a teacher, what counts as “good” teaching). Stakeholders interested in this issue are encouraged to look into work on critically reflective teaching (e.g., Brookfield 1996) and to pursue critical incident approaches to data collection (e.g., asking participants what surprised them during a session, what they were skeptical about during a session, “aha” moments, etc.) as a means to tap further into such issues.

5 *Building the National Community of Engineering Education Researchers: Institute for Scholarship on Engineering Education*

The primary goal of the Institute for Scholarship on Engineering Education (ISEE) component of CAEE was to cultivate a diverse community of engineering education researchers who can think and work across disciplines with the ultimate aim of improving the engineering student experience. A secondary goal was to formulate principles and models for advancing this community of scholars. Both goals address a mission of *building capacity* (people and models) in engineering education.

As part of accomplishing these goals, three cycles of the Institute for Scholarship on Engineering Education were held. The three cycles involved 49 engineering education researchers (Institute “Scholars”) representing 20 institutions (Table 5-A). Recruitment of ISEE Scholars sought to represent the range of diversity within the national academic community: 20 (40%) were women, and 17 (36%) were underrepresented minorities. All faculty ranks were represented: 6 full professors, 12 associate professors, and 9 assistant professors. The remaining participants held other academic roles: 13 graduate students and 9 participants in other roles, including staff and administration.

5.1 **Institute Organization and Themes**

Each ISEE cycle consisted of five main phases: (1) designing and/or adapting the Institute model, (2) recruiting Scholars for the current year’s Institute, (3) a week-long Summer Summit kick-off event at the host school, (4) activities during the academic year to support Scholars in conducting their studies, and (5) a culminating Leadership Summit event.

The week-long Summer Summit was designed to engage the Scholars in the process of engineering education research, introducing many to new techniques and ideas in educational research. Activities and discussions during the Summit helped Scholars refine their research questions, decide on appropriate methodology, and, very importantly, to form a community that could be sustained beyond the week-long meeting. After the Summit, Scholars typically returned to their respective campuses to conduct their research, with frequent electronic communication and interaction with fellow Scholars and the ISEE team. Approximately one year after the Summer Summit, Scholars participated in a Leadership Summit at an engineering education conference. (Adams *et al.* 2006)

Table 5-A: Primary institutional affiliation of the ISEE Scholars (with number of participants in parentheses)

2004–2005	2005–2006	2006–2007
California Polytechnic State University, San Luis Obispo	Howard University (2)	Case Western Reserve University
Howard University (2)	Stanford University (8)	George Mason University
North Carolina A&T University	University of Minnesota (2)	Howard University (2)
Purdue University	University of Washington (4)	John Brown University
Stanford University (2)		Lafayette College
University of Washington (10)		Michigan Technological University
		Minnesota State University, Mankato
		North Carolina A&T University
		Oklahoma State University
		Oregon Institute of Technology
		Purdue University
		Binghamton University, State University of New York
		Texas University State, San Marcos
		University of Colorado, Boulder
		University of Michigan at Ann Arbor
		University of Wisconsin, Madison

Each Institute had a different theme (Table 5-B). The individual projects for the 2004–2005 Institute were focused primarily on classroom changes under the broad theme of “classroom as lab.” The cohort drew from three CAEE partner campuses and two CAEE affiliates. A week-long Summer Summit was held on the University of Washington campus in July 2004 that helped Scholars refine their research topics. The cycle concluded with a special session at the 2005 Frontiers in Education (FIE) conference in October (Adams *et al.* 2005).

For the 2005–2006 Institute, Scholars worked on projects aimed at impact on engineering education at their campus (*i.e.*, a theme of “campus as lab”). Nine Scholars from Stanford worked on one project together, and the remaining Scholars focused primarily on individual, campus-impact projects. The Institute began with a Summer Summit at Stanford University in June 2005. As part of the second Institute, the team created the IdeaLog (a wiki) to enhance communication among Scholars at remote institutions.

The 2006–2007 theme was “Advancing Engineering Education Research to Meet the Needs of the 21st Century.” Scholars were recruited through a competitive, national application process and were asked explicitly to consider issues of diversity in their projects. As such, the focus was “nation as lab,” and participants considered change on a national scale and

collaborated to run a national workshop at the 2007 FIE conference in October (Allendoerfer, Bates, *et al.* 2007). The 2006–2007 Scholars continued use of the IdeaLog developed in the previous Institute.

Table 5-B summarizes representative themes and research topics for the three Institute cycles.

Table 5-B: Themes and representative research topics for each ISEE cycle

ISEE cycle year	Theme	Representative research topics
2004–2005	Class as lab	<ul style="list-style-type: none"> Gender imbalance of students majoring in computer science Factors influencing student empowerment Acquisition of professional design expertise Creative thinking in 5th grade as compared to freshman engineering Student retention of materials sciences concepts over time Attributes of workplace writing expectations Students' understanding of life sciences and impact on choice of major
2005–2006	Campus as lab	<ul style="list-style-type: none"> Student use of college of engineering resources Characteristics of early engineering education (e.g., fundamentals courses) and their impact on the student experience American and international students' experiences in engineering majors Understanding the school-to-work transition Use of portfolios in teacher learning communities that seek to retain underrepresented minorities in engineering
2006–2007	Nation as lab	<ul style="list-style-type: none"> Relationship of learning and personality styles with perceptions of success Factors influencing students' global awareness; learning about cultural and global diversity Academic empowerment of Hispanic students transferring from community colleges Impact of case studies on students' extrapolations to societal and global issues; presenting course material in socially relevant contexts Models for characterizing social justice in engineering Influence of cooperative education experiences on retention in engineering

5.2 The Impact of the Institutes

The subsections below describe accomplishments and impact for the three Institute cycles. Subsection 5.2.1 describes the influence of the year-long Institute experience on the Scholars, personally and professionally. Subsection 5.2.2 describes the impact of the Scholars on engineering education, through their research projects and activities.

In order to improve the overall Institute design, as well as to ascertain the impact of the Institute on Scholars, a set of evaluation data was collected from Scholars immediately before, during, and following each Summer Summit. There were also follow-up interviews with individual Scholars during the Institute year and a final, cumulative follow-up evaluation effort across all cohorts after the last Institute cycle. Data were gathered through surveys, focus groups, and interviews. The results of this effort are discussed in Subsection 5.4.

Many of the descriptions and quotations about impact included below are based on excerpts from the ISEE internal evaluation report produced by the University of Washington's Office of Educational Assessment in April 2009 (Maring).

5.2.1 The Impact of the Institute on Scholars

This subsection draws on the cumulative evaluation findings to describe the impact on the Institute on the Scholars in the following areas: skills, knowledge, and experience; career; and community. The subsection concludes with a vignette ("Engineering an Interdisciplinary Career") that describes the effect on one Scholar in his own words.

Skills, knowledge, and experience

90% of all scholars reported in a follow-up survey that they learned more about educational research methods during the Institute than they had known prior to participation. When asked a separate question about the most important thing they learned, some of the most frequent responses included learning to do educational research and learning about specific methods or research techniques, in particular their familiarity with ethnographic observation, qualitative studies, quantitative studies, and teaching/design experiments. Scholars generally also indicated that they had increased their frequency of reading literature on engineering education and attending presentations on engineering education research and workshops on teaching in engineering.

Career effects

Evaluation data suggest that career effects were various, multi-faceted, and positive. These effects included an increased awareness of the field of engineering education research and participation in activities related to educational research. Scholars also felt that participation in the Institute had a positive effect on different types of career pathways and the reception of their work within their respective departments, colleges, and/or institutions. For example, 81% of survey respondents agreed or strongly agreed with the statement, "Being part of the Institute was a positive addition to my CV"; 71% agreed or strongly agreed with the statement, "The education research I did as an Institute Scholar was well-integrated into my career goals"; and 63% agreed or strongly agreed with the statement, "I believe that my participation in the Institute advanced my career."

81% of survey respondents agreed or strongly agreed with the statement, "Being part of the Institute was a positive addition to my CV."

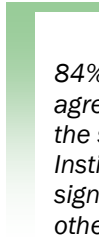
Tenured faculty saw the experience as a catalyst for incorporating engineering education in their research in a substantial way, and one intended to gain added legitimacy through external funding. Many of the early-career faculty saw ISEE as fitting perfectly within their current position, although some were less sure of the fit with their career progress. Graduate students noted that the Institute provided critical support to an interdisciplinary career in both engineering and education, helped prepare them for a teaching-oriented career, provided an opportunity to pursue research independent of their dissertation work, and opened up new career options (see Scholar focus in Figure 5.2-A).

Those who found their institution supportive tended to investigate issues deemed important within their program, link efforts to ongoing evaluation needs such as ABET, and use the Institute to gain legitimacy for their work.

The benefits of community

Perhaps one of the most consistent findings across all four years of data about the Institute and impact on Scholars was how appreciative these individuals were to have been supported in the creation of a sustained community. When asked on the follow-up survey about the most important thing they learned, the most frequent response was some mention of community: the existence of it, the importance of having people available as resources, and of validation from being part of it.

For some, it was this general sense of community—of realizing the existence of a group of like-minded individuals—that seemed to be an antidote to the sense of isolation within a department or institution reported by a substantial number of Scholars. In the follow-up survey, 84% of participants agreed or strongly agreed with the statement, “During my Institute experience, I made significant connections with other Institute Scholars.” For example, several 2006–2007 Scholars from different institutions, who had not known each other previously, went on to collaborate on research projects and/or grant proposals.



84% of surveyed participants agreed or strongly agreed with the statement, “During my Institute experience, I made significant connections with other Institute Scholars.”

Scholars’ comments suggest that their idea of ISEE community included members of the CAEE team working in the Institutes, and there was clear evidence that the ISEE team played a large role in ushering Scholars into the larger community of engineering education research. In the follow-up survey, the majority of responding Scholars indicated a sustained affiliation with the national engineering education community, with 65% agreeing or strongly agreeing with the statement, “Because of my Institute experience, I became more a part of the national engineering education community,” and 70% agreeing or strongly agreeing with the statement, “After my Institute experience, I remained a part of the national engineering education community.”

Engineering an interdisciplinary career

The vignette in Figure 5.2-A describes the profound impact that ISEE had on one Scholar through his Institute research and interaction with other Scholars.

Figure 5.2-A: Vignette of a 2004–2005 Scholar and ISEE’s profound impact on his career (Maring, 2009)

Scholar focus: Engineering an interdisciplinary career

The Institute for Scholarship on Engineering Education was a perfect fit for one Scholar in the 2004–2005 group, a graduate student in computer science and engineering who was seeking to study why so few women enter the field. Already determined to pursue this unconventional topic for his dissertation, he was seeking guidance, training, and validation that he could not find within his department.

According to this Scholar, ISEE was a “big, formal and public foray into engineering education research” and was an invaluable starting point for this Scholar’s early career in engineering education. This included the Summer Summit, when he found the community he had been seeking; continued with regular meetings among a small group of Scholars and ISEE team members on his campus during the following year; and culminated with a poster at FIE in 2005. In the fall of 2005, he described the impact of ISEE as follows:

This project is really critical to my remaining in the Ph.D. program, in that I had made a decision after finishing my Master’s work in traditional computer science that I was much more interested in teaching, and if I could complete a dissertation in something closer to education, then I could see myself completing my Ph.D.

After the Institute year, this scholar became a research assistant on the CAEE team working on the large-scale, longitudinal Academic Pathways Study (APS). In subsequent years, he continued to present at major national conferences, co-authoring papers with other CAEE team members and presenting his own work. He described the connection to CAEE as a vital way for him to get engineering education researchers interested in his work, as he describes below:

I had all of these high-profile opportunities where I wasn’t [a research assistant] working on APS, but more publicly establishing my identity as an engineering education researcher doing my own thing as well.

One example of such synergy was a workshop he developed with CAEE team members and an affiliate from the Women in Engineering ProActive Network (WEPAN). The interactive sessions (held at the national WEPAN and ASEE conferences in 2008) focused on several provocative quotes and findings from APS about how undergraduates perceive women in engineering. This Scholar helped develop the presentation and facilitate the conversations, and the workshops provided a perfect opportunity for him to discuss findings from his dissertation research, both formally and informally, with session attendees.

Several years later, the impact of being an ISEE scholar and his connection to CAEE was clear. In 2008, he successfully defended his dissertation, with three CAEE team members serving on his committee and a former ISEE Scholar serving as his co-adviser.

As this scholar put it,

Whatever I end up doing, one thing is for sure, I don’t want to give up the momentum and the communities and the other great things I’ve gained while working at the Center and the Institute...[ISEE] is definitely one of the important pieces of my research career as a graduate student and, in particular, my engineering education research career.

5.2.2 The Impact of the Scholars on Engineering Education

The ISEE Scholars demonstrated their ability to contribute to the scholarship of engineering education by their productivity regarding peer-reviewed publications, presentation of their work in different venues, and receiving awards drawing from their ISEE experience.

During the course of the three Institutes from 2004 through September 2007, 20 Scholars had authored a total of 43 conference presentations or posters, and their production has continued in the ensuing years. Since the completion of the final Institute in 2007, a large majority of the scholars continue to be successful contributors to the community of engineering education researchers, with funding from the National Science Foundation (e.g., Engineering Education Programs, Research and Evaluation on Education in Science and Engineering, Course, Curriculum, and Laboratory Improvement, etc.) and the Fulbright Scholars Program. Appendix A, Subsection A.4 lists selected Scholar outputs.

The four vignettes in Figures 5-B through 5-E illustrate some of the impacts Scholars had on engineering education—both the practice of education and the foundation of knowledge on engineering teaching and learning.

Figure 5.2-B: Vignette of a 2004–2005 Scholar and his project on storytelling and learning of concepts (Maring, 2009)

Project Focus: Scholarship of Teaching translates to industry training classes

“How does context increase student learning?” was how one Scholar (a self-described “dabbler” in the scholarship of teaching and learning) articulated his research question on the first pre-survey administered before the 2004 Summer Summit.

During the week-long Summit, this Scholar struggled to define and operationalize the factors involved in his question. In group discussions, he revealed that he had been in a workshop on storytelling and frequently told stories in his classes and wondered whether doing so affected student learning. Throughout the week, he continued to specify aspects of his question: defining storytelling, understanding what aspects of student learning he wanted to investigate, and exploring what methods he might use. By the end of the week, his research question had changed to “Do students develop deeper understanding when presented concepts through contextually relevant narratives in the format of ten-minute stories?”

With such a specific focus, this scholar had a strong foundation for following through with his project. After help from the ISEE team with his human subjects research application, he collected both survey and interview data about the impact of his stories on student learning. At the follow-up interview in the summer of 2005, preliminary results suggested that the storytelling was effective. More importantly, the process of working on the research project had a strong impact on his classroom practices. During the year, he had developed additional stories to use in his classroom and had applied a more structured, systematic, 10-minute format (which he had learned at the workshop) to stories he already told.

In 2006, this Scholar left his university faculty position and started working in industry. The evaluator was able to follow up with him, and, in 2007, he indicated that he was no longer using his ISEE project research as part of his professional work. However, in 2008, the Scholar changed his industry position and began teaching a course on engineering basics to employees at the company where he worked. He indicated that he now did more teaching than when he was at a university. The class was originally planned for 30 people, but it turned out to be in such high demand that, by June of 2008, he had already taught the class three times within a six-month period to 300 employees. He noted that the storytelling techniques he had refined and studied as an ISEE scholar were a prominent part of these popular training sessions.

