

**Center for the Advancement of Engineering Education**

# **Findings from the Academic Pathways Study**



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## Reader's Guide

This report highlights several areas of particular interest to engineering education that emerged from the Academic Pathways Study (APS):

- The College Experience
- Motivation
- Confidence
- Knowledge of Engineering

Findings are drawn from the major components of APS: the Broader National Sample (APPLE Survey), the Longitudinal Cohort, and the Transition to Work. Some of the findings included in the report describe aspects of the undergraduate engineering learning experience that the APS researchers found to be interesting or surprising; others are those that might be perceived more as "common knowledge" or seem to confirm what might be expected.

As you read the report, we hope that you will balance our research against your own experience, deciding if a finding seems to fit what's happening on your campus or if it indicates a difference.

As part of Special Session #2530 at the 2009 ASEE Conference, the APS research team will be leading the audience in a discussion of some of the aspects of the research presented in this report. If you, as an independent reader, find things that are intriguing, have questions, or would like to engage in further discussion, please feel free to contact the research team through our website at [caee@enr.washington.edu](mailto:caee@enr.washington.edu).

More information about CAEE is available at <http://www.engr.washington.edu/caee/>. We welcome any feedback you may have on the findings presented in this report or any other aspects of our work.

### Organization, Nomenclature, and Symbols

- "Seniors" includes 4<sup>th</sup> and 5<sup>th</sup> year students in the APPLE Survey.
- "non-URM (non-underrepresented minorities)" students are defined as Caucasian, Asian, or Asian-American for engineering.
- Use of symbols: bullets "•" denote findings; arrows "→" denote comments, interpretations, or "food for thought" by the APS research team.
- Citations are provided for the various findings; in some cases, bullets from the same source are grouped with a single citation under the last bullet or comment.

## 1. Introduction

### -- CAEE and the Academic Pathways Study

The **Center for the Advancement of Engineering Education (CAEE)** began in January 2003 with funding from the National Science Foundation's Engineering and Education & Human Resources Directorates (ESI-0227558). CAEE conducts research into the engineering undergraduate learning experience and school-to-work transition; methods to expand the engineering education research community; understanding engineering faculty teaching decisions; and the professional development of engineering graduate students using teaching portfolios.

The **Academic Pathways Study (APS)** represents the largest portion of CAEE's research. The APS consists of longitudinal and cross-sectional studies of engineering undergraduates' learning experiences and the transition to work. Primary research questions discussed in this report are:

- **Skills:** How do students' engineering skills and knowledge develop and/or change over time?
- **Education:** What elements of students' engineering educations contribute to changes observed in their skills and identity?
- **Workplace:** What skills do early career engineers need as they enter the workplace? Where did they obtain these skills?

This report was produced as part of the 2009 ASEE Conference Special Session #2530 dedicated to Academic Pathways Study findings. The report draws on over 80 papers and articles published since the beginning of the study as well as additional unpublished analysis in a highly condensed collection of findings accompanied by occasional comments or interpretations.

Overall, there is much good news about the state of undergraduate engineering education. Students become engineers in multiple ways – gaining proficiency in the skills, learning the engineering "language"; developing their identity as engineers; and coming closer to knowing what an engineer does. They become more confident and feel prepared in teamwork, problem-solving and communication skills. Over time, engineering students gain exposure to more "real" engineering experiences, often through off-campus activities. Engineering students who start in engineering tend to stay there.

There are also challenges. Heavy workloads in competitive environments can lead to stress for some and the occasional "stick it out" mentality; there is sometimes a rough transition to upper level classes with more focus on teamwork. Many students feel financial pressures, particularly in the early years. Some students feel a disconnect between early courses in math/science and "engineering" and often do not feel prepared at graduation in issues of global/societal context. Many graduate but do not practice engineering. And women and men often have different experiences: women generally show lower confidence, respond more negatively to the heavy workloads, and sometimes "go underground" to find resources for help. Although most engineering students who start in engineering stay there, fewer students migrate into engineering.

We hope that this report will spur your further interest in our research. We have included references to our work if you want to delve deeper into the research.

### -- Data Sources Used for this Report

This report draws from four components of research and analysis by the Academic Pathways Study team:

The **Broader National Sample** (a part of APS, also referred to as APPLES, the Academic Pathways of People Learning Engineering Survey) (Section 3). APPLES was a short (approximately 10 minutes time to take) survey piloted in early 2007 on the four Longitudinal Cohort campuses and administered in the first quarter of 2008 to over 4,200 engineering undergraduates at 21 institutions around the U.S.. The results provide a broad portrait of students' college experiences, motivation, confidence, skills and knowledge, and plans for the future. Students from all academic levels were surveyed, and the data offers a set of comparisons between first year and senior year engineering students, and by gender and underrepresented minority status.