Figure 5.2-C: Vignette of a 2004–2005 Scholar and her continuing involvement in engineering education research (Maring, 2009)

Scholar focus: Progress amid resistance

One Scholar from the first cohort continued involvement in engineering education research and provided reflections on her work at several points between 2004 and 2008. In general, the theme of these reflections was that she had experienced resistance from her department and felt isolated as she pursued this line of work. Remarkably, she had also made considerable progress, not only in generating research in the area, but also in developing an innovative course for students that has become institutionalized.

This Scholar began her work driven to understand undergraduates' experiences in engineering and in particular in the effects of empowerment on students' performance. She teamed with a graduate student who was also an ISEE Scholar, and, in the first Institute year, collected survey data from students at three institutions across the country, focusing on differences in the student experience between men and women, as well as across different regions in the country.

Another graduate student took on the project and became an ISEE Scholar in the 2005–2006 cohort. At this point, the project shifted due to preliminary findings to focus more on the extent to which students had a sense of belonging in engineering. The two Scholars collected data from students, as well as from practicing engineers, about belongingness. In addition, they developed a syllabus for a “savvy sessions” course to support undergraduates in navigating their undergraduate years and foster a sense of belonging. As the Scholar put it, “Increasing belonging in any environment tends to enable minorities and under-represented populations to persist.”

These “savvy sessions” were piloted during the following academic year. Although this Scholar was no longer working with research assistants through ISEE, she continued developing this course, sought and received external funding for related research, and entered a Masters in Education program with a focus on cognitive studies. In reflecting on her decision to obtain an additional degree, the Scholar stated simply, “I thought if I was going to do research in education long-term, surely I should train myself appropriately.”

When the evaluator spoke with this Scholar in 2008, she reported that she had taught a revised version of the “savvy sessions” twice, despite some opposition from her colleagues. She indicated that she overcame the strong resistance when an ABET review indicated that the College of Engineering was missing courses in ethics and broader context. After making some revisions to her course, she was able to incorporate these ABET components, while also fostering a sense of belonging among students

This Scholar reported that not only has her course become an official part of the curriculum in engineering, but that it could potentially become a required component of the undergraduate degree program. This Scholar has also recently received an NSF grant that builds on these themes of belonging, community, and engagement.

However, when reflecting on the impact of the Institute experience on her career, the Scholar stated,

I don't have a fairy-tale story. The technical area of my research goes up and down quite a bit, so I need to retrain, and what better area to retrain than in something that I'm interested in. It's an obvious choice...My only regret is that [with federal funding], you get all this marvelous support and buoyancy and help getting started and then you get left on your own...I would prefer a collaborative work environment.

Figure 5.2-D: Vignette of a group of 2005–2006 Scholars and their large-scale project (Maring, 2009)

Project focus: Raising questions about engineering curriculum on campus

During the second Institute, a group of Scholars from one institution worked together on a large-scale project with the purpose of effecting change in engineering education on their campus. One of the Institute leads assembled a team of Scholars consisting of engineering graduate students with an interest in educational research, professional staff working in the university's Center for Teaching and Learning (CTL), and faculty who served on the undergraduate council (a body that makes decisions about engineering curriculum).

During the Summer Summit and after much discussion, the group settled on a set of classes referred to as "engineering fundamentals," with a goal of answering the two following questions:

1. What do faculty who teach engineering fundamentals courses think about them: Do they serve their originally intended functions and what is it like to teach these courses?
2. Do the fundamentals courses fit within the curriculum in a way that aligns with the stated goals to provide a broad introduction to engineering concepts and expose students to different areas of engineering?

During the course of the following academic year, the team met fairly regularly, and, most importantly, two people joined the team. The first was the Associate Dean for Student Affairs in engineering and the second was a member of the CAEE team who came on board as a project manager. The graduate students, along with the project manager, gathered transcript data to try and answer the second question (above), while staff from CTL, in collaboration with other Scholars on the team, set up a series of faculty luncheons for instructors of engineering fundamentals classes to address the first question (above).

One year after the Summer Summit, members of the team considered the project a success. They had analyzed relevant data, answered their two questions, and already seen some impact of the work. Most immediate was a notable increase in the amount of discussion and reflection about these courses. The faculty luncheons provided a forum for the instructors to discuss their experiences, and two participants later consulted with CTL to discuss how to incorporate learning goals into their classes. These instructors' conversations with each other also created a sense of community where there had been very little connection up to that point.

Subsequently, the project continued with the Associate Dean taking the lead in trying to use the findings to stimulate additional curriculum change. The team presented at a meeting of all deans and department chairs in engineering, and CTL continued to work with engineering faculty on the fundamentals courses and on teaching issues in general.

Two years after the project (during the 2007–2008 academic year), the Associate Dean funded one of the graduate students and the project manager part-time to collect data on other institutions for the purpose of benchmarking engineering fundamentals courses. A series of reports were generated and submitted to the Associate Dean for future use. In the fall of 2008, the project manager commented,

...the Dean of the School of Engineering is publicly talking about the notion of design thinking as an engineering fundamental. I don't know that this is necessarily an outcome of our work...but the role and importance of design in the early engineering experience is something we had talked about in our early ISEE conversations.

Figure 5.2-E: Vignette of a 2006–2007 Scholar’s extensive STEM education work during and beyond her Institute year (Maring, 2009)

Project focus: Integrating engineering into middle school curriculum (ISEE Scholar 2007)

“Well, my kids are in middle school,” one Scholar reported, when asked why she decided to add work on engineering education to an already-thriving career in chemical engineering. On her pre-survey, the Scholar indicated an intention to study the perceptions of engineering among middle school teachers. By the end of the Summer Summit, she had come to re-think and re-scope her project, realizing it would occur in three phases: first understanding teachers’ perceptions of engineering education, then comparing these to teacher candidates’, and finally determining ways that engineering concepts could be integrated into middle school curriculum.

One year after the Summer Summit, this Scholar had four papers at the 2007 ASEE Conference, one based on her ISEE project. As she told the evaluator, “Well, remember how I thought my one year project was a three-year project? I am doing all three things at the same time.” She was in the process of analyzing data on both pre-service and in-service teachers about their perceptions of engineering and had developed both an engineering camp for middle school students and a mentoring program for female students interested in math and science. She had also worked with teachers to integrate engineering concepts, not just into math and science, but also into social science and English classes.

In addition, this Scholar had reached beyond her original proposed project to consider other questions. In her work with middle schools, she targeted one particular rural county with a significant Native American population and had become particularly interested in bringing engineering concepts to schools in that region. She was also in the process of writing an NSF Research Experience in Teaching grant for teachers in that county. She continued to present the results of her work, with three papers at the 2007 FIE Conference.

At ASEE 2008, this Scholar co-authored a paper with an education graduate student whom she was mentoring. This student was conducting a study on how engineering faculty started to engage in scholarly work on teaching and learning. The Scholar indicated that she was still extremely busy in research on STEM education, conducting workshops for math and science teachers, working under a CCLI grant on fostering critical and creative thinking in freshmen, and starting a study on how math is (or is not) contextualized for freshman seeking to study engineering.

She jokingly reported on the impact of the Institute by saying, “Well, I am really busy, and it’s all [the ISEE lead’s] fault! I wake up in the middle of the night thinking about new research questions!”

5.3 The ISEE Model

The ISEE model (Adams *et al.* 2006) includes content and activities that focus on building community and developing an understanding of how to design and conduct engineering education research (similar to other capacity-building programs). The model also draws on previous efforts to target particular challenges of engaging in this kind of work. Unique attributes of the ISEE model include the use of research-story posters and storytelling; development of plans to enhance the scholarship of impact; approaches to studying diversity; and approaching educational experiences (at the class, campus, or national level) as laboratories for investigating student experiences and learning.

The paragraphs below provide an overview of the Institute year and an accompanying set of key strategies and design principles. These highlights draw from the more detailed discussion of the ISEE model in Adams *et al.* 2006. Additional details of ISEE implementation are provided in Allendoerfer, Bates, *et al.* 2007; Allendoerfer, Jones, *et al.* 2007; and Lande *et al.* 2007.

Unique attributes of the ISEE model include the use of research-story posters and storytelling, and approaching educational experiences as laboratories.

5.3.1 Five Stages of ISEE

The Institute year consists of five stages, as described below:

Recruiting and selecting Scholars

Each ISEE cycle brings together a cohort of engineering faculty, graduate students, and (in some cycles) educational support staff. The process of reviewing and selecting candidates emphasizes recruitment of diverse participants, with a focus on building community. An important consideration in assembling the cohort is to promote change at host and affiliate schools/institutions. Honoraria for faculty and fellowships for graduate students are provided.

The Summer Summit

This week-long, intensive, interactive, face-to-face learning experience launches the Institute year. During the Summit, Scholars (1) learn about research design and methods from the learning sciences; (2) have opportunities to practice research methods; (3) develop as a community; (4) discuss current issues in engineering teaching and learning as part of deciding on a research topic; and (5) formally define a research study to be conducted during the academic year.

Conducting a year-long research study

During the academic year, Scholars are mentored (by both peers and experts) as they implement their research study. A variety of methods are used to sustain community and provide resources for moving studies forward (*e.g.*, just-in-time presentation of content, work-in-progress meetings, invited experts across the community). A collaboratively maintained web site or “wiki” called the IdeaLog was developed for use in the second and third Institutes to build and support a community of practice among the Scholars. This online tool was used both during the Summer Summit and while the Scholars were on their home campuses. The IdeaLog is like an informal sketchbook in which Scholars have a shared space to capture information and inspiration in ways that are personally meaningful. To promote continual feedback, Scholars are encouraged to visit and respond to each other’s postings. The tool

was initially implemented with an understanding that the IdeaLog requires adaptation and tuning to the adopting community (Chen *et al.* 2005)

A culminating Leadership Summit

This is an event in which Scholars present their work to specific communities (e.g., at professional conferences or local meetings), are introduced into the broader engineering education community, and refine leadership skills. In the first and third of the three Institutes sponsored by CAEE, the culminating summit took the form of an interactive session at the Frontiers in Education Conference (Adams *et al.* 2005; Allendoerfer, Bates, *et al.* 2007).

Mapping and adapting the Institute model

In this iterative design stage, the ISEE leadership team collaborated with an evaluation team from the Office of Educational Assessment at the University of Washington to distill what had been learned from the previous Institute. The team identified opportunities for improvement and aligned the Institute model with the needs of the next host campus.

Formative and summative evaluation played crucial roles in this iterative process. Information from surveys of Scholars before their initial Summer Summit meeting was used to tailor Summit activities. Focus groups with Scholars informed improvements to the IdeaLog and to community-building activities during the academic year. Evaluative interviews with Scholars provided additional insight and advice into the challenges of becoming an engineering education researcher.

A sample schedule for the week-long Summer Summit is shown in Table 5-C.

Table 5-C: Sample schedule for an ISEE Summer Summit

Day 1	Day 2	Day 3	Day 4	Day 5
Institute Theme	Defining a Good Research Question	Draft Presentations of Research Plans	Critiquing Research	Study Presentations
Motivations for Research	Research Tools	Draft Presentations of Research Plans (cont.)	Making Sense of Research Frameworks and Theories	Study Presentations (cont.) and Reflection on Being a Community
Lunch	Lunch	Lunch	Lunch	Lunch
Posters and Group Work	Research Tools (cont.)	Rigor, Sampling, and Bias	Individual Work Time	Next Steps
Communication and Community Building Technology	Study Design	End-of-Day Social and Evaluation	Designing Studies for Impact and IRB Issues	Evaluation Focus Groups
End of Day Social and Evaluation	End of Day Social and Evaluation	Homework	End of Day Social and Evaluation	End of Summit
Homework	Homework	Social Time	Homework	

5.3.2 Strategies to Help Scholars Succeed

We found that Institute Scholars who were new to the field of educational research were greatly helped by participating in a local community of like-minded colleagues. This was particularly important for giving and receiving feedback about research work in progress.

We also found that the engineering faculty were often unfamiliar with particular aspects of educational research, such as navigating a new disciplinary language, utilizing qualitative research methods, and/or analyzing qualitative data. We developed a range of strategies that were useful in helping Scholars move past these barriers:

- providing structured, formal interactions during the Institute year;
- using project plans as milestones;
- providing just-in-time activities that introduce various research methods and educational theories;
- providing templates and guidelines for human subjects processes;
- using work-in-progress meetings to promote accountability and support interactions among the Scholars and ISEE team members;
- seeking campus-based resources (and working with local administrators to access these resources);
- continuing efforts to build community (outside ISEE in particular) as a means to support motivation; and
- implementing activities about how to build social networks and how to communicate with different audiences.

5.3.3 ISEE Design Principles

During the course of multiple iterations of the Institutes, the team developed a set of overarching design principles behind the ISEE model. These include

- using a tiered waterfall model for recruiting Scholar cohorts and building local community over time;
- adopting a user-centered approach (informed by evaluation activity conducted throughout the ISEE process) to identify and address the challenges Scholars encounter before or during their ISEE experience;
- creating a focus on learning contexts as “laboratories for investigation and impact,” where Scholars have or can create the influence to enact change;
- engaging in interactive, community-centered activities (e.g., interactive study posters, work-in-progress sessions, and sharing ISEE stories);
- establishing a safe environment for open discussion and feedback;
- using both structured and unstructured/informal activities for building community;
- having the Scholars complete the first phase of activity with at least a draft study plan; and
- recognizing that a focus on impact is a key motivation for participation in this community.

Fundamental to all of these principles is the understanding that the ISEE experience is about facilitating relationships that encourage shared construction of knowledge, mentoring, and enabling others to pursue a passion.

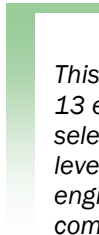
5.3.4 Additional Implementations and Adaptations

Aspects of the ISEE model have been adapted and expanded by others in the engineering education research community. These include the use of Scholars' research posters developed during the summer summit; expansion of curricular materials and scholarship models to an international audience; use of findings from the Institute cycles in the development of a Ph.D. program in Engineering Education at Purdue University; and a next-generation partnership with the NSF-funded Rigorous Research in Engineering Education (RREE) program for building capacity in engineering and engineering technology education (Streveler and Smith 2006).

5.4 Research Findings on How Educators Enter, Navigate, and Work in the Interdisciplinary Field of Engineering Education

As part of the overall goal of building capacity in engineering education research, in 2006–2007, the ISEE team investigated details of the pathways into engineering education research, examining how people enter, navigate, and work in this type of interdisciplinary space. An additional goal of this study was to provide feedback into the ISEE model developed by the team (as well as other capacity-building programs) regarding factors that can enable engineering education research pathways and the construction of identities.

This study of pathways included 13 engineering educators selected to represent varying levels of membership in the engineering education research community (e.g., low to high level of contributions, low to high level of formal learning in education research). Semi-structured interviews were used to engage participants in conversations about their engineering education work, how they began doing engineering education research, what challenges they faced and strategies for overcoming those challenges, and what advice they would give to others who wish to enter the community. (Allendoerfer, Adams, *et al.* 2007)



This study of pathways included 13 engineering educators selected to represent varying levels of membership in the engineering education research community.

Analysis of the interview data suggests common elements in people's pathways into engineering education research, although there are also many unique characteristics. Two significant themes that emerged, among a number of others, are

- the importance of a community of practice perspective and
- the development of a composite identity, with many frames and many combinations that help to establish an identity as a cross-disciplinary engineering education researcher.