Ethnicity data for the Broader National Sample was obtained from a multiple-choice question on the APPLE survey. The ethnic breakdown of the Broader National Sample was 73% "non-URM" (Caucasian, Asian, or Asian-American) and 23% "underrepresented minority (URM)" (all other ethnicities); 4% of the sample did not respond or preferred not to answer. The male-female ratio was approximately 65-35.

**NSSE**, the National Survey of Student Engagement (Section 3). NSSE is a survey used by numerous institutions nationally (and increasingly internationally) to look at how involved their students are in their education. The APS team studied the NSSE data from students across a wide variety of majors to explore the engineering student college experience in comparison with those of students in other majors. NSSE is administered annually between January and June to students across class standing. By using student identifiers in the data files, NSSE analysts were able to identify over 11,000 students who responded as first-year students in 2002 and again as seniors in subsequent administrations.

The **Longitudinal Cohort** (part of APS; Section 4). Data from the Longitudinal Cohort provide the basis for more detailed findings on specific aspects of the engineering student learning experience. The Longitudinal Cohort consisted of 160 undergraduates on four campuses studied from their first through fourth years (2003-2007). Data collection involved different subsets of the cohort and utilized multiple methods including surveys (the APS-created Persistence in Engineering survey, PIE), structured interviews, semi-structured ethnographic interviews, and engineering design tasks. Academic transcripts and exit interviews of those leaving the study provided additional data. Results from this combination of qualitative and quantitative data provide a rich portrait of students' many pathways, their growth in learning, and their overall college experiences, thoughts, and plans.

Ethnicity data for the Longitudinal Cohort was obtained from a multiple-choice question that was periodically included as part of the PIE survey. Students could select multiple responses. For reporting purposes, Mexican American /Chicano, Puerto Rican, and Other Latino have been combined into one category, "Latino". The ethnic breakdown of the Longitudinal Cohort was 60% non-URM and 35% URM. (5% answered Other). The male-female ratio was approximately 60-40.

Investigations of student plans and activities beyond graduation (data from the **Broader National Sample** and **APS' Transition to Work** studies) are presented in Section 5. The **APPLE survey** gathered data on post-graduation plans of students in the Broader National Sample. In addition, the **Transition to Work** component of APS involved over 100 newly hired engineers in their first two years of an engineering job (and 10 of their supervisors) at a variety of private firms and public agencies. Data were gathered through a combination of interviews and observations.

## 2. Results from the Broader National Sample (supplemented with analysis of NSSE data)

The Broader National Sample involved over 4200 engineering undergraduates at 21 institutions across the U.S. In Spring 2008, these students took the APPLE Survey (Academic Pathways of People Learning Engineering). As part of an extended analysis, the APS team also studied findings from NSSE to compare engineering undergraduates with those in other majors. The APPLE survey focused on specific aspects of the students' learning, college experiences and future plans.

The majority of findings in this section are from the CAEE technical report *TR-09-02, Exploring the Engineering Student Experience: Findings from the Academic Pathways of People Learning Engineering Survey (APPLES)*. (Available later in 2009.) Findings reported in other publications are referenced accordingly.

### College Experience

#### Interaction with Instructors

- Seniors interact more with instructors than do first year students, and their courses utilize more project-based learning.

#### Academic Involvement

- Seniors are less academically involved in their courses than first year students. This is true for both engineering and liberal arts courses.
- Lower academic involvement of seniors vs. first years can be interpreted in light of increasing extracurricular participation in engineering and research activities.

→ *This is certainly an issue that merits consideration by faculty and programs—why do students who should be deeply invested in their major attend class less or not turn in their best work? Are students, as they progress through their academic career, expanding their ways of learning about engineering, maybe at the expense of their courses? Are they learning to optimize their time and have they learned what is needed to “do school” (since in general their self-reported GPAs are not dropping)? How can programs support students’ expanding and shifting priorities, particularly as they enter senior year when many work to combine school, extracurricular and career development activities (e.g., looking for jobs, interviewing, graduate school visits, etc), not to mention personal and family demands.*

#### Curriculum overload

- Senior men report a greater sense of curriculum overload and more difficulty in balancing their personal and academic lives than do first year men.
- Women’s sense of curriculum overload and difficulty with balance are greater than men’s at both the first- and senior-year levels.

#### Learning outside the classroom

- More seniors have had research, co-op and internship experiences than first year students, and many report that these experiences are a primary source for their learning about engineering work.

#### Extracurricular activities

- Participation in engineering extracurricular activities is greater for seniors than first year students, but participation in non-engineering extracurricular activities is comparable.

- Women consistently participate more than men in engineering extracurricular activities, and URM men more than non-URM men.
- There is greater participation in non-engineering extracurricular activities by women than men (just as with engineering extracurricular activities), and more participation by non-URM men compared to URM men (just the opposite as with engineering activities).

→ *Why do URM men prioritize engineering activities, whereas non-URM men prioritize non-engineering activities?*

#### Satisfaction – all students

- Looking at all students, seniors are less satisfied than first year students with their overall college experience; however, they also self-report similar GPAs.
- Seniors are also less satisfied than first-years with their instructors and are less academically involved (although they interact more frequently with faculty in their 4th year).

→ *This decrease in satisfaction with instructors for seniors when coupled with the increase in interaction with faculty is a challenge we need to address. Understanding its root causes might suggest means of enhancing the student-instructor relationship.*

#### Satisfaction – URM students

- When describing the experiences of multiple groups of students the story on overall college satisfaction is more nuanced. While the overall satisfaction of non-URM students is lower among seniors than for first-years, that of URM students is lower to begin with, and stays low.
- URM students show lower satisfaction as first year students than non-URM students, and it stays low through their fourth year, so the gap between URM and non-URM student satisfaction in the first year is not present among seniors because the non-URM students have become less satisfied.

### Motivation

#### Sources of motivation

- Primary motivators: intrinsic (behavioral - "I like to build stuff" and psychological – "I think engineering is fun") and social good ("engineers improve the welfare of society through creative work").
- Also important motivators are financial considerations, mentors, and family, in that order

#### Patterns of motivation

- There is little difference in motivational factors between first and fourth year students.
- URM and non-URM students are also similar with respect to three of the six motivation factors we considered (intrinsic psychological, intrinsic motivational, financial, social good, mentor, and parental) — their levels of parental, mentor and behavioral motivation to study engineering are comparable.
- Taking all six motivation factors together suggests that URM men may be more motivated than non-URM men to study engineering.
- There are also some differences in motivation when looking at different majors, for example mechanical engineering vs. industrial engineering vs. bioengineering.

#### Gender Differences

- For senior men, intrinsic behavioral motivation is the strongest factor, followed by intrinsic psychological and social good. Psychological motivation related to interest in the

engineering field, whereas behavioral motivation relates to the practical and hands-on nature of the field.

- For senior women, intrinsic psychological and behavioral and social good are the leading motivators
- Women are generally more motivated by mentors than men.

## Confidence

### Math and Science

- Confidence in math and science skills is comparable among first-year and senior students. At the same time, men are consistently more confident than are women, regardless of class standing.
- Confidence in math and science skills among seniors is predicted by self-reported GPA.

→ *Why doesn't confidence in math and science increase, particularly since over a year of college coursework is devoted to developing these skills? Why does a confidence gap between men and women persist, even though they are likely to be attending the same courses?*

→ *We cautiously interpret this as indicating that this confidence is grounded in school-measured academic performance. Notably absent as predictors of self-reported GPA are academic involvement and exposure to the profession through co-op, internship or research experiences, or frequency or satisfaction of interaction with instructors.*

### Open-ended Problem solving

- Confidence in open-ended problem solving is comparable among first-year and senior women. For men it is higher among seniors than among first-year students. This implies that college is contributing to men's open-ended problem solving confidence in ways that it is not for women.

→ *Why doesn't college contribute to growth in women's confidence in their open-end problem solving skills?*

### Social Skills

- Confidence in social skills among seniors is predicted by family income (an indicator of socio-economic status (SES)) and participation in non-engineering extracurricular activities. The model for first-year students suggests that, in addition to participation in non-engineering extracurricular activities, also important are the frequency of interaction with faculty and more weakly, family income. Absent as predictors in either of these models are academic involvement and exposure to the profession through co-op and internship experiences.

### Professional and Interpersonal Skills (e.g., written and oral communications, time management skills, teamwork, leadership, etc.)

- Seniors had lower confidence in their interpersonal skills than in their math and science skills, and are no more convinced of their importance in engineering practice than are first-year students.
- The most socially confident students tend to lean away from pursuing engineering work after they graduate.

→ *Does the simple descriptive fact that seniors are "least" confident in their professional and interpersonal skills (even though their confidence is still, on average, high) add fuel to the argument that engineering could be doing more to help students integrate both technical and social skills in their picture of what engineering work is all about?*

## Knowledge of Engineering

### Sources of Engineering Knowledge

- The number of sources students cite for their learning about engineering work is greater for seniors than for first-years.
- Seniors, more so than first-year students, report knowledge of engineering work coming from co-op and internship experiences. For seniors, co-op and internship experience is the most frequently reported source, followed next by course-related experiences.