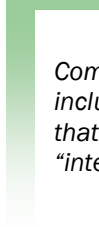
5.4.1 A Community of Practice Perspective

The *community of practice* perspective involved exploring the data through interrelated lenses of *domain*, *community*, and *practice*. Here, domain is marked by a commitment to a shared domain of interest, community by engaging in joint activities and relationship

building, and practice by a shared repertoire of resources, experiences, tools, and ways of addressing recurring problems. Participation in a community of practice with respect to engineering education research allowed the participants to engage in joint activities and discussions, help each other, share information, and build information that enabled them to learn from each other.

The study participants shared a “domain of interest” that implies a commitment to the domain and shared competence that distinguishes members of the domain. Participants shared a common entry point into engineering education research that included experiences with teaching and learning that generated researchable questions. Participants also commonly focused on application-oriented research, though some were oriented toward basic research. They all shared a passion for supporting student learning and enabling effective learning environments. Further, the participants demonstrated their commitment to the domain by pursuing formal knowledge, either through education or collaborations.

Participants engaged in the community of engineering education research to varying degrees through small and local community entry points; other people served as catalysts into the domain or as motivation for continued commitment. Community building practices included using informal networks as pathways to the broader community, networking strategies that may be characterized as “intentional serendipity” rather than “luck,” proactively building collaborations that enable shared learning and sustaining passion, and interacting in a variety of communities that can support multiple identities. Community played a pivotal role in the development of an engineering education research identity and was observed to interact substantially with the themes of domain and practice.



Community building practices included networking strategies that may be characterized as “intentional serendipity.”


A number of engineering education research practices were observed in the evaluation interview data. These include determining where to find information and how to decide if it is useful, experiencing different forms of inquiry, seeking rigor, and coming to terms with the complexities of studying humans. There were also community-building practices to create collaborations that help address inadequacies in training or knowledge and that bring new people into the practice. Cross-disciplinary practices included activities to bridge perspectives and cross-disciplinary tendencies and identities. Institutional and cultural practices included “spinning” stories for different audiences and participating in traditional academic culture with “non-traditional” work.

5.4.2 Developing a Composite Identity

In addition to finding ways to join the community of engineering education research at both local and broader levels, participants reported developing a composite identity as their new involvement in this community expanded. This composite identity was made up of many combinations for making sense of self. The frames associated with this composite identity included “interdisciplinary,” teacher, agent of service, educational researcher, and engineering researcher. Participants were essentially “performing an identity”: attending to situational aspects of their careers and lives by strategizing an identity in relation to an audience. For example, participants used an identity of “teacher” to engage others in conversations about student learning, “educational researcher” to participate in the broader educational research community, and “interdisciplinary” to act as a bridge between traditional engineering faculty and the community of engineering education research.

5.5 Summary

The three cycles of the Institute for Scholarship on Engineering Education (ISEE) component of CAEE resulted in significant capacity-building in engineering education research, both in terms of people and program models. First, it helped a total of 49 faculty, graduate students, and staff representing 20 institutions develop as new engineering education researchers. As Institute Scholars, they were guided through the process of designing and carrying out engineering education research projects. Second, ISEE produced and refined a model describing the content and activities used to prepare new engineering education researchers, with an emphasis on building community, within each cohort of Scholars, as well as the larger engineering education community. This model includes a set of specific design principles, including those that highlight techniques for recruiting prospective Scholars and the importance of interactive, community-centered activities.



ISEE helped a total of 49 faculty, graduate students, and staff representing 20 institutions develop as new engineering education researchers.

Evaluation data describes the multiple ways in which Institute participation impacted the Scholars—in terms of skills, knowledge, and experience; career paths; and community. At the same time, the Scholars themselves, through their research projects and associated activities, impacted engineering education in a variety of concrete ways. Examples include innovations in industry training and integration of engineering across the middle school curriculum in a rural county with a significant Native American population.

Other contributions of this work include identifying strategies that have proved useful in helping Scholars face common challenges in undertaking engineering education research. These strategies address a wide range of activities, from handling the human subjects research approval process to integrating with the engineering education community. Finally, a research study of 13 engineering education researchers detailed two significant aspects of their pathways into the field of engineering education research: the importance of a community of practice perspective and the development of composite identity.

6 Getting the Word Out

The CAEE team made significant efforts to get the word out about the work of the Center. A fundamental part of this activity was sharing news about the research and results with as wide a variety of audiences and at as many different venues as possible. These dissemination activities began early in the life of the Center and continue beyond the formal end of the grant period.

This section summarizes some of the methods we have used to let others know of our research. In addition to publications and presentations, we list examples of the research instruments and other materials made available for use by others, of programs developed for use and adaptation, and of the impact that the many people affiliated with the Center, either as team members or collaborators, have had in spreading the word.

6.1 Sharing Findings at Different Venues, Addressing Different Audiences

The large and varied body of data produced by CAEE provided the foundation for over 100 scholarly publications. In addition to engineering education publications, the team sought to disseminate findings through presentations, special sessions, and workshops.

Major activity from January 2003 to June 2010 included

- over 130 papers and journal articles in both engineering education and education publications, including 6 articles in the July 2008 special issue of the *Journal of Engineering Education*;
- 9 plenary and keynote presentations; and
- 9 conference special sessions.

Publication activity spanned journals and proceedings that focused on engineering education, education, the learning sciences, sociolinguistics, and anthropology.

As a part of building a national presence, CAEE team members presented findings in invited talks, keynotes, and plenary addresses. Examples (with venue, date, and title of the talk) include the following:

- Frontiers in Education (FIE) Conference (2009): “Educating the Well-Rounded Engineer: Insights from the Academic Pathways Study”
- Women in Engineering ProActive Network (WEPAN) National Conference (2009): “Women in Engineering: Interests, Perspectives, Confidence...and Experiences”
- Rice University Dean’s Invited Lecture (2008): “Does Teaching Matter? (Making a Case for Better Teaching)”
- NSF Science, Technology, Engineering, and Mathematics Talent Expansion Program (STEP) Meeting (2008): “Undergraduate Pathways to Engineering: Insights from a Longitudinal Study”

- ASEE Global Colloquium on Engineering Education (2008): “Implications of the Academic Pathways Study (APS)”
- Center for the Advancement of Scholarship in Engineering Education (CASEE) Annual Meeting, Dane and Louise Miller Symposium (2007): “CAEE: An Overview of Accomplishments to Date”
- Danish Centre for Engineering Education Research and Development, opening address (2007): “Engineering Education Research: Some History and Examples from the U.S.”
- American Society of Mechanical Engineers Chairs Meeting Plenary Session (2007): “Center for the Advancement of Engineering Education (CAEE): Research on Engineering Education”

Examples of national conference special sessions dedicated to CAEE research include the following:

- FIE Conference (2009): “Research Findings on Engineering Student Learning and Engineering Teaching: Interactively Exploring the Implications for Engineering Education”
- ASEE Annual Conference (2009): “Findings from the Academic Pathways Study of Engineering Undergraduates 2003–2008, Overview and Panel Discussion”
- ASEE Annual Conference (2008): “Describing the Engineering Student Learning Experience Based on CAEE Findings,” Part 1 and Part 2
- FIE Conference (2007) Communities of Practice in Engineering Education: “How Do We Investigate Diversity and Global Engineering?”
- American Educational Research Association Annual Meeting (2006), Round Table: “Identity in the Making: Engineering Students’ Pathways to Their Professions”
- FIE Conference (2005): “Communities of Practice in Engineering Education: What Are We Learning?”

In addition, the team offered more than 25 workshops based on CAEE findings to groups at the WEPAN, FIE, Professional and Organizational Development Network in Higher Education (POD), and CASEE national meetings, on local CAEE campuses for faculty and dean’s office staff, and at other many local and national venues.

The team also took advantage of opportunities to present CAEE findings to audiences outside of the traditional scholarly publications and conferences in engineering education. Highlights of some of these include the following:

- ASEE *Prism* teaching toolbox article (January 2010): “Not What Students Need”
- Anita Borg Institute for Women and Technology: Gendered Pathways to Success in Engineering (November 2007): “Results from CAEE’s Academic Pathways Study”
- U.S. House of Representatives STEM Education subcommittee caucus (November 2007): “Design and Student Engagement: Some Differences by Gender”
- Alliance for Graduate Education and the Professoriate (AGEP) Capacity-Building Meeting (February 2007): “CAEE - Implications for your Retention Study”

Several final examples describe the use of CAEE's findings to address existing problems and/or effect change:

- All five of the campuses involved in the Academic Pathways Study research used results from the study to address specific questions on their campuses with respect to programmatic changes, potential curricular reform, illumination of student responses on another national survey, or to better ascertain students' thoughts on a variety of topics.
- Results from one of the workplace studies were used to engage managers at a participating company in making changes to their on-boarding process for new hires.

A complete listing of publications, presentations, special sessions, workshops, and other dissemination activity is available in Appendix A of this report and on the CAEE web site.

6.2 Creating a Set of Resources for General Use

One very important outcome of the development of the various research studies was the creation of materials that could be used by others. These include a set of resources that are available to assist others in conducting similar research: the PIE and APPLE surveys; the APS structured, ethnographic, and workplace interview protocols; the engineering design task instruments; and the SEED interview protocol. In order to provide a detailed look at the design and implementation of the Academic Pathways Study, we created the summary document, "An Overview of APS Research Processes & Procedures" (Sheppard *et al.* 2009).

The team also created several sets of program materials that can be used as models and/or guides by those interested in conducting similar programs. These include the ETPP curriculum and supplemental materials and the ISEE Summer Summit outline. The ASEE 2006 paper that describes the ISEE models also provides information for those interested in staging similar capacity-building events (Adams *et al.* 2006). The record of web site visits and downloads suggests that these tools and materials have already been used extensively by others.

As a way to provide a quick introduction to CAEE's research, the team created a series of research briefs that summarize findings and implications from published papers in short, easy-to-scan documents. The briefs allow interested readers to rapidly get a sense of the scope and content of our research. Over 60 articles and papers are summarized in the briefs to date.

Materials are available on the CAEE web site:

<http://www.engr.washington.edu/caee>

These materials and resources (described more fully below) are all available on the CAEE web site, which provides additional background and history for the Center. The web site has averaged over 1,000 visits per month over the last several years.

6.2.1 The Academic Pathways Study (APS): Detailed Study Description and Instruments

The APS team created a detailed description of how the Academic Pathways Study research was designed and implemented, from initial conception through administration of the APPLE Survey in 2008. This technical report is available on the CAEE web site under the following title:

- [CAEE-TR-09-03: An Overview of the Academic Pathways Study: Research Processes and Procedures](#)

Of particular interest are the specific instruments and protocols for the different methods and cohorts that are included as appendices in the technical report, as listed below:

- [Structured Interview protocols](#)
- [Engineering Design Task protocols](#)
- [Ethnographic Interview protocols](#)
- [Workplace Interview Guide: Big car company](#)
- [Workplace Interview Guide: County-State-Aerospace](#)
- [Persistence in Engineering \(PIE\) Survey instrument](#)
- [APPLE Survey Questions](#)

6.2.2 Studies of Engineering Educator Decisions (SEED): Interview Protocols

The SEED interviews used a Critical Decision Method approach, in which engineering faculty were asked to identify critical incidents in their decision-making process. Interviewees were asked to explain their teaching decisions in general and to identify two recent and memorable decisions: a planning decision made in advance of a class or other interaction with students and a more immediate, interactive decision made “in the moment.”

- [SEED Interview Protocol](#)

6.2.3 CAEE Research Briefs

The CAEE [research briefs](#) were created to summarize research findings in short, easy-to-scan documents. Over 60 articles and papers are summarized in the briefs. The research briefs are accessible through a [page on the CAEE web site](#) that groups the briefs under the following five subject themes:

- Understanding Student Pathways and Experiences
- Examining Student Learning and Skill Development
- Exploring Issues of Diversity
- Developing Community and Building Models for Engineering Education Research
- Developing Effective Teaching Practices

The Research Briefs are also linked from individual papers and articles listed on the Publications page of the CAEE web site.

6.2.4 Program Materials: ETPP and ISEE

Two components of CAEE's activity (ETPP and ISEE) were focused on creating and implementing programs that targeted different populations but had a similar goal to build community. Both programs were successfully demonstrated by the CAEE team, and each program served as a powerful means of reaching out to other audiences. Each program was adopted or adapted by others. We summarize the available materials below. For more complete descriptions of the two programs, see Section 4 (ETPP) and Section 5 (ISEE) of this report.

The Engineering Teaching Portfolio Program (ETPP) was focused on building the skills of engineering graduate students interested in careers in teaching. Curriculum and supplemental materials are available through the CAEE web site.

The ETPP curriculum describes a program that uses the development of a teaching portfolio as a means to expand the skills of engineering graduate students and recent Ph.D. graduates who are interested in teaching. The curriculum serves as a guide for the eight peer-facilitated sessions during which participants create and discuss teaching and diversity statements and provide annotations of representative teaching artifacts. Supplemental materials used in the original offerings (2004–2005) provide examples and background information.

- [ETPP Curriculum](#)
- [ETPP Supplemental Materials](#)

The Institute for Scholarship on Engineering Education (ISEE) was focused on expanding the community of engineering education researchers. An expanded description of the development of the Institute models (with a focus on establishing a community of practice) was presented at the 2006 ASEE Conference (Adams *et al.* 2006). The representative Institute Summer Summit Schedule provides an example of the organization and topics covered during the five-day summit meeting that began each year-long Institute cycle. The following ISEE materials are available through the CAEE web site:

- [Institute Model](#) (Adams *et al.* 2006)
- [Institute Schedule](#)

6.3 Getting the Word Out... Through a Large and Diverse Team and Collaborating with Others

6.3.1 The CAEE Team

The CAEE team began as a group of researchers from five universities representing eight disciplines in engineering and education. An explicit goal in assembling the team was to combine researchers from both engineering and education departments who had a mix of quantitative and qualitative research expertise.

Over the course of the grant, the Center grew to involve 63 faculty members and staff, 41 graduate students, and almost 50 undergraduates during the period 2003–2010. As research scientists and graduating Ph.D. students took positions at other campuses, they typically continued their involvement with CAEE, spreading the Center's influence even further.

Figure 6.3-A: The growth of the CAEE team and affiliates (2003-2009) (Maring 2009)

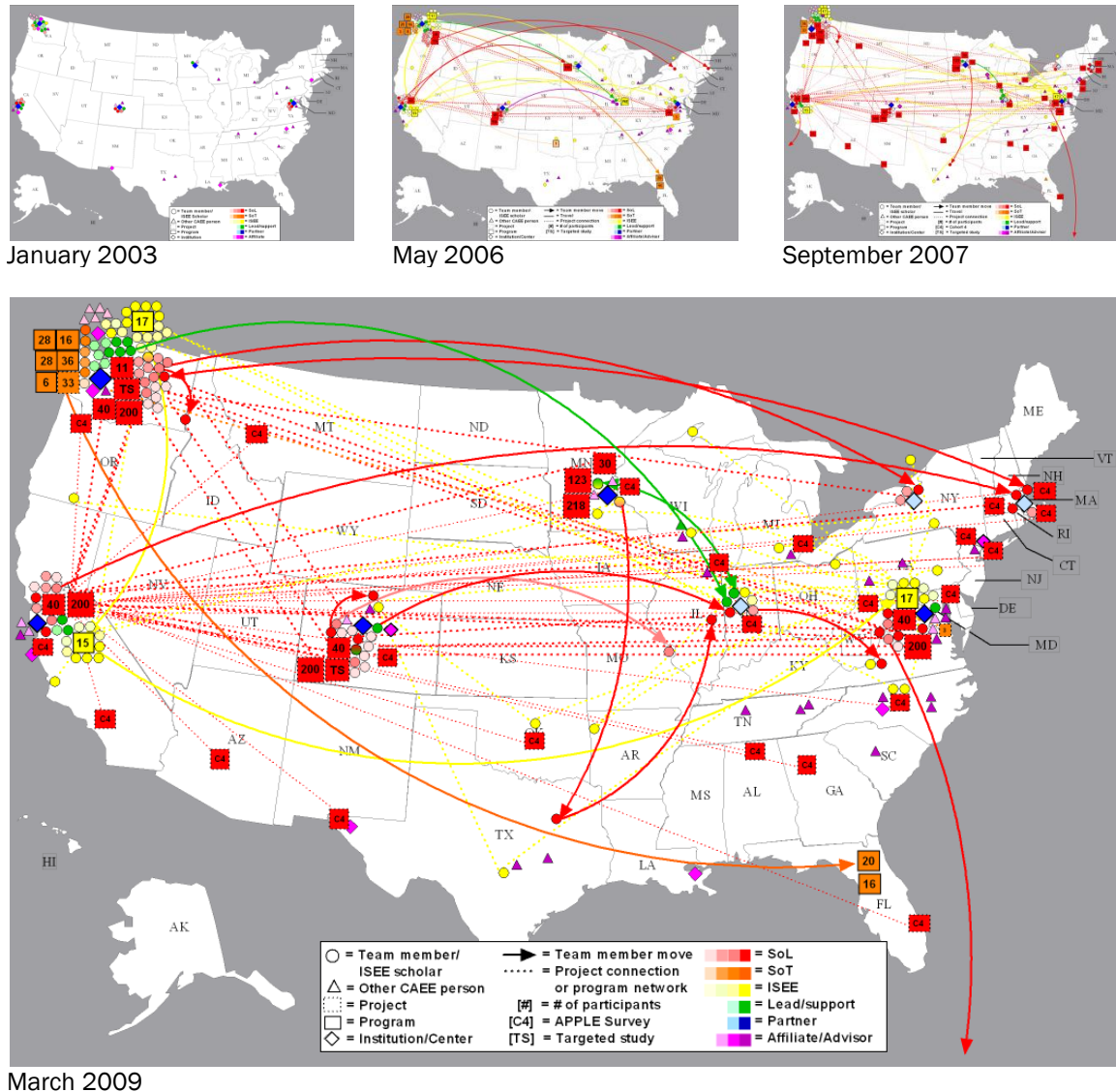


Figure 6.3-A shows sequentially the expansion of the CAEE team from the beginning in January 2003 through March 2009 (Maring 2009). The maps present a cumulative record of the growth of the team, movement to other campuses, and collaborations. The figures also include extended team members: the Institute Scholars and Advisory Board members.

Much of the movement to other campuses shown in Figure 6.3-A resulted from the growth of CAEE team members' careers. Research scientists and graduate students were "moving up" to faculty positions as assistant professors:

- Two joined Purdue University's recently established School of Engineering Education.
- One went to an education faculty position at the University of Rochester.
- Another joined the Department of Psychology at the University of the Virgin Islands.

- One became a member of Olin College of Engineering's Department of Mechanical Engineering.
- A former graduate student began a position in the College of Education at the University of Illinois.
- Another CAEE graduate researcher went to Virginia Tech's Department of Engineering Education.
- A third graduate student joined the University of Portland Computer Science faculty.

In addition, three graduate research assistants used CAEE research as the basis for their Ph.D. dissertations.

6.3.2 Collaborating Beyond the Center

From the beginning in 2003, the CAEE team sought to engage with colleagues at other national research and educational organizations, as well as a selection of companies with an interest in the education of future engineers. The team's goal in this was two-fold: to increase the audience for the growing body of our findings and to help others in their efforts to improve engineering education, whether through using CAEE's results or through using CAEE's tools and methods to conduct their own research. Some highlights are provided below.

Women in Engineering ProActive Network (WEPAN)

CAEE began contact with WEPAN early in 2003 through Sherry Woods, at that time president of WEPAN, who was also a member of the CAEE Advisory Board. Extending beyond her role on the Board, she was an active participant in annual CAEE team meetings and Academic Pathways Study data workshops, providing insight based on her expertise on the role of women in engineering. With her assistance, CAEE team members presented a workshop and the keynote address at the WEPAN National Conferences in 2008 and 2009, respectively.

Center for the Advancement of Scholarship on Engineering Education (CASEE)

Norman Fortenberry, Director of CASEE, served as an Advisory Board member over the last two years of activity for the Board (2006–2007). For the 2007 CASEE Annual meeting, CAEE Director Cindy Atman was invited to give the plenary address for the Dane and Mary Louise Miller Symposium, and she and other CAEE team members also presented an interactive workshop that engaged the attendees in discussion of APS results.

Center for the Integration of Research, Teaching, and Learning (CIRTL)

CIRTL and CAEE were the two centers funded by NSF in 2003 as higher education Centers for Teaching and Learning. CIRTL joined CAEE in sharing a booth at the ASEE Annual Conference in 2003 and 2004. CIRTL researcher Sandy Courter was there both years and in 2004 she was accompanied by graduate students Alice Pawley and Gina Svarovsky. CAEE team members also participated in all three CIRTL Forums in 2003, 2005, and 2008.

National Action Council for Minorities in Engineering (NACME)

CAEE's initial contact with NACME was in 2004 when Daryl Chubin, Senior Vice President for Policy and Research, reviewed an early draft of the Persistence in Engineering (PIE) survey. Four CAEE team members also met with Dr. Chubin to discuss diversity in engineering and possible dissemination strategies for CAEE results. CAEE's contact with Dr. Chubin continued after he took a position with AAAS (see below). NACME representatives participated in two of

CAEE's Advisory Board meetings: James Jones, Senior Director, in 2005, and Melonia Guthrie, Program Manager for University Programs, in 2007. CAEE leadership also discussed aspects of our research into diversity in engineering education in a series of phone calls with other senior NACME personnel, including VPs Tom Davis and Aileen Walter.

American Association for the Advancement of Science (AAAS)

Daryl Chubin, Director of the AAAS Center for Advancing Science & Engineering Capacity, attended several team meetings and the 2006 Advisory Board meeting. He also provided several reports for CAEE, including a "big picture" look at CAEE research directions as well as a guide to diversity-related resources that would be helpful in our research.

CAEE had two significant relationships with companies who were very supportive of our research into undergraduate engineering education.

Hewlett-Packard

Hewlett-Packard became involved in 2003 through their University Relations group, sending engineering representative William Wickes to APS data workshops. Bill also reviewed an early draft of the PIE survey from the perspective of a practicing engineer.

The Boeing Company

John Craig, the Boeing engineering focal contact for the University of Washington's Center for Engineering Learning and Teaching, participated in several APS data workshops held in the Seattle area, beginning in 2004. He also met with the Engineering Teaching Portfolio Program team to discuss possible extensions to the project, including a portfolio tool adapted for industry use. Throughout the period 2004–2010, John served as a sounding board for our results, drawing on his experience as a chief engineer in charge of a large group of engineers. He has provided valuable insights into CAEE's work on the learning experiences of students and the transition of graduates to their first engineering jobs.

APPLE Survey Collaborators

Finally, the group of researchers at the 21 institutions who participated in the Broader National Sample (the APPLE Survey administered in spring 2008) is a significant example of CAEE's collaboration efforts. This branch of the research was originally planned for only four other campuses but was expanded to 21 in early design modifications. These collaborating individuals were the primary contacts on each campus, responsible for leading the local activities, including the critical tasks of recruiting student participants and helping arrange details of the survey administration. The APS team produced individual reports for each of the 21 campuses, and these served as the basis for discussions about the results among the campus survey leads and their engineering administrators. In one instance, a CAEE co-PI was invited to present a workshop using the broader APS results on the participating APPLES campus, and this further collaboration led to a joint paper at ASEE (Waters, Chen, and Sheppard 2010).

7 *Looking Ahead: Ideas for Further Work*

In this section we discuss ideas for further work on being and becoming an engineer, an engineering educator, and an engineering education researcher.

This report described four different components of CAEE's work. It presented findings from two research studies: the Academic Pathways Study (APS) and the Study of Engineering Educator Decisions (SEED). It also described two programs: the Engineering Teaching Portfolio Program (ETPP) and the Institute for Scholarship in Engineering Education (ISEE). The following subsections discuss ideas for looking ahead to facilitate change on engineering campuses and for conducting future research in engineering education. We close by briefly discussing relevant research infrastructure issues and recalling the larger picture within which research on engineering education takes place.

7.1 **Effecting Change on Engineering Campuses**

Our hope is that the results from our work will inspire conversations and ensuing actions that will lead to change on engineering campuses.

To facilitate those conversations, in addition to presenting the findings in this report, we offer the following:

- Research briefs that present a short overview of many of the research papers that can be viewed on the CAEE web site at http://www.engr.washington.edu/caee/portal_research_briefs.html.
- A set of research-based questions that can be used to engage in conversations about student learning on engineering campuses. These questions are motivated by the summary of the APS results in Subsection 2.10 and presented as a full set of questions in Appendix D.
- Materials to run workshops that can be used to present specific research findings to interested faculty and administrators. These workshops have been successfully run with engineering educators and faculty development professionals. Workshops are listed in Appendix A, Subsection A.3.
- A set of research instruments that campuses interested in collecting their own data can use. The instruments are described in this report in Section 6 and on the CAEE web site at http://www.engr.washington.edu/caee/APS_Process_Procedures.html.
- Materials from the Engineering Teaching Portfolio Program on our web site at <http://www.engr.washington.edu/caee/etpp-sessions.htm> for campuses seeking to prepare graduate students for teaching in a cost-effective way.

7.2 Ideas for Future Research

The Academic Pathways Study guides us to certain areas of educational research that warrant further analysis. For example, considering the diverse programs and student perspectives we observed across the institutions we studied, it makes sense that other institutions will have their own nuances to be explored. We also observed substantial changes in students between their first and senior years, both in terms of learning and development. This warrants further inquiry into the middle years—the experiences of sophomore and junior level students. Further, APS longitudinal research focused on the experiences of students who spend the entirety of their undergraduate careers at one institution. However, APS cross-sectional research shows that this represents only a portion of engineering students. Studies of community college and transfer students are becoming important as students increasingly follow this academic path. Finally, there are important questions concerning students who never consider or enter engineering.

Given that the current Studies of Engineering Educator Decisions work focused on participants from a single institution, extending the research to confirm or refine findings reported here would be valuable. Such additional data could also be used to further investigate issues such as the role of research results in informing teaching decisions; the relationship between satisfaction, dissatisfaction, and additional change; and the broad issue of how engineering educators conceptualize students.

Building on the Engineering Teaching Portfolio Program efforts, we could further explore the ways in which the portfolio construction activities help participants reflect on their existing ideas about teaching and ultimately develop a more sophisticated, integrated, personalized, and actionable understanding of teaching. Building on research on the community of engineering education scholars that was conducted as part of the Institutes for Scholarship in Engineering Education, we could expand our investigations into how people enter and navigate the field of engineering research, even as the community itself is growing.

Appendix E represents an effort to move a conversation about future work beyond a direct extension of our work to a more expansive conversation about new research. In particular, the appendix contains research questions in the following seven areas:

1. **On pathways:** These questions follow directly from the theme of the Academic “Pathways” Study. The questions relate to students moving into, through, and out of engineering education systems.
2. **On learning engineering:** These questions focus on multiple aspects of the engineering education experience.
3. **On significant learning experiences:** The questions in this category draw attention to specific types of experiences that students have and the benefits of these experiences.
4. **On engineering knowing:** The questions in this category raise issues related to the underlying nature of engineering knowing, and how answers concerning what counts as engineering knowing can influence other curricular decisions.
5. **On teaching engineering students:** This category contains questions related to how engineering educators engage in teaching activities and how to help them engage more effectively.
6. **On researching issues in engineering education:** This category includes questions on how to support engineering education researchers and how the process of engaging in such research might affect the researcher.

7. **On bringing about change in engineering education:** The final set of questions raises issues concerning the phenomenon of change in academic settings.

The research questions in each category were assembled with four design principles in mind. First, 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. Second, 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. Third, we include questions that are at multiple levels of detail, in order to satisfy the interests of a wide range of readers. Finally, 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.

7.3 A Research Infrastructure for Scholarship in Engineering Education

To engage in scholarship to address the range of issues in the list of future research questions presented in Appendix E, there is need for a sound research infrastructure. Central to this infrastructure is a vibrant and engaged community of individuals with an appropriate range of expertise to engage in the work. This infrastructure also includes tools (e.g., communication, computing, databases) to enable the increasingly interdisciplinary and geographically distributed set of individuals in the community to collaborate to conduct scholarship in engineering education.

The community of individuals has been expanding in recent years. The CAEE team began work in January 2003. In 2010, at the end of the seven years that the Center was funded, the engineering education community is much larger, more distributed, more interdisciplinary, and it has expertise in a larger set of research methods. Building on the dedicated set of individuals in the Educational Research and Methods division of the American Society for Engineering Education (ASEE), there has been rapid growth in the field in the last decade (Adams and Cummings-Bond 2004; Adams *et al.* 2006; Atman 2006; Atman, Engineering education research, 2007; Streveler and Smith 2006; Sheppard *et al.* 2008; Jamieson and Lohmann 2009).

When initiated in 2003, CAEE joined the ranks of several centers with a focus on engineering education, including the NSF-funded Vanderbilt-Northwestern-Texas-Harvard/MIT Engineering Research Center (VaNTH, <http://www.vanth.org/>) and the NAE's Center for the Advancement of Scholarship in Engineering Education (CASEE, <http://www.nae.edu/casee>), as well as a growing number of campus based centers such as the Center for Engineering Learning and Teaching at the University of Washington (<http://depts.washington.edu/celtweb/>), the Leonhard Center at Pennsylvania State University (<http://www.engr.psu.edu/leonhardcenter/>), and the Center for Research on Learning and Teaching North at the University of Michigan (<http://www.engin.umich.edu/teaching/crltnorth/>). In addition to growth in the number of centers, engineering education departments have been established on such campuses as Purdue, Virginia Tech, Utah State, and Clemson. Growth has not been limited to colleges of engineering. There are now faculty positions with a focus on engineering education at several colleges of education across the country.

CAEE contributed to this growing field not only through the generation of research results, but also by directly contributing to the growth of the community through ISEE and through the large number of individuals who were involved directly with the Center.

While the number of issues that are pressing for research in engineering education grows, so does the community of scholars who are not only interested but also have the expertise to address those problems.

7.4 Remembering the Big Picture

Engineering education is a rich and vibrant area for research, with many opportunities for in-depth scholarship that can contribute significantly to improving engineering education for many constituencies. It is important to remember that the research is intended to support a variety of actors in the engineering education system to work towards goals that represent improvement in the system.