→ *There was no difference between first-year and senior students in how frequently they cited school-related experiences as a source of knowledge of engineering. This is somewhat surprising in that coursework in upper division courses is typically designed to consider problems that are more representative of practice, and seniors are even more involved in engineering extracurricular activities than first-years; perhaps these school-related experiences simply have less effect on students' knowledge of engineering practice than do co-op and internship experiences.*

→ *Given the finding above that students have low confidence in, and place low value on, professional and interpersonal skills, could it be that co-ops and internships are too short for students to fully experience the*

*importance of these skills in engineering work? Or could it be that their work assignments tend to isolate them from the social dimensions of the workplace? It may also be that students don't connect the social dimensions of project-based learning and extracurricular activities to real engineering work, particularly if there is no opportunity to reflect on how a variety of skill types are brought to bear on this in-class and out-of-class experiences.*

School-related experiences have less effect on students' knowledge of engineering practice than do co-op and internship experiences.

### Math and Science

- Both first-year and senior students perceive math and science skills as being more important than professional and interpersonal skills.

### Differences between men and women, URM and non-URM students

- URM senior men indicate greater gains in knowledge about engineering over the four years than do non-URM senior men. They also ascribe greater importance to math and science, and professional and interpersonal skills than do non-URM senior men. (A difference in perceived importance of professional and interpersonal skills is also present between URM and non-URM first year men).
- For senior women, knowledge gain is strongly correlated with their self-reported level of knowledge of engineering *before* entering college. For senior men, knowledge gain is correlated with frequency of interaction with instructors, satisfaction with instructors, research experience, extra-curricular involvement (both engineering and non-engineering), and school-related sources of knowledge.

Both first-year and senior students perceive math and science skills as being more important than professional skills.

→ *We found no significant correlations between perceived importance of math and science skills and selected academic experiences for women, and only one significant correlation (satisfaction with faculty) for men. This suggests that students' perceptions of math and science are related to*

factors beyond faculty, engineering work and research experiences, perhaps factors not measured in APPLES. Alternately, it may be that little in the college experience actually serves to reinforce the perceived importance of math and science. Another interpretation could be that our construct, by combining math and science, muddied the distinctions between these two skill sets.

→ Findings suggest that men, more so than women, may be connecting more of their daily educational experiences into an overall picture of engineering work. In contrast, women seem to more tightly connect their current state of knowledge to their pre-college experiences. (It could also be that our survey did not capture the full range of ways that students--particularly, female students--gain an understanding of engineering.)

- Self-reported GPA is comparable between senior and first year students within the URM and non-URM women groups. For URM men, self-reported GPA is lower for seniors than for first-years.
- Also noteworthy is that among senior women, self-reported GPA is significantly lower for URM women than for non-URM women (but this difference is not present among first year women).
- This self-reported GPA “gap” among senior women may go unnoticed by the women themselves, as within group (e.g., URM women) there is no significant drop from first-year to senior year. A self-reported GPA “gap” also exists between first year URM and non-URM men, but disappears when the two groups are seniors.
- Seniors report having learned more about engineering work since entering college than first year students, as we would hope. Notably, senior URM men report a greater gain than non-URM men.

#### Comparing Engineering Students with Other College Students (NSSE data)

- Engineering students in general are more likely to stick with their major when compared to other college students
- Engineering students are equally engaged with their studies and similar in other factors to students in other majors ranging from grades to overall satisfaction
- They differ in some college experiences (engineering majors are more likely to have a culminating senior experience, but less likely than other majors to study abroad), and learning gains (greater gains in practical competence and higher order thinking, and lower gains in personal and social development and general education than other majors).
- Overall, students are less likely to migrate into engineering than into other majors.

→ There is strong evidence that engineering students do stick with their major (i.e., the primary problem is not one of retention), but that fewer students migrate into engineering programs, and fewer begin their college careers in engineering. A challenging question for all of us to consider is how can students who don't start college on the engineering track migrate into engineering and still graduate on time? To resolve this lack of students coming in later to the major, engineering needs more pathways for inward migration (McCormick, et al., AERA 2009; Ohland et al., JEE 2008).



### 3. Extending the Portrait of Engineering Learning (Details from the Longitudinal Cohort)

Primary data from the Longitudinal Cohort were collected from 160 undergraduates on four campuses over four academic years (2003-2007). Data gathering relied on multiple methods including surveys, structured interviews, semi-structured ethnographic interviews, and engineering design tasks. All participants received the series of surveys and different subsets of the cohort participated in data collection by the other methods. Academic transcripts and exit interviews of those leaving the study provided additional data. In addition, there were two other supplemental data sources: 1) a cross-sectional study of engineering undergraduates at a fifth institution using the PIE survey that also included some additional focus groups to investigate transfer students and 2) a pilot version of the APPLE survey (APPLES1) that was given to undergraduates from all grade levels at the Longitudinal Cohort schools early in 2007.

Results from this combination of qualitative and quantitative data from a smaller group of students studied over time provide a richer and more detailed picture that can help to illuminate findings from the national APPLE Survey. At the same time these results suggest the great variety of pathways that students take through their undergraduate years and can offer insights into the details of specific and individual student learning experiences.

#### College Experience

The findings from the Longitudinal Cohort expand on themes from Broader National Sample research and provide additional details on other aspects of engineering students' overall college experiences.

#### Persistence – Factors Affecting the Commitment to Stay in Engineering

- For some students, their commitment to engineering can be challenged by the pressures associated with what they perceive is a highly competitive and demanding program, frustrations with grading practices, and concerns with advising (Korte and Smith, 2007).
- Once securely in an engineering major, some students can adopt a feeling of superiority because they feel that their major is more difficult and competitive and requires more hard work than other college majors (collectively defining a “meritocracy of difficulty”). Some students perceive that these beliefs are supported by the faculty and cultures of engineering education. Over time, this feeling of superiority can lead to development of an "us/them" attitude because other intellectual pursuits are perceived as less rigorous and valuable than engineering (Stevens et al., ASEE 2007).

*Sponsorship of student interests or behaviors by individuals or organizations can play a central role in how and under what circumstances students entered, stayed in, or left engineering education.*

- Some students exhibit a "doggedness" in continuing in engineering, an intention towards perseverance for its own sake with little regard for enjoyment or satisfaction, although this tendency was observed to fade by the fourth year (McCain et al., ASEE 2007).
- Sponsorship of student interests or behaviors by individuals or organizations can play a central role in how and under

what circumstances students entered, stayed in, or left engineering education (O'Connor et al., 2007).

→ *The data suggest that one way students' intrinsic interests develop into discipline-relevant intrinsic interests is through the processes of sponsorship. Thus, "intrinsic interest in engineering" is mutually constructed by the student and sponsors within the discipline (O'Connor et al., ASEE 2007).*

- A commonly-held view among students at one public institution involved in the study, was that women had advantages in the engineering college admission process, thus leading some students to believe that women applicants were less qualified for admission than their male counterparts (Garrison et al., 2007; Garrison, 2009, dissertation in preparation).

→ *There were some indications of these feelings in interviews at other schools. These beliefs about advantage and the parallel belief that women were less qualified seemed to feed off of the competitive and uncertain standards for admission to the major at one particular public institution (Garrison et al., 2007; Garrison, 2009, dissertation in preparation).*

→ *We also note that on occasion, a perception of having unearned advantage can have a detrimental effect on women's self-confidence (Chachra et al., ASEE 2008).*

- Some students engage in a constant re-evaluation of whether to stay in engineering (Lichtenstein et al. ASEE 2007; Lichtenstein et al., JEE in press).

→ *The data suggest that students' decisions whether or not to major in engineering are malleable. This provides both challenge and opportunity for those seeking to increase the numbers of undergraduates who complete degrees in engineering. If our initial analyses are borne out through further study, we believe that important but relatively minimal changes in classroom instruction as well as institutional structure and outreach could tilt the odds in favor of students' declaring an engineering major (Lichtenstein et al., ASEE 2007).*

- About 80% of the students in the Longitudinal Cohort reported that race had no impact on their engineering aspirations (Fleming et al., ASEE 2008).
- There was no significant difference between the SES quartiles in terms of academic persistence (defined as intending to complete an engineering major).
- However, the results showed that low SES students were more likely to persist professionally (defined as intending to do engineering-related work and/or study for three years following graduation) than their high SES counterparts (Donaldson et al., ASEE 2008).
- The process of choosing engineering (persistence) varies for students depending on whether, or not, they identify with the types of activities in which engineers engage
- Even in their fourth undergraduate year, students can be uncertain about themselves as future engineers (Matusovich, PhD dissertation, 2008).

→ *Students' choices to pursue engineering majors are based on beliefs about their engineering-related competence and how much they value succeeding in an engineering major.*

### Reasons for Leaving Engineering

- Some students make decisions about majoring in engineering or leaving the major based on pre-requisites and before they are enrolled in engineering courses (Lichtenstein et al., ASEE 2007).
- There is often little exposure to the many possibilities that an engineering career can offer in the first two years while students are taking math and science courses taught outside of engineering departments (Garrison, 2009, dissertation in preparation; Stevens et al., JEE 2008).