The breadth of potential contributions and constituencies can be seen in the ways that one could fill in the blanks in the statement, “Through our research, we are creating 1 for 2 to enable 3 .” Figure 7.4-A lists some of the ways that such a prompt can be populated. Combining the three elements in various ways demonstrates the breadth of the pathways for change. To illustrate, combinations include (a) individual students using stories of other students to make informed decisions about their own pathways, (b) classroom educators using findings about student motivation to increase the effectiveness and inclusiveness of their teaching, and (c) policy makers using information about supports and

Figure 7.4-A: Filling in the blanks in the statement, “Through our research, we are creating 1 for 2 to enable 3 .” (Smith *et al.* 2004)

1: foundation, database, pictures, stories, opportunities, expectations, revelations, problems, questions, relationships, lessons learned, pathways, resources, ideas, accounts, descriptors, processes, definitions, scenarios, grounded theory, research models, empirical claims, tools, instruments, quick read, publication series on engineering education, quality control model for engineering education, confidence, legacy, learning career guide for students, misconceptions, future research directions, roadmap, territory, “how people learn engineering,” forum, venue, place, context

2: U.S., students, engineers, teachers, policy makers, National Science Foundation, educational programs, education institutions, industry, learning sciences community, engineering faculty, faculty, potential students, guidance counselors, teachers in the U.S., U.S. president, employers, National Research Council, National Academy of Engineering, CAEE team, American Society of Engineering Education, European community, engineering professional societies, educational technology, parents, globe, mentors (coaches), community, administrators, legislature, the electorate, educational foundations, higher education community, corporate presidents, community colleges, student organizations

3: better learning, change, better society, informed electorate, broadly thinking engineers, new research directions, better teaching, better mentoring, better retention, better recruiting, clearer pathways, better self-understanding/awareness, knowledge base, awareness of diversity in many senses, multiple pathways, autonomous learning, enable learning how to be a good student, better policy, diversity in pedagogical practices, success for all, concept based learning, better educational support, improved self-efficacy/confidence, better engineering

barriers to structure the entire educational experience.

CAEE contributed to the field of engineering education during our seven years of funding, not only through the generation of a rich body of research results, but also by demonstrating the scope of research and program activity that a large center is uniquely capable of accomplishing. CAEE also contributed to the growth of the engineering education community through the many individuals who were involved directly and collaboratively with the Center and through the community-building efforts of ISEE.

Moving forward, the engineering education community needs to consider a large range of challenges, issues, stakeholders, constituencies, and opportunities involved with and affected by improving engineering education. In closing, we anticipate further research-based improvements to engineering education, ensuring that a diverse cadre of engineering graduates are prepared for the challenges they will face in the coming years.

8 Dedication

This report is dedicated to the memory of Denice D. Denton. Denice was with us through the initial years of CAEE. During this period, she was a team member in every sense of the word. She stayed up late nights with us as we wrote our proposal and conducted our reverse site visit at the National Science Foundation. She helped us to organize our research and was continually an inspiration as she reminded us about the larger vision of why we were doing this work: to improve the engineering education environment for *all* students.

We hope that our work will honor Denice's memory and help carry on her commitment to creating a diverse cadre of engineering students who are ready to meet the challenges of the 21st century.



The CAEE team (above) and Denice Denton (above right) at the 2003 spring kick-off meeting

9 Acknowledgements

9.1 National Science Foundation

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We would like to acknowledge the substantial support that Sue Kemnitzer and Susan Hixson, our two program directors, gave to the CAEE team.

9.2 People

Many individuals contributed to the success of CAEE. We would like to acknowledge and thank those individuals who helped make the Center run smoothly, participated in our studies, and provided us with both formal and informal advice.

9.2.1 CAEE Team

The CAEE team was large, interdisciplinary and geographically distributed. Team members, numbering more than 100 over the course of seven years of the Center, are listed in Appendix B in this report. The efforts of these researchers are documented in this final report and in the papers and presentations that are listed in Appendix A. We would like to highlight the contributions of two team members in particular. Jim Borgford-Parnell has been instrumental in helping the CAEE team think about how our research results could have a direct impact on engineering student learning in the classroom and in using our results in his engineering faculty development work. Angela Linse, part of the original CAEE team, took the lead in the design and implementation of the Engineering Teaching Portfolio Program, ensuring its success and long-term contributions to the field.

We would also like to acknowledge the additional contributions of almost 50 undergraduate students who worked with the research team across our many campuses.

9.2.2 Making the Center Run Smoothly

None of the work of CAEE would have been possible without the help of valuable staff members on each campus. These staff assisted us in submitting the proposal, allocating the funds, maintaining our budgets, organizing our board meetings, traveling to meetings to discuss our work, hiring staff, and reimbursing our research participants (to name just a few things). The individual who was principally responsible for leading all of these efforts is Sylvia Bach, administrator for the Center for Engineering Learning and Teaching at the University of Washington. Sylvia kept us going with a terrific sense of humor and enabled all the work that is represented in this report.

In addition, we would like to thank George Toye from Stanford University, who organized data collection and storage. George effectively helped the researchers in the Academic Pathways

Study archive data from participants in all of our studies in a secure database that could be shared by researchers who were distributed across the country.

Thanks also go to our evaluation team: Bayta Maring and Liz Moore at the University of Washington, and Susan Millar at the University of Wisconsin. They are truly dedicated professionals who helped collect both formative information, to continually improve the effectiveness of our center, and summative evaluation data for our more formal reports.

9.2.3 Study and Program Participants

Many individuals participated in the work of our center. There were more than 5,400 undergraduate students, faculty, and practicing engineers who participated in the APS and SEED research studies. There were also graduate students who participated in ETPP sessions and engineering education colleagues who were Scholars in the ISEE. All of these individuals were central to CAEE's efforts to improve the engineering education system.

We would also like to thank the campus contacts across the country who worked with us to identify and recruit participants for our studies.

9.2.4 Advisory Boards

External Board

The external board met with us in person on an annual basis. They ensured that we kept our research and programs both rigorous and relevant to both the academic and corporate world. Dave Wormley, engineering dean from Penn State, was extraordinary as the chair of the board. He ensured that we provided the board with information relevant for their evaluation, ensured that we received feedback that could help us to continually improve our work, and, not insignificantly, presided over our meetings (that included Board members, CAEE team, NSF representatives, and frequent host-campus guests) with humor and a wonderful sense of timing. Many thanks to all the members of the board, including Susan Ambrose, Richard Felder, Thomas Foot, Norman Fortenberry, Louis Gomez, Mario Gonzalez, Rogers Hall, Carolyn Meyers, Gregory Moses, Alfred Moyé, John W. Prados, John Roundhill, Elaine Seymour, Karan Watson, and David Wormley.

Internal Board

The internal board consisted of the engineering deans at each of the five partner schools as well as some additional experts in faculty development and the learning sciences on the campus at the University of Washington. The board was led by the dean at the lead school – the University of Washington. This meant that the leadership moved from Denice Denton to Mani Soma (interim dean) to Matt O'Donnell. All three provided strong leadership which included sound advice and additional funding to aid the work of the center. Although we were more than halfway through our work when Matt O'Donnell joined, his support has been notable. He provided us with new insights and fresh energy that motivated the team as we were moving to completion. We want to thank all of the internal board members who provided their support and insights: John Bransford, Steven L. Crouch, H. Ted Davis, Peter Hudleston, James H. Johnson, Jr., Nigel Middleton, Jody D. Nyquist, Matt O'Donnell, James D. Plummer, Mani Soma, Orlando Taylor, and Patricia A. Wasley.

9.2.5 Informal Advisors

We would particularly like to thank several people who provided us with valuable insights throughout the project.

- John Craig is the Boeing point person for UW's Center for Engineering Learning and Teaching, which is also directed by Cindy Atman. On many occasions, during CELT meetings with John, we would present him with CAEE findings to get his reactions. He always provided us with honest, direct feedback that helped us ensure the relevance of our work to future employers of engineering graduates.
- Jerry Gilmore helped us to frame our work by providing insights from his many years as a leader in educational evaluation.
- Barbara Olds gave us great advice to keep our project going through the whole process.
- Eve Riskin not only provided support for our overall project, but also was an "early adopter" of our research results. Eve incorporated APS results on gender differences into presentations that she has given on the UW campus and nationally, helping disseminate our work to bring change to engineering education.
- Sherry Woods, our WEPAN collaborator, was the person who continually held our feet to the fire at every team meeting. We appreciate the hard questions she asked all the way through the project and hope we answered them by the time we addressed her feedback on this report!

In addition, CAEE team members received informal advice from numerous people along the way through our many conversations at national meetings, talks and workshops on campuses, collaborations with colleagues on projects other than CAEE and through reviews of this report and our larger set of papers. We have continually received useful feedback that helped us improve our scholarship, and we would like to thank these many members of the community.

As CAEE ends, the CAEE team members look forward to continuing collaborations with colleagues in the engineering education community and beyond as we all work to help improve the engineering education system.

A Appendix: References and Cumulative Bibliography

References are listed in three groups:

- External (non-CAEE funded) references in the CAEE Final Report
- CAEE journal articles, conference papers, technical reports, and dissertations (2003 through June 2010, including items that are currently in press or submitted for review)
- Other CAEE Outputs, including talks and presentations, workshops, posters, and a section of ISEE Scholar work (2003 through June 2010)

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Turns, Jennifer, Kathleen Gygi, and Michael Prince. 2009. How Do Engineering Educators Take Student Motivation into Account?. In *Proceedings of the Research in Engineering Education Symposium 2009, Palm Cove, Queensland, Australia, July 20–23, 2009*.

Turns, Jennifer, Elisabeth Cuddihy and Zhiwei Guan. Submitted. I thought this was going to be a waste of time: Using portfolio construction to support reflection on project-based experiences. *Interdisciplinary Journal of Problem-Based Learning*.

Turns, Jennifer, Kathleen Gygi, and Michael Prince. Forthcoming. How engineering educators take student motivation into account.

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Yellin, Jessica M. H., Jennifer Turns, and Beza Getahun. 2005. How Early Is Too Early to Start Teaching? Teaching Portfolios as a Training Tool for Undergraduate Instructors. In *Proceedings of the American Society for Engineering Education Annual Conference, Portland, OR, June 12–15, 2005*.

Yellin, Jessica M.H., Yi-Min Huang, Jennifer Turns, and Charity Tsuruda. 2006. Teaching Portfolios in Academia – How Are They Used? In *Proceedings of the American Society for Engineering Education Annual Conference, Chicago, IL, June 18–21, 2006*.

Yellin, Jessica M.H., Yi-Min Huang, Jennifer Turns, Brook Sattler, Colin Birge, and Jerrod Larson. 2007. The Real World: A Factor That Engineering Faculty Consider In Making Decisions About Teaching. In *Proceedings of ASME International Mechanical Engineering Congress and Exposition, Seattle, WA, November 11–15, 2007*.

Yellin, Jessica M.H., Jennifer Turns, and Yi-Min Huang. 2008. Learner centered? How engineering faculty talk about students when reporting teaching decision. In *Proceedings of the Research in Engineering Education Symposium, Davos, Switzerland, July 7–10, 2008*.

Zimmerman, Heather T. 2005. Adolescent peer groups' argumentation in online spaces. In Proceedings of First Congress of the International Congress of International Society of Cultural and Activity Research (ISCAR), Sevilla, Spain, September 20–24, 2005.

A.3 Other CAEE Outputs

Talks and presentations

Adams, Robin S. 2004. Building Capacity in Engineering Education: Research, Community, Careers. Invited talk at Purdue University, March 25–26, 2004.

Atman, Cynthia J. 2003. "Improving Engineering Student Learning." Invited talk presented at the American Society of Engineering Education Engineering Deans Institute, Santa Monica, CA, March 24, 2003.

Atman, Cynthia J., Robin S. Adams, and Jennifer Turns. 2003. "Building Capacity in Engineering Education." Invited talk presented at the University of Queensland, Brisbane, Australia, November 2003.

Atman, Cynthia J. and Dennis Lund. 2004. Introduction to the Center for the Advancement of Engineering Education. Invited talk at American Society for Engineering Education Pacific Northwest Conference, Seattle, WA, April 22–24, 2004.

Atman, Cynthia J. 2007. "Describing and Doing Design: Multiple Views of Student and Expert Engineering Designers." Presented to faculty and staff of Arizona State University, Tempe, AZ, January 17, 2007.

Atman, Cynthia J. 2007. "Engineering Education Research: Some History and Examples from the U.S." Opening address to the Danish Centre for Engineering Education Research and Development, June 8, 2007, Copenhagen, Denmark.

Atman, Cynthia J. 2007. "Center for the Advancement of Engineering Education: An Overview of Accomplishments To Date." Luncheon Plenary at the NAE/CASEE Dane and Mary Louise Miller Symposium, Milwaukee, WI, October 9, 2007.

Atman, Cynthia J. 2008. "Undergraduate Pathways to Engineering: Insights from a Longitudinal Study." Presentation at the NSF Science, Technology, Engineering, and Mathematics Talent Expansion Program (STEP) PI Meeting, Arlington, VA, March 7, 2008.

Atman, Cynthia J. 2008. "Undergraduate Pathways to Engineering: Insights from a Longitudinal Study." Presentation to the Washington State University Engineering Education Research Center, Pullman, WA, April 14, 2008.

Atman, Cynthia J. and Sheri Sheppard. 2008. "Women in Engineering: Interests, perspectives, confidence ... and experiences." Keynote presentation at the *Women in Engineering Program Advocates Network Conference*, Austin, TX, June 18, 2009.

Atman, Cynthia J. and Sheri D. Sheppard (moderators). 2008. "APS and SEED: Introduction and Methodology." Presented at Special Session 1531, American Society for Engineering Education Conference, Pittsburgh, PA, June 22–25, 2008.

Atman, Cynthia J. and Sheri D. Sheppard (moderators). 2008. "Describing the Engineering Student Learning Experience Based on CAEE Findings" Presented at Special Session 2531, American Society for Engineering Education Conference, Pittsburgh, PA, June 22–25, 2008.

Atman, Cynthia J., Deborah Kilgore, Ken Yasuhara, Andrew Morozov and Dennis Lund. 2008. Thinking Design, Doing Design...and Becoming Designers. Keynote Address and Workshop at the ASEE Pacific Northwest Conference, University of Washington, Seattle, WA, November 7, 2008.

Atman, Cynthia J. 2009. "Current Activities of the Center for the Advancement of Engineering Education." Presented at the NSF Engineering Education Programs Awardees Conference, Reston, VA, February 1–3, 2009.

Atman, Cynthia J., 2009. Educating the Well-rounded Engineer, Insights from the Academic Pathways Study. Keynote presentation at the FIE Annual Conference, San Antonio, TX, October 20, 2009.

Atman, Cynthia J., Sheri D. Sheppard, Lorraine Fleming, Ronald L. Miller, Karl A. Smith, Reed Stevens, and Ruth A. Streveler. 2009. "Findings from the Academic Pathways Study of Engineering Undergraduates 2003–2008 – Overview and Panel Discussion." Presented at Special Session 2530, American Society for Engineering Education Conference, Austin, TX, June 16, 2009.

Atman, Cynthia J. 2010. "Educating the Well-Rounded Engineer: A View into the U.S. System." Invited Keynote Presentation, Joint International IGIP-SEFI Annual Conference 2010, Trnava, Slovakia, September 19–22, 2010.

Bell, Phillip. 2005. "How people learn: Established principles, research gaps, and methodological approaches." Presentation at the Institute on the Scholarship of Engineering Education at Stanford University. Menlo Park, CA, June 20, 2005.

Bell, Philip and S. Hsi. 2005. "Children's digital learning and play." Presentation at the Bay Area Institute, Center for Informal Learning and Schools. San Francisco CA, August 19–20, 2005.

Carrier, Ed and Sheri D. Sheppard. 2010. "Inspiring millennials-fostering peak performance across the generational divide." Presentation at the INNOVATION MASTER SERIES: Gaining a Competitive Advantage in an Uncertain Economy, Stanford University, Palo Alto, CA, June 16–18, 2010.