- Some students experience fear of losing a scholarship if their grades fall as a result of poor performance in prerequisite courses and this can cause some of them to abandon their engineering aspirations (Fleming et al., ASEE 2006).

→ *Institutions can assume a proactive role by first identifying the many reasons for students' departures from their engineering programs, and then developing intervention programs to specifically address these reasons* (Fleming et al., ASEE 2006).

→ *An important role for engineering programs is to help students understand the richness of the engineering field so that they are making an informed choice about staying or leaving engineering* (Atman 2008, NSF STEP Meeting).

#### Perceived changes in course emphasis [expectations], years 1-2 vs. years 3-4

- Some students struggle to adjust to the shift from individual work in years 1-2 to group work in years 3-4, and even more to the shift from questions and coursework based on problem sets (with the expectation of a right or wrong answer) to more open-ended problems (Stevens et al., JEE 2008).

#### Satisfaction and Engagement

- One sample of students in the Longitudinal Cohort indicated that most students were satisfied with the quality of instruction and availability of faculty, whereas they were much less satisfied with their academic advising experiences (Fleming et al., ASEE 2005).
- Academic disengagement, in both liberal arts courses and engineering courses, increases steadily for all students (Chachra et al., in preparation).
- Students can have a desire for more balance (i.e., pursuits and learning projects aside from engineering studies) than their prescribed program of study will allow (Stevens, et al., ASEE 2005; Loshbaugh et al., ASEE 2006).

#### Satisfaction and academic engagement – transfer students

- Compared to non-transfer students, transfer students reported a lower level of satisfaction with their overall collegiate experience (Korte and Smith, ASEE 2007).

→ *This lower satisfaction could possibly be related to other things that some of the transfer students reported: they had difficulty transferring credits, getting started in their programs, and meeting people (typically because they missed the freshman year)* (Korte and Smith, 2008 TR0802).

- Compared to non-transfer students, transfer students reported lower levels of academic engagement for liberal arts classes and lower levels of overall satisfaction with their collegiate experience (Korte and Smith, ASEE 2007).

#### Gender Differences in the College Experience

- Women report higher degrees of curriculum overload than their male counterparts (Chachra et al., in preparation).
- Female engineering students report somewhat less satisfaction with their collegiate experience than their male counterparts; there is some weak evidence that they are less satisfied with academic facilities and services but men and women report equal degrees of satisfaction with their instructors (Chachra et al., manuscript in preparation).
- Some female study participants at one of the study's public institutions spoke of the importance of doing well to favorably represent their gender.

- 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, because of perception, 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., 2007).

→ *Since this institution required a formal application to engineering, students developed a perception of the admission process that included the view that women have an easier time getting into the major than men do. This is cause for concern because this cultural model seemed to force women to “go underground” when they need help, and avoid working in teams with their male peers (Garrison et al., ASEE 2007).*

- A series of one-on-one interviews across the four campuses revealed evidence of female students feeling they were being compared for selection to engineering honor societies, obtaining employment and internships, or being graded in classes, etc.
- Female engineering students across all four schools in the Longitudinal Cohort also mentioned being out-numbered by males in courses and in some programs.
- Although women mentioned sticking together in solving problems, over time there was a discussion of learning how to work with “these guys” and talk to “these guys.”
- Some female APS students across the four institutions mentioned how gender bias or discrimination was more of an issue during their first two years, but that it had essentially disappeared by the time they were seniors (Garrison et al., 2007; Garrison et al., 2008).
- Some women and men at one APS institution described women's lack of self-confidence as a primary difference between the sexes in engineering education (Chachra et al., ASEE 2009).
- Across the institutions, women reported greater involvement in extra-curricular activities than men, as well as a greater sense of curriculum overload. An in-depth examination of the experiences of some students at one of the institutions showed different patterns of involvement, with women more often taking leadership roles in student organizations. Also, men who were significantly involved in extra-curriculars tended to focus their efforts on one activity or organization, while women tended to be involved in more than one (Chachra et al., FIE 2009).

## Motivation

The APPLE Survey looked at how students prioritized six predefined motivational factors. Data gathered through interviews of the longitudinal cohort of students allowed the research team to look at the other components of student's motivation to study engineering.

### Sources of Motivation

- First year students were motivated to study engineering primarily by a desire to contribute to the social good, and an expectation that an engineering degree would lead to financial rewards. Parental influence was also mentioned as a factor by first year students, but this influence decreased after the first year. (Korte et al., TR-08-02; Fleming et al., ASEE 2005; Eris et al., ASEE 2007; Stevens et al., 2007).
- There was no difference in motivations (familial, financial, or social good, high school mentor, college mentor) between men and women. (Chachra et al., in preparation).
- An in-depth examination of the factors motivating students at one institution revealed that students' confidence in their math and science skills led them to consider an engineering major that would build on their strengths (Kilgore et al, AERA 2009b).

- In all four years of college at one institution, social good and financial rewards remained relatively high motivators, in comparison to parents' influence (Kilgore et al, AERA 2009b).
- There was a perception among some students that majoring in math or science would lead to a job with lower status (e.g., in teaching or lab work) when compared to an engineering career (Garrison, 2009, dissertation in preparation).
- In the case of APS students several features of engineering were key in deciding to major in the field, namely working on cutting edge projects, making a good salary in a secure field, and having a degree that was viewed as being highly valued and respected by other fields, including being perceived as a degree that was potentially transferable, in that it could allow them to pursue other careers outside of the field of engineering (Garrison, unpublished data).

#### Sources of Motivation – gender differences

- At one institution, mentors were more important to women's decisions to remain in engineering. At the same time, some students distinguished between teachers and others who provided mentoring informally, and mentors assigned to them in some kind of official capacity (Kilgore et al, AERA 2009b).
- At one of the public institutions, there were no significant differences between men and women or upper and lower division students regarding motivations to study engineering. (Korte and Smith, 2008 TR0802).

#### Sources of Motivation – transfer students

- At one public institution, transfer students were less motivated by financial considerations than non-transfer students (Korte and Smith, 2008 TR0802).

→ *As greater numbers of students choose to attend community college to contain costs, it is interesting to see that some students consider the potential financial rewards of an engineering degree as less important than their counterparts who attend the university from the start. Perhaps their greater challenges in getting a college degree lead them to emphasize the intrinsic rewards of their chosen degree.*

### Confidence

With the APPLE survey we explored student confidence in math and science skills, open-ended problem solving, and professional and interpersonal skills. The longitudinal cohort interviews, PIE survey, and design tasks allowed us to probe confidence in a more detailed manner.

#### Confidence – Gender, Ethnicity, and Socioeconomic class

- On the PIE and APPLE surveys, women reported less confidence in math and science skills and open-ended problem solving than men (Chachra et al., ASEE 2009).
- Women and men at one institution both disparaged recognition for women's accomplishments, perceiving that women were given more credit than they deserved (Chachra et al., ASEE 2009).
- At one institution, senior women presented themselves as ready to learn and work hard to become valuable to employers, while the senior men presented themselves as already valuable (Chachra et al., ASEE 2009).

→ *Women's lower self-confidence may be a product of holding higher standards for themselves. Qualitative inquiry at one of the APS institutions tells another story, that students believe that women get special advantages not available to men, and therefore probably are not as qualified as their academic and professional records suggest (Garrison et al., 2007; Chachra et al., ASEE 2009).*

- Across the four APS institutions, and throughout the four years, men generally reported higher levels of self-confidence and course preparation to engage in design than women.
  - This gender difference was primarily accounted for by the majority group, while no significant differences were found between underrepresented (URM) men and women or between URM and non-URM students more generally (Morozov et al., 2008).

Over time, men generally reported higher levels of self-confidence and course preparation to engage in design than women. This gender difference was primarily accounted for by the non-URM group.

→ *The localization of the gender gap in confidence to do design within the non-URM students demonstrates that, at least for this sample and with respect to design, a commonly held understanding about gender differences in confidence does not extend to URM men and women (Morozov et al., 2008).*

- Low SES students reported lower confidence with math and science skills, and with solving open-ended problems than high SES students (Donaldson et al., ASEE 2008).

→ *Faculty and advisors need to recognize that student confidence, in particular for women and students from low SES backgrounds, can be low in spite of high grades or other outward-appearing successes.*

- Women with consistently high grades can still doubt their engineering ability and have uncertainty about practicing engineering (Matusovich et al., ASEE 2009).
- Students generally have positive beliefs about their competence in engineering, although some show a pattern of renegotiating this belief and this may be more prevalent for women (Matusovich, PhD dissertation, 2008).

→ *Students' self-perceptions as future engineers are connected to both competence and value beliefs and to the choice to persist in engineering.*

#### Confidence - Transfer Students compared to traditional students

- Transfer students reported lower confidence in personal and interpersonal skills (non-engineering skills).
- Transfer students reported higher confidence in solving open-ended problems (Korte and Smith, ASEE 2007).

### Knowledge of Engineering

The APPLE survey explored broad areas of engineering skills and knowledge including the importance of math and science, interpersonal and professional skills, and sources of knowledge. The multiple methods used in the Longitudinal Cohort portion of APS allowed investigation of more detailed aspects of students' perceptions and feelings including learning related to design, difficult concepts, and learning outside the classroom.