Chachra, Debbie. 2007. "Design and Student Engagement: Some Differences by Gender." APS research results presented at the House STEM Education Caucus, Washington, D.C., November 19, 2007.

Chen, Helen L. 2009. "Samples of Findings from the Academic Pathways Study—Implications for Engineering Education." Presented to Associate Deans of Engineering, Stanford University, Palo Alto, CA, April 10, 2009.

Fleming, Lorraine. 2004. Studying the Engineering Student Experience: A Longitudinal Approach. Talk presented at Scholarship of Teaching and Learning Day, Howard University, Washington, D.C., October 7, 2004.

Fleming, Lorraine and Kimarie Engerman. 2007. "Designing an Evaluation Framework for Retaining Students in STEM Ph.D. Programs." Presented at the Third Annual Alliance for Graduate Education and the Professoriate (AGEP) Capacity Building Meeting, February 2007.

Kilgore, Deborah. 2008. Panelist for "Gendered Innovation in Engineering" with CAEE co-PI Sheri D. Sheppard as moderator. APS results presented at *Gendered Innovations in Science and Engineering II* conference, hosted by the Clayman Institute for Gender Research at Stanford University, March 13–14, 2008.

Korte, Russell F. 2007. "How New Engineers Learn the Social Norms at GM". Presented at General Motors Inc., July 2007.

Korte, Russell 2007. "How New Engineers Learn the Social Norms at MnDOT". Presented to Minnesota Department of Transportation, May 2007.

Sheppard, Sheri D. 2003. "Taking Stock: A Look at Engineering Education at the End of the Twentieth Century and Beyond." Invited keynote talk presented at the IEEE Deans Summit II: Fostering Campus Collaborations, Miami, FL, January 9–12, 2003.

Sheppard, Sheri D. 2003. "A Description of Engineering: An Essential Backdrop for Interpreting Engineering Education." Invited talk presented at the Mudd Design Workshop IV, Claremont, CA, July 10–12, 2003.

Sheppard, Sheri D. 2003. "A Look at Engineering Education in the U.S. at the Turn of the Century." Invited talk presented at the Lemelson-MIT Workshop, Lenox, MA, October 17–19, 2003.

Sheppard, Sheri D. 2003. "Students Entering and Exiting the Engineering Pipeline – Identifying Key Decision Points and Trends." Invited talk presented at the Jing Lyman Lecture Series, sponsored by the Institute for Research on Women and Gender, Stanford University, Palo Alto, CA, November 5, 2003.

Sheppard, Sheri D. 2004. "Advancing Inventive Creativity through Education." Invited talk presented at the Invention Assembly, sponsored by Lemelson-MIT Program and National Science Foundation, National Academy of Engineering, Lenox, MA, April 23, 2004.

Sheppard, Sheri D. 2004. "U.S. Models for Teaching Inventiveness." Invited plenary talk at the Berlin International Colloquium on Enhancing Engineering Education in Europe (E4), Berlin, Germany, May 7–8, 2004.

Sheppard, Sheri D. 2004. Advancing Inventive Creativity-A Systems Problem. Invited talk presented at the Mechanical Engineering Seminar, Berlin Technical University, Berlin, Germany, June 7, 2004.

Sheppard, Sheri D. 2007. "Taking Stock: A Look at Engineering Education at the End of the Twentieth Century and Beyond." Invited speaker in Purdue's Department of Engineering Education's Winter Seminar series, West Lafayette, IN, January 30, 2007.

Sheppard, Sheri D. 2007. "Engineering Education in the United States: How Well Are We Preparing Our Students for Practice?" Invited speaker in the 2007 Air Products Distinguished Lecture Series, Penn State, University Park, PA, April 3, 2007.

Sheppard, Sheri D. 2007. "Changing Contexts of Undergraduate Engineering Education," Plenary panel at the 3rd International CDIO Conference, "Changing contexts for Engineering Education", Massachusetts Institute of Technology Cambridge, MA, June 11–14, 2007.

Sheppard, Sheri D. 2007. "The Bigger Context of Capstone Design," Keynote presentation at the National Capstone Design Conference, Univ. of Colorado, Boulder, CO, June 13–15, 2007.

Sheppard, Sheri D. 2007. Academic Pathways Study (APS) Overview. Special presentation at the 2007 American Society for Engineering Education Annual Conference, Honolulu, HI, June 24–27, 2007.

Sheppard, Sheri D. 2007. "Gendered Pathways to Success in Engineering." APS Results Presented at the Anita Borg Institute for Women and Technology, Palo Alto, CA, November 13, 2007.

- Sheppard, Sheri D. 2007. Presentation on APS findings given to the Stanford Western Area School and Colleges Committee (WASC), Palo Alto, CA, December 6, 2007.
- Sheppard, Sheri D. 2008. "Women's Perspectives—Discovering Your Inner Geek." Presentation to Stanford graduate seminar series E311A, Palo Alto, CA, January 10, 2008
- Sheppard, Sheri D. 2008. "Does Teaching Matter? (Making a Case for Better Teaching)." APS results presented at Rice University Dean's Invited Lecture Series, Houston, TX, April 9, 2008.
- Sheppard, Sheri D. 2009. "An Engineering Degree Does Not an Engineer Make—Findings from a National Survey Study of Engineering Students." Presented at the Stanford Institute for Higher Education (SIHER) Seminar 2009, Stanford University, Palo Alto, CA, January 13, 2009.
- Sheppard, Sheri D. 2009. "Samples of Findings from the Academic Pathways Study—Implications for Engineering Education." Presented to the Department of Engineering Education, Virginia Polytechnic Institute and State University, Blacksburg, VA, April 10, 2009.
- Sheppard, Sheri D. 2009. "Retention is Not the Problem: A National Study of Academic Persistence and Engagement of Undergraduate Engineers Compared to other Majors." Presentation at the AERA Annual Meeting, Session on Career Choice and Persistence, San Diego, CA, April 14, 2009.
- Sheppard, Sheri D. 2009. "Samples of Findings from the Academic Pathways Study—Implications for Engineering Education." Invited talk and workshop, NC A&T, Greensboro, NC, April 24, 2009.
- Sheppard, Sheri D. 2009. "Retention is Not the Problem: A National Study of Academic Persistence and Undergraduate Engineers Compared to Other Majors." Presented at the Stanford Society of Physics Students Faculty Colloquium, Stanford University, Palo Alto, CA, May 15, 2009.
- Sheppard, Sheri D. 2009. "Overview of APS results." Presented to Mechanical Engineering Education Redesign Leadership Team at ASME Turbo Expo, Orlando, FL, June 8–12, 2009.
- Smith, Karl A., Joyce Weinsheimer, and Victor Bloomfield. 2003. "Faculty Development: Enhancing Teaching Throughout the Career." Invited talk presented to the University of Minnesota Board of Regents, Minneapolis, MN, February 13, 2003.
- Smith, Karl A. 2003. Engineering and Education: Studies at the Interface. Invited talk presented to the Civil Engineering Department at University of Minnesota, Minneapolis, MN, October 17, 2003.
- Streveler, Ruth A. 2008. "Implications of the Academic Pathways Study (APS)." Plenary talk presented at the 7th Annual ASEE Global Colloquium on Engineering Education, Cape Town, South Africa, October 19–23, 2008.
- Yasuhara, Ken, Cynthia J. Atman, and Deborah Kilgore. 2007. "Snapshots of Engineering Design in First-year Undergraduates." Pacific Northwest Section Meeting of the American Society for Engineering Education (PN-ASEE), Pullman, WA. April 26–27, 2007.

Workshops

- Adams, Robin S. 2005. "Learning in Informal and Formal Environments: How People Learn." Workshop presented at Research Triangle Park, NC, March 15–16, 2005.

- Adams, Robin S., Cheryl Allendoerfer, Philip Bell, Lorraine Fleming, and Larry Leifer. 2005. "Communities of Practice in Engineering Education: What Are We Learning?" Special Session T2A presented at the Frontiers in Education Annual Conference, Indianapolis, IN, October 19–22, 2005.
- Adams, Robin S., Norman Fortenberry, Karl A. Smith, and Ruth A. Streveler. 2006. "Building Capacity for Engineering Education Research." Workshop presented at the 2006 American Society for Engineering Education Annual Conference, Chicago, IL, June 18–21, 2006.
- Allendoerfer, Cheryl, Rebecca Bates, Karen High, Lorelle Meadows, Kristyn Masters, Carol Stwalley, and Robin S. Adams. 2007. Special Interactive Session – "Communities of Practice in Engineering Education: How Do We Investigate Diversity and Global Engineering?". Presented at the 37th Frontiers in Education Conference, Milwaukee, WI, October 10–13, 2007.
- Atman, Cynthia J., Lorraine Fleming, Jennifer Turns, and Robert Mathieu. 2004. "Looking at Learning." Invited workshop presented at the Course, Curriculum, and Laboratory Improvement (CCLI) Conference, Arlington, VA, April 17, 2004.
- Atman, Cynthia J., Theresa Barker, Monica Cardella, and Susan Mosborg. 2004. "Looking at Research on Learning: an Interactive Workshop." Presented to University of Washington College of Engineering Teaching Assistants' Workshop, Seattle, WA, 2004.
- Atman, Cynthia J., Jennifer Turns, and Lorraine Fleming. 2005. "Looking at Learning: An Application of Research from the Learning Sciences to Engineering Classrooms." Workshop presented at the American Society of Engineering Education Conference, Portland, OR, June 12–15, 2005.
- Atman, Cynthia and Jim Borgford-Parnell. 2007. Applying Research from *How People Learn* to Engineering Classrooms. Presented at the 2007 INFORMS Combined Colloquia, Seattle, WA, November 2–3, 2007.
- Atman, Cynthia J., Deborah Kilgore, Özgür Eriş, Lorraine Fleming, Ronald L. Miller, Sheri D. Sheppard, Karl A. Smith, Reed Stevens, Ruth A. Streveler, Daniel M. Amos, Tori Bailey, Debbie Chachra, Helen Chen, Krista M. Donaldson, Monica Geist, Marcus Jones, Russell Korte, Sislina Ledbetter, Gary Lichtenstein, Heidi Loshbaugh, Christine Loucks, Dennis Lund, Holly Matusovich, Janice McCain, Andrew Morozov, Andrene Taylor, Jennifer Turns, Dawn Williams, and Ken Yasuhara. 2007. The Academic Pathways Study: Special interactive session on findings and implications for engineering education and practice. Presented at the 37th Annual Frontiers in Education Conference, October 10–13, 2007.
- Atman, Cynthia J., Jim Borgford-Parnell, and Jennifer Turns. 2008. "Thinking Design, Doing Design...and Becoming Engineers." Workshop presented at the ASEE–Pacific Northwest Conference, University of Washington, Seattle, November 6–8, 2008.
- Atman, Cynthia J., Lorraine Fleming, Deborah Kilgore, Ronald L. Miller, Sheri D. Sheppard, Karl A. Smith, Reed Stevens, Ruth A. Streveler, Jennifer Turns, Debbie Chachra, and Ken Yasuhara. 2008. "Linking Research Findings on Engineering Student Learning and Engineering Teaching Implications for Engineering Education." Workshop presented at the 38th Frontiers in Education Conference October 22–25, 2008.
- Borgford-Parnell, Jim, Jennifer Turns, and Ken Yasuhara. 2008. "Research on Engineering Learning and Teaching: Implications for Engineering Education." Workshop presented at the Professional and Organizational Development (POD) Network and the National Council for Staff, Program and Organizational Development (NCSPOD) Annual Conference, Reno, NV, October 22–25, 2008.

- Borgford-Parnell, Jim. 2009. "Applying Design Research Findings in Engineering Classrooms". Presented at the American Society of Mechanical Engineering Asia Pacific Congress, Taipei, Taiwan, April 2009.
- Borgford-Parnell, Jim and Jennifer Turns. 2010. Using Personas to Convey Research Findings and to Motivate Professional Development. Interactive Session at the 35th Annual POD Conference, Nov. 3–7, 2010, St. Louis, MO
- Fincher, Sally and Robin S. Adams. 2004. "Developing Engineering Education Research Questions: What do they look like? How do I get one?" Special Interactive Session at the Frontiers in Education Annual Conference, Savannah, GA, October 20–23, 2004.
- Linse, Angela and Jennifer Turns. 2004. "Using Diversity Statements to Help Future Engineering Faculty Explore Inclusive Teaching." Workshop at the Women in Engineering Programs & Advocates Network 2004 National Conference, Albuquerque, NM, June 6–9, 2004.
- Loshbaugh, Heidi G., Ruth A. Streveler, Kimarie Engerman, Dawn G. Williams, Lorraine Fleming, Marcus Jones, Tori Bailey, Sheri D. Sheppard, Kevin O'Connor, Reed Stevens, Portia Sabin, Lari Garrison, Lisa Perhamus, and Derek Seward. 2006. "Identity in the Making: Engineering Students' Pathways to their Profession." Workshop presented at the 2006 American Educational Research Association Annual Meeting, San Francisco, CA, April 7–11, 2006.
- Miller, Ronald L., Ruth A. Streveler, Barbara M. Olds, and Mary A. Nelson. 2004. "Concept-Based Engineering Education: Designing Instruction To Facilitate Student Understanding of Difficult Concepts in Science and Engineering." Workshop presented at the Frontiers in Education Annual Conference, Savannah, GA, October 20–23, 2004.
- Sheppard, Sheri D. and Cynthia J. Atman. 2007. Research in Engineering Education. Workshop presented at the plenary session of the American Society of Mechanical Engineering Chairs meeting, San Juan, Puerto Rico, March 2007.
- Sheppard, Sheri D. 2007. "Meeting with the Education Experts II: Research on Engineering Education." Workshop presented at the Changing Contexts for Engineering Education, 3rd International CDIO Conference, Massachusetts Institute of Technology, Cambridge, MA, June 11–14, 2007.
- Socha, David and Skip Walter. 2005. Special Session – User Observation and Sketching as Core Stages in the Software Design Process. Special Session T3A presented at the Frontiers in Education Annual Conference, Indianapolis, IN, October 19–22, 2005.
- Streveler, Ruth A. and Don L. Evans. 2003. "Identifying Difficult to Learn Concepts and "Repairing" Misconceptions." Workshop presented on Concept Inventories, North Carolina Agricultural & Technical University, Greensboro, NC, 2003.
- Streveler, Ruth A. and Don L. Evans. 2003. "Improving Student Learning in Science and Engineering Through the Use of the Concept Inventories." Workshop presented on Concept Inventories, North Carolina Agricultural & Technical University, Greensboro, NC, 2003.
- Streveler, Ruth A., Mary A. Nelson, Ronald L. Miller, and Barbara M. Olds. 2003. "Difficult Concepts in Science and Engineering: Identifying, Assessing, and Helping Students Learn Them." Workshop presented at the Share the Future IV Conference, Tempe, AZ, 2003.
- Streveler, Ruth A., Ronald L. Miller, and Barbara M. Olds. 2005. Special Session – Cognitive Legos: Helping Your Students Construct Scientifically Accurate Mental Models; Special Session S2A presented at the Frontiers in Education Annual Conference, Indianapolis, IN, October 19–22, 2005.

Yasuhara, Ken, Sherry Woods, and Holly Matusovich. 2008. "Bridging research and practice: What does the Academic Pathways Study tell us about women and engineering education?" Workshop presented at the WEPAN National Conference, St. Louis, MO, June 8–10, 2008.

Posters

Atman, Cynthia J., Jennifer Turns, Robin S. Adams, and Sheri D. Sheppard. 2003. Center for the Advancement of Engineering Education (CAEE). Poster presented at NSF ECE Grantees meeting, Washington, D.C., September 22–23, 2003.

Atman, Cynthia J., Jennifer Turns, Robin S. Adams, and Sheri D. Sheppard. 2003. Center for the Advancement of Engineering Education (CAEE). Poster presented at 1st CIRT Forum, Madison, WI, November 5–6, 2003.

Atman, Cynthia J., Robin S. Adams, Sheri D. Sheppard, and Jennifer Turns. 2005. Center for the Advancement of Engineering Education (CAEE). Poster presented at National Science Foundation Engineering and Computing Education Grantees meeting, Washington D.C., February 17–18, 2005.

Atman, Cynthia J., Robin S. Adams, Phil Bell, Lorraine Fleming, Larry G. Leifer, Ronald L. Miller, Barbara M. Olds, Sheri D. Sheppard, Karl A. Smith, Reed Stevens, Ruth A. Streveler, and Jennifer Turns. 2006. CAEE Overview. Poster presented at the Annual NAE/CASEE Dane and Louise Miller Symposium, San Diego, CA, October 27, 2006.

Atman, Cynthia J., Robin S. Adams, Phil Bell, Lorraine Fleming, Larry G. Leifer, Ronald L. Miller, Barbara M. Olds, Sheri D. Sheppard, Karl A. Smith, Reed Stevens, Ruth A. Streveler, and Jennifer Turns. 2007. CAEE Overview. Poster presented at the NSF Grantees Poster Session as part of the American Society for Engineering Education Annual Conference, Honolulu, HI, June 24–27, 2007.

Atman, Cynthia J., Robin S. Adams, Phil Bell, Lorraine Fleming, Larry G. Leifer, Ronald L. Miller, Barbara M. Olds, Sheri D. Sheppard, Karl A. Smith, Reed Stevens, Ruth A. Streveler, and Jennifer Turns. 2009. "Nuggets from CAEE Research." Poster presented at the NSF Engineering Education Programs Awardees Conference, Reston, VA, February 1–3, 2009.

Atman, Cindy, Robin Adams, Phil Bell, Lorraine Fleming, Larry Leifer, Ron Miller, Barbara Olds, Sheri D. Sheppard, Karl Smith, Reed Stevens, Ruth Streveler, and Jennifer Turns. 2010. Highlights of recent CAEE research findings. Poster presented at the NSF Engineering Education Awardees Conference, Reston, VA, January 31–February 2, 2010.

Gygi, Kathleen. 2010. What do we think we are preparing students for when we talk about professional socialization? What do they think?. Poster presented at the Scholarship of Teaching and Learning Symposium, University of Washington, Seattle, WA, April 2010.

Huang, Yi-Min, Jessica M.H. Yellin, Jennifer Turns and Brook Sattler. 2008. Investigating the Teaching Decisions of Engineering Educators. Poster presented at the University of Washington Teaching and Learning Symposium, Seattle, WA, May 6, 2008.

Jocuns, Andrew and Reed Stevens. 2008. "Current is the one that's mean: The Development of Engineering Student Trajectories of Identification." Poster presented at the International Conference for the Learning Sciences 2008, Utrecht, The Netherlands, June 23–28, 2008.

Lande, Micah. 2007. "The Scholarship of Impact In Engineering Education Research: A Case Study From The Institute On The Scholarship On Engineering Education." Poster presented at the Emerging Trends in Engineering Education Poster Session, American Society for Engineering Education Annual Conference, Honolulu, HI, June 24–27, 2007.

Matusovich, Holly M., Ruth A. Streveler, Helen Patrick, Ronald L. Miller, and Barbara M. Olds. 2009. "Choosing Engineering: A Longitudinal Qualitative Examination of Subjective Task Values." Poster presented at the American Educational Research Association Annual Conference 2009, San Diego, CA, April 13–17, 2009.

Matusovich, Holly M. 2010. Perceptions of Socializers. Poster presented at the American Educational Research Association Annual Meeting, Denver, CO, April 30–May 4, 2010.

Neeley, Lawrence, Sheri D. Sheppard, and Larry G. Leifer. 2006. "Design is Design is Design (or is it?) What We Say vs. What We Do In Engineering Education." 2006. Poster presented at the 2006 American Society for Engineering Education Annual Conference, Chicago, IL, June 18–21, 2006.

Turns, Jennifer, Jessica M.H. Yellin, and Yi-Min Huang. 2007. "Teaching Decisions: What Do Engineering Educators Say?" Poster presented at the Pacific Northwest-ASEE Spring Conference, Pullman, WA, April 26–28, 2007.

Yellin, Jessica M.H., Yi-Min Huang, Jennifer Turns, and Brook Sattler. 2008. Learner centered? How engineering faculty talk about students when reporting teaching decisions. Poster presented at the University of Washington Teaching and Learning Symposium, Seattle, WA, May 6, 2008.

Zimmerman, Heather Toomey, Lee, T.R., Philip Bell, Bricker, L. A., Reeve, S., and Maisy McMaughey. 2005. Studying the development of technological fluencies from children to young adults. Pressing Questions of the Information Age. Poster presented at the UW Digital Media Working Group Meeting, Seattle, WA, May 17, 2005.

Posters from Special Session F3E, 2007 FIE Conference (Academic Pathways Study)

Atman, Cynthia J., Robin S. Adams, Phil Bell, Lorraine Fleming, Larry G. Leifer, Ronald L. Miller, Barbara M. Olds, Sheri D. Sheppard, Karl A. Smith, Reed Stevens, Ruth A. Streveler and Jennifer Turns. 2007. "Center for the Advancement of Engineering Education." Poster presented at Special Session F3E, 2007 FIE Conference, Milwaukee, WI, October 10–13, 2007.

Donaldson, Krista, Helen L. Chen, George Toye, and Sheri D. Sheppard. 2007. "Targeting Undergraduate Students for Surveys: Lessons from the Academic Pathways of People Learning Engineering Survey (APPLES)." Poster presented at Special Session F3E, 2007 FIE Conference, Milwaukee, WI, October 10–13, 2007.

Chachra, Debbie, Özgür Eriş, Krista Donaldson, Sheri D. Sheppard, Camelia Rosca and Larry Ludlow. 2007. "Correlates of Persistence in Engineering Education: Preliminary Results from the Academic Pathways Study." Poster presented at Special Session F3E, 2007 FIE Conference, Milwaukee, WI, October 10–13, 2007.

Kilgore, Deborah, Cynthia J. Atman, Ken Yasuhara, Theresa J. Barker, and Andrew Morozov. 2007. "Considering Context." Poster presented at Special Session F3E, 2007 FIE Conference, Milwaukee, WI, October 10–13, 2007.

Light, Jennifer. 2007. "Development and Usage of an Alternative Methodology for Analyzing Large Quantities of Qualitative Data for Engineering Design Tasks." Poster presented at Special Session F3E, 2007 FIE Conference, Milwaukee, WI, October 10–13, 2007.

Korte, Russell F. and Karl A. Smith. 2007. "Portraying the Academic Experiences of Students in Engineering: Students' Perceptions of Their Educational Experiences and Career Aspirations in Engineering." Poster presented at Special Session F3E, 2007 FIE Conference, Milwaukee, WI, October 10–13, 2007.

Korte, Russell F., Sheri D. Sheppard and William C. Jordan. 2007. "A Case Study of the Socialization of Engineers: How New Engineers Learn the Social Norms of the Organization." Poster presented at Special Session F3E, 2007 FIE Conference, Milwaukee, WI, October 10–13, 2007.

Streveler, Ruth A., Monica Geist, Ravel Ammerman, Candace Sulzbach, Ronald Miller, Barbara Olds, and Mary Nelson. 2007. "Identifying and Investigating Difficult Concepts in Engineering Mechanics and Electric Circuits." Poster presented at Special Session F3E, 2007 FIE Conference, Milwaukee, WI, October 10–13, 2007.

Stevens, Reed, Andrew Jocuns, Lari G. Garrison, and Daniel M. Amos. 2007. "Becoming an Engineer: Ethnographic Perspectives on Engineering Education." Poster presented at Special Session F3E, 2007 FIE Conference, Milwaukee, WI, October 10–13, 2007.

Matusovich, Holly M., Ruth A. Streveler and Heidi G. Loshbaugh. 2007. "The Impact of Professional Goals on Students' Educational Experiences: A Longitudinal Case Study from Engineering." Poster presented at Special Session F3E, 2007 FIE Conference, Milwaukee, WI, October 10–13, 2007.

Birge, Colin, Kathleen Gygi, Eli Goldberg, Yi-Min Huang, Jerrod Larson, Brad Loetel, Rosalinda Rosales, Brook Sattler, Jennifer Turns, and Jessica M.H. Yellin. 2007. "Teaching Decisions: What Do Engineering Educators Say?" Poster presented at Special Session F3E, 2007 FIE Conference, Milwaukee, WI, October 10–13, 2007.

Other dissemination activity

Book chapters

Atman, Cynthia J., Jennifer Turns, Lorraine Fleming, Robin S. Adams, Larry Leifer, Sheri D. Sheppard, Karl A. Smith, Reed Stevens, and Ruth A. Streveler. 2005. The Center for the Advancement of Engineering Education: A Description at Year 2. In *Invention and Impact: Building Excellence in Undergraduate Science, Technology, Engineering, and Mathematics (STEM) Education*. Washington, D.C.: American Association for the Advancement of Science (AAAS).

Other mention of CAEE work

Centers for Learning and Teaching Network (CLTNet). 2003. CAEE Overview. Available at http://cltnet.org/cltnet/do/CltnetAction?ROOM_ID=1&TENANT_NICKNAME=CAEE&state=displayCenterOverview

Centers for Learning and Teaching Network (CLTNet). 2005. CAEE Teaching Portfolio Program: Preparing future faculty to teach. CLTNet Quarterly Newsletter. 4(1) Available at http://cltnet.org/cltnet/do/NewsAction?NEWSITEM_ID=137&ROOM_ID=1&state=displayNewsItem

Centers for Learning and Teaching Network (CLTNet). 2006. CAEE's Institute for Scholarship on Engineering Education: Building the community of engineering education researchers. CLTNet Quarterly Newsletter, 4(4). Available at http://cltnet.org/cltnet/do/NewsAction?NEWSITEM_ID=200&ROOM_ID=1&state=displayNewsItem

- Hickey, Hannah, University of Washington Office of News and Information. Engineering overdrive: Undergrads in field overworked, not informed about their major, study finds. *University Week*, 24(32), July 5, 2007. Accessed July 11, 2007: <http://uwnews.org/uweek/uweekarticle.asp?visitsource=uwkm&articleID=34853>
- Lord, Mary. 2010. Not what students need. *Prism Magazine*, January 2010, 19(5):44–46.
- ScienceDaily. 2009. Myth of high engineering dropout rate refuted by new study. 6 August 2009. Available at <http://www.sciencedaily.com/releases/2009/08/090804114104.htm>
- Seymour, Elaine; with Ginger Melton, Douglas J. Weise, and Liane Pedersen-Gallegos. 2005. *Partners in Innovation: Teaching Assistants in College Science Courses*. Rowman and Littlefield: Boulder, CO.

A.4 Selected Outputs from the Institute Scholars (2005–2010)

Institute Scholar Posters from Special Interactive Session T2A, 2005 FIE Conference

- Flinn, Brian D. and Russell J. Caspe. 2005. Knowledge Retention Between Sequential Classes: A Study on Students Recollection. Poster presented at the Special Interactive Session T2A at the Frontiers in Education Annual Conference, Indianapolis, IN, October 19–22, 2005.
- Imbrie, P.K. 2005. What does it mean to be “an effective team”. Poster presented at the Special Interactive Session T2A at the Frontiers in Education Annual Conference, Indianapolis, IN, October 19–22, 2005.
- Lee, Linda A., Lisa E. Hansen, and Denise M. Wilson. 2005. Empowering the Engineering Undergraduate in an Era of Economic Globalization. Poster presented at the Special Interactive Session T2A at the Frontiers in Education Annual Conference, Indianapolis, IN, October 19–22, 2005.
- Rhoulac, Tori D. 2005. Is My Writing That Bad? Understanding Technical Writing Challenges in Civil Engineering. Poster presented at the Special Interactive Session T2A at the Frontiers in Education Annual Conference, Indianapolis, IN, October 19–22, 2005.
- Socha, David. 2005. Finding My Research Home: Being Free to do Research My Way. Poster presented at the Special Interactive Session T2A at the Frontiers in Education Annual Conference, Indianapolis, IN, October 19–22, 2005.
- Yasuhara, Ken. 2005. The Secret Life of Engineering Education Researchers. Poster presented at the Special Interactive Session T2A at the Frontiers in Education Annual Conference, Indianapolis, IN, October 19–22, 2005.

Institute Scholar posters from Special Interactive Session S1E, 2007 FIE Conference

- Bates, Rebecca. 2007. “Asking a Question: Diversity in Student Learning Styles.” Poster presented at the Special Interactive Session S1E, Frontiers in Education Annual Conference, Milwaukee, WI, October 10–13, 2007.
- Bielefeldt, Angela R. 2007. “Engineering for Developing Communities, Cultural Competency, and Diversity.” Poster presented at the Special Interactive Session S1E, Frontiers in Education Annual Conference, Milwaukee, WI, October 10–13, 2007.

Bland, Larry. 2007. "Investigating Cultural Diversity and Global Engineering." Poster presented at the Special Interactive Session S1E, Frontiers in Education Annual Conference, Milwaukee, WI, October 10–13, 2007.

High, Karen A. 2007. "To Be or Not to Be (a research question)...That is the Question!" Poster presented at the Special Interactive Session S1E, Frontiers in Education Annual Conference, Milwaukee, WI, October 10–13, 2007.

Masters, Kristyn S. 2007. "Teaching-as-Research: How I Learned That Educational Research Is Not All That Different From My Usual Lab Experiment." Poster presented at the Special Interactive Session S1E, Frontiers in Education Annual Conference, Milwaukee, WI, October 10–13, 2007.

St. Clair, Sean. 2007. "Diversity?...In Southern Oregon?...Seriously?..." Poster presented at the Special Interactive Session S1E, Frontiers in Education Annual Conference, Milwaukee, WI, October 10–13, 2007.

Adams, Robin S. and Cheryl Allendoerfer. 2007. "ISEE 2006–2007 Additional Scholars' Questions." Poster presented at the Special Interactive Session S1E, Frontiers in Education Annual Conference, Milwaukee, WI, October 10–13, 2007.

Other Institute Scholar work

Bailey, Margaret, Caroline Baillie, John Impagliazzo, Donna M. Riley, and George D. Catalano. (2006). Special Session: Not Many Women in Engineering – So Why Should I Care? Bridging Gender Gaps and Stereotypes. In *Proceedings of the Frontiers in Education Conference, San Diego, CA, October 2006*.

Baillie, Caroline, Lauren Sharpe, and George D. Catalano. 2006. Special Session: Engineering and Social Justice, Part II: Looking Inward. In *Proceedings of the Frontiers in Education Conference, San Diego, CA, October 2006*.

Bielefeldt, Angela. 2007. Introduction to Environmental Engineering Courses Aimed at Recruiting and Retaining Students. In *Proceedings of the American Society for Engineering Education Annual Conference, Honolulu, HI, June 24–27, 2007*.

Bielefeldt, Angela, Bernard Amadei and Robyn Sandekian. 2007. Engineering for the Developing World Course Gives Students International Experience. In *Proceedings of the American Society for Engineering Education Annual Conference, Honolulu, HI, June 24–27, 2007*.

Bland, Larry. 2007. Incorporating Global Issues Into Freshman Engineering Course. In *Proceedings of the American Society for Engineering Education Annual Conference, Honolulu, HI, June 24–27, 2007*.

Catalano, George D. 2007. Engineering in a Morally Deep World: Applications and Reflections. In *Proceedings of the American Society for Engineering Education Annual Conference, Honolulu, HI, June 24–27, 2007*.

Fleming, Lorraine and Kami Carey. 2007. The Road to the Global Engineer: Using Liberal Arts Prerequisites Effectively in Engineering Design. In *Proceedings of the American Society for Engineering Education Annual Conference, Honolulu, HI, June 24–27, 2007*.

High, Karen A. 2006. Engineering Experiences for Elementary Education Majors in a Science Methods Course. Presentation prepared for the *Association of Science Teacher Educators Southwest Regional Conference, Wichita, KS, September 2006*.

High, Karen A. 2006. Elementary Education Majors Learn How To Teach Science and Engineering From an Engineer. Presentation prepared for the *American Institute of Chemical Engineers Annual Conference*, San Francisco, CA, November 2006.

High, Karen A. 2007. Science and Engineering Experiences for Elementary Education Majors from an Engineering Faculty Member. Presentation at the *Association of Science Teacher Educators Annual Conference*, January 2007, Tampa, FL.

Hilger, Helene, Francis De Los Reyes, Warren DiBiase, Len Holmes, Stephanie Luster-Teasley, Siva Mandjiny, Keith Schimmel, Todd Steck, and Chuang Wang. 2007. Multi-campus Design and Implementation of Problem-based Learning Courses in Environmental Biotechnology With Interdisciplinary Learning. In *Proceedings of the American Society for Engineering Education Annual Conference, Honolulu, HI, June 24–27, 2007*.

Imbrie, PK, Jason Immekus, and Susan Maller. 2005. Work in progress: A model to evaluate team effectiveness. In *Proceedings of the Frontiers in Education Conference, Indianapolis, IN, October 19–22, 2005*.

Jones, Sharon A. and Martha Were. 2008. Impact of the POSSE Program on First-Year Retention of Minority Engineering Students at Lafayette. *Proceedings of the Frontiers in Education Conference, Saratoga Springs, New York, October 22–25, 2008*.

Lee, Linda A. and Denise M. Wilson. 2005. Empowering the Engineering Undergraduate in an Era of Economic Globalization. In *Proceedings of the Frontiers in Education Conference, Indianapolis, IN, October 19–22, 2005*.

Lee, Linda A., Lisa E. Hansen, and Denise M. Wilson. 2006. The Impact of Affective and Relational Factors on Classroom Experience and Career Outlook among First-year Engineering Undergraduates. In *Proceedings of the 36th Annual Frontiers in Education Conference, San Diego, CA, October 28–31, 2006*.

McGaughey, Maisy. 2005. Images of science and becoming an engineer. Paper presented at the National Association for Research in Science Teaching (NARST) Conference, Dallas, TX, April 2005.

Meadows, Lorelle A., Jana Nidiffer, Stephen R. Ball, Cinda-Sue G. Davis, Cynthia J. Finelli, and William W. Schultz. 2006. Work in Progress: An Initial Assessment of the Effect of the First Year Experience on Under-represented Student Retention in Engineering. In *Proceedings of the Frontiers in Education Conference, San Diego, CA, October 2006*.

Nelson, Jill K. 2006. Work in progress: Project-based Assignments for a Graduate-level Digital Signal Processing Course. In *Proceedings of the Frontiers in Education Conference, San Diego, CA, October 2006*.

Rhoulac, Tori and Pamela Crenshaw. 2006. Preparing Civil Engineering Students to Meet Workplace Writing Expectations. In *Proceedings of the Frontiers in Education Conference, San Diego, CA, October 2006*.

Rosenberg, Louis. 2006. Design is Elementary: Are Kids Better Inventors Than Everybody Else? *Ambidextrous*, Issue 5, Fall 2006.

Socha, David and Skip Walter 2005. Is Designing Software Different from Designing Other Things? Paper presented at Harvey Mudd Design Workshop, May 2005.

Socha, David and Skip Walter. 2005. Special session: User Observation and Sketching as Core Stages in the Software Design Process. In *Proceedings of the Frontiers in Education Conference, Indianapolis, IN, October 2005*.

- Stwalley, Carol. 2007. The Effects of Gender on Elementary-aged Students' Interest In Technology: A Preliminary Report. In *Proceedings of the American Society for Engineering Education Annual Conference, Honolulu, HI, June 24–27, 2007*.
- Wilson, Denise M. 2007. Engaging Engineering Students in Broader ABET Outcomes Via Community of Learners Instruction. *Proceedings of the Frontiers in Education Conference, Milwaukee, WI, October 10–13, 2007*.
- Wilson, Denise M. 2008. Does it Matter? Psychological Sense of Community & Belonging in Engineering Education. *Proceedings of the Frontiers in Education Conference, Saratoga Springs, NY, October 22–25, 2008*.
- Wilson, Denise M., Philip Bell, Diane Jones, David Spring, and Lisa Hansen. 2010. Cross Sectional Study of Belonging in Engineering Education. *International Journal of Engineering Education*, in press.
- Yasuhara, Ken. 2005. Choosing computer science: Women at the start of the undergraduate pipeline. In *Proceedings of the American Society for Engineering Education Annual Conference, Portland, OR, June 12–15, 2005*.
- Yasuhara, Ken. 2005. Work in Progress – Gender and Preconceptions of Undergraduate Computer Science. In *Proceedings of the Frontiers in Education Conference, Indianapolis, IN, October 19–22, 2005*.
- Yasuhara, Ken. 2007. Viewpoints From the Doorstep: What's Turning Students Away From Computer Science and Engineering? In *Proceedings of the American Society for Engineering Education Annual Conference, Honolulu, HI, June 24–27, 2007*.
- Yasuhara, Ken. 2008. Viewpoints from the doorstep: Pre-major interest in and perceptions of computer science. Ph.D. dissertation, University of Washington, Seattle, WA, 2008.
- Yasuhara, Ken, and Richard Anderson. 2005. Talking about entering: Why women and men choose/reject computer science. Faculty poster. 36th SIGCSE Technical Symposium on Computer Science Education.

B *Appendix: Cumulative Team List and Advisory Board Members*

The CAEE team consisted of faculty, postdoctoral research associates, graduate research assistants, undergraduates, and professional staff at the five CAEE partner campuses, as well as at many additional campuses. In addition, External and Internal Advisory Boards provided guidance and oversight of Center activity.

The cumulative lists below show a team member's duration of service with CAEE and their academic title and institution for the date of their last affiliation with the Center. Graduate research assistants are listed separately, but undergraduate students are not listed by name.

The following abbreviations are used for the four main threads of CAEE activity:

- APS = Academic Pathways Study
- ISEE = Institute for Scholarship on Engineering Education
- SEED = Studies on Engineering Educator Decisions
- ETPP = Engineering Teaching Portfolio Program

A single asterisk denotes people who moved to a different institution during their time with CAEE. A double asterisk denotes a graduate research assistant who moved to a research scientist or faculty position during their tenure with CAEE (and are listed in both groups).

B.1 Faculty, Research Scientists, and Staff

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Purdue University
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Tammy VanDeGrift
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Katherine Winters
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2009–2010

Ken Yasuhara**
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2003–2010

B.3 ISEE Institute Scholars

Faculty and graduate students who participated in the Institute for Scholarship on Engineering Education are listed below by cycle year with their institutional affiliation at the time of ISEE participation. See Section 5 for details about ISEE.

2004–2005 Institute Scholars

Joe Cannon
Howard University

Russ Caspe
University of Washington

Eric Cheek
North Carolina A&T State University

Scott Eberhardt
University of Washington

Brian Fabien
University of Washington

Brian Flinn
University of Washington

PK Imbrie
Purdue University

Linda Lee
University of Washington

Maisy McGaughey
University of Washington

Lawrence Neeley
Stanford University

Tori Rhoulac Smith
Howard University

Louis Rosenberg
California Polytechnic State University,
San Luis Obispo

David Socha
University of Washington

Jeremy Sabol
Stanford University

Tom Williams
University of Washington

Denise Wilson
University of Washington

Ken Yasuhara
University of Washington

2005–2006 Institute Scholars

Frank Ashby
University of Washington

Tawana Carr
Howard University

Rebecca Currano
Stanford University

Greg Deierlein
Stanford University

Robyn Dunbar
Stanford University

Lisa Hansen
University of Washington

Marcus Jones
Howard University

Cathryne Jordan
University of Washington

Russ Korte
University of Minnesota

Micah Lande
Stanford University

2006–2007 Institute Scholars

Caroline Baillie
Queen's University

Rebecca Bates
Minnesota State University, Mankato

Angela Bielefeldt
University of Colorado, Boulder

Larry Bland
John Brown University

Kami Carey
Howard University

Marcel Castro
Howard University

George Catalano
Binghamton University, State University of
New York

Jaime Hernandez Mijangos
Texas State University, San Marcos

Karen High
Oklahoma State University

Reginald Mitchell
Stanford University

David Prince
University of Washington

Jeremy Sabol
Stanford University

Ross Shachter
Stanford University

Karl Smith
University of Minnesota

Simon Wong
Stanford University

Sharon Jones
Lafayette College

Stephanie Luster-Teasley
North Carolina A&T State University

Kristyn Masters
University of Wisconsin, Madison

James McGuffin-Cawley
Case Western Reserve University

Lorelle Meadows
University of Michigan, Ann Arbor

Donna Michalek
Michigan Technological University

Jill Nelson
George Mason University

Sean St. Clair
Oregon Institute of Technology

Carol Stwalley
Purdue University

B.4 External Advisory Board Members

The CAEE External Advisory Board consisted of engineering deans, educators, and industry representatives from around the U.S. who provided guidance and oversight of CAEE activity. Board members met annually with the CAEE team from 2003 to 2007. (The two-year extension for added work on APS did not include provisions for an advisory board.) The 16 people listed below served on the External Advisory Board during 2003–2007, with 9 to 13 active members at any one time.

David Wormley, Ph.D., Chair
The Pennsylvania State University
Dean of Engineering
(2003–2007)

Susan Ambrose, Ph.D.
Carnegie Mellon University
Associate Provost for Educational
Development
Director, Eberly Center for Teaching
Excellence
Principal Lecturer, Department of History
(2003–2007)

Denice Denton, Ph.D.
University of Santa Cruz
Chancellor
(2005–2006)

Richard Felder, Ph.D.
North Carolina State University
Professor Emeritus of Chemical
Engineering
(2003–2007)

Thomas Foot
Ford Motor Company, retired
Manager, Super Duty Powertrain
(2003–2006)

Norman Fortenberry, Ph.D.
National Academy of Engineering
Director, Center for the Advancement of
Scholarship on Engineering Education
(2006–2007)

Louis Gomez, Ph.D.
Northwestern University
Professor, Education and Social Policy
(2006–2007)

Mario Gonzalez, Ph.D.
University of Texas-Austin
Professor, Electrical & Computer
Engineering, retired
(2004–2007)

Rogers Hall, Ph.D.
Vanderbilt University
Professor, Department of Teaching and
Learning
(2003–2007)

Carolyn Meyers, Ph.D.
North Carolina A&T State University
Provost and Vice Chancellor for Academic
Affairs
(2003–2006)

Gregory Moses, Ph.D.
University of Wisconsin
Professor, Engineering Physics
(2003–2007)

Alfred Moyé, Ph.D.
Hewlett-Packard Company
Director of University Affairs, retired
(2003–2007)

John W. Prados, Ph.D.
University of Tennessee
Vice President Emeritus
Professor, Chemical Engineering
(2003–2007)

John Roundhill
The Boeing Company
Vice President for Product Strategy &
Development, retired
(2003–2007)

Elaine Seymour, Ph.D.
Director Emeritus and Research Associate:
Ethnography & Evaluation Research
Center to Advance Research and Teaching
in the Social Sciences (CARTSS)
(2003–2006)

Karan Watson, Ph.D.
Texas A&M University
Associate Provost and Dean of Faculties
Professor, Electrical Engineering
(2003–2007)

B.5 Internal Advisory Board Members

The CAEE Internal Advisory Board provided advice and support for CAEE activity on the five partner campuses. The Internal Advisory Board held periodic phone conferences and was chaired by an administrator from the University of Washington's College of Engineering.

Matt O'Donnell, Ph.D., Chair
University of Washington
Dean, College of Engineering
(2007)

John Bransford, Ph.D.
University of Washington
Professor, College of Education
(2004–2007)

Steven L. Crouch, Ph.D.
University of Minnesota
Dean, Institute of Technology
(2005–2007)

H. Ted Davis, Ph.D.
University of Minnesota
Dean, Institute of Technology
(2003–2004)

Denice D. Denton, Ph.D.
University of Washington
Dean, College of Engineering
(2003–2004)

Peter Hudleston, Ph.D.
University of Minnesota
Associate Dean for Student Affairs,
Institute of Technology
(2004–2007)

James H. Johnson, Jr. Ph.D.
Howard University
Dean, College of Engineering, Architecture
& Computer Sciences
(2003–2007)

Nigel Middleton, Ph.D.
Colorado School of Mines
Vice President for Academic Affairs
(2003–2007)

Jody D. Nyquist, Ph.D.
University of Washington
Associate Dean, Graduate School
(2003–2007)

James D. Plummer, Ph.D.
Stanford University
Dean, School of Engineering
(2003–2007)

Mani Soma, Ph.D.
University of Washington
Acting Dean, College of Engineering
(2005–2006)

Orlando Taylor, Ph.D.
Howard University
Dean, Graduate School
(2003–2007)

Patricia A. Wasley, Ph.D.
University of Washington
Dean, College of Education
(2003–2007)

Donald H. Wulff, Ph.D.
University of Washington
Associate Dean, Graduate School
Director, Center for Instructional
Development and Research
(2003–2007)

C *Appendix: APS Headlines*

This appendix provides an at-a-glance summary of Academic Pathways Study findings presented in Section 2 (Student Learning Experiences) in the form of a compilation of the “headlines” or lowest-level subsection headings. Many headlines summarize claims, while others identify specific topics addressed by the APS findings. The introductory and concluding subsections (2.1, Overview of the APS, and 2.10, Enabling Success for Engineering Students) were excluded from this compilation.

2.2 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.

2.3 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

2.4 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

2.5 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.

2.6 Engineering Design Knowledge, Conceptions, and Confidence

Conceptions of engineering design shift during the undergraduate years.

Conceptions of engineering design vary with gender and institution.

Men report higher confidence and course preparation with design than women.

First-year students consider design problem context.

Many sophomores do not consider design problems in temporal context.

Students do not consider broad context more as juniors and seniors than as first-years.

Consideration of temporal context does not develop significantly by senior year.

Women are more likely to consider certain aspects of broad context during design.

2.7 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.

2.8 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 coworkers 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

2.9 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

- **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?

D.2 Understanding and Connecting with Today's Learners

- **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?

D.3 Helping Students Become Engineers

- **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?

D.4 Developing the Whole Learner

- **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, 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:** 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?

D.5 Positioning Students for Professional Success

- **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 a career or just their first job? 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?

D.6 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? 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 the new hires able 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 the new hires have an appreciation for the needs 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?

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?