#### Most Important Skills and Knowledge

- In their senior year, we asked students to select the five most important skills and types of knowledge for practicing engineers, from a list of 20 adapted from ABET student learning outcomes and other skills and knowledge garnered from the *Engineer of 2020* report. The vast majority of APS students prioritized problem-solving, communication, and teamwork. However, almost no students prioritized global context, societal context, or contemporary issues (Atman et al., ASEE PNW 2008c).

- Students were then asked to rate their own preparedness to employ each of these skills and knowledge in professional practice. On average, students felt very well prepared to engage in the same activities that most had prioritized: problem-solving, communication, and teamwork. On the other hand, students felt unprepared to employ knowledge of global context, societal context, or contemporary issues (Atman 2008, NSF STEP Meeting; Atman 2007).
- Students' interpretations of classroom, campus, and internship experiences can impact their beliefs about the skills needed to be successful engineers (Matusovich et al., ASEE 2008).

→By understanding students' perceptions of important skills and knowledge, we can infer whether we are conveying the field's priorities. As we discuss above, students who "belong" to engineering may take on the interests and behaviors that are sponsored. Are we emphasizing all the interests and behaviors that we intend to? Do the priorities of engineering education adequately reflect those of the profession?

- A study of difficult concepts in mechanics suggests that engineering students who are academically successful often lack deep understanding of fundamental concepts in their field (Streveler et al., ASEE 2006).

→Even if students' learning priorities match those of educators and the field more generally, we must be vigilant that their understandings of concepts are accurate.

### Knowledge of Engineering Design

- Overall, student perceptions of important elements of design changed during their college years, with an increased focus on identifying constraints and iterating, and decreased focus on communicating, planning, and visualizing (Atman et al., JEE 2008).

→ This shift in emphasis may reflect students' increasing familiarity with engineering specific language (Atman et al., JEE 2008).

- Students who responded to the engineering design task given in their third year (design of a retaining wall on the Mississippi) offered more factors for consideration in designing the wall than they had in their first year (Atman et al., 2008b).

→This reflects students' increased engineering knowledge and knowledge of the engineering design process.

- In their retaining wall design responses, third-year students on average listed more close context-oriented factors, like budget or wall dimensions, than they had in the first year (Atman et al., 2008b).

→This may reflect a curriculum focused on developing technical skills.

- When second year students were asked to propose and evaluate a solution to a busy pedestrian intersection, few considered trade-offs over the life cycle of their chosen solution. All students based their decision on the proposed solution in place, without consideration for the design and construction phase or operation and maintenance of the solution for the duration of its useful life (Kilgore et al., 2009b).
- Consideration of life cycle did not broaden from the second year to the fourth, when students were asked to consider the pedestrian intersection again (Kilgore et al., 2009b).

→ This may reflect a lack of emphasis on the context of engineering design in engineering programs.

### Gender and Ethnicity Differences – Design Learning

- Women prioritized "seeking information", while men prioritized "building" and "prototyping" as first year students responding to questions about most important design activities; in

their fourth year, women prioritized "goal setting" and men "building" and "testing" in data collected from a similar written design task (Morozov et al., TR0706 2009).

- In both their first and third years, women listed more factors than men in response to the retaining wall design task. Women considered approximately the same number of close context-oriented factors than men, but significantly more broad context-oriented factors (Atman et al., 2008b; Atman et al., ASEE PNW 2008c; Kilgore et al., JEE 2007a).

→ *Women may see a "bigger picture" than men in engineering design problems, focusing more on broader contextual factors, and can provide a different and broader perspective on the approaches to, and details of, a design (Kilgore et al., ASEE 2007b).*

- Students at one of the APS institutions perceived they were receiving the same quantity of design education, but men rated their courses more highly with respect to how well those courses were preparing them to do design (Morozov et al., ASEE 2008).

→ *One interpretation of this finding is that women and men hold different standards for how they perceive the quality of their design education. Another possibility is that the design experiences that men and women have in their engineering courses are qualitatively different. Although men and women are engaging in the same design activities in their courses, they may be doing so in different ways. This has implications for instructors who aim to provide all students with equal opportunities to learn design.*

### Learning Outside the Classroom

- Students' knowledge of the engineering profession is often very low in the beginning, and increases over time (Stevens et al., ASEE 2007).
- Data from the cross-sectional survey at the fifth APS school indicated that students' knowledge of engineering practice was limited by a lack of exposure to the profession, especially a lack of internship and co-op experiences (Korte and Smith 2008, TR-08-02).
- Sponsorship (both by specific individuals and student support organizations provided people with a view of how they fit (or did not fit) into the field of engineering (O'Connor et al., 2007).

→ *Organizations, and not necessarily specific persons within these organizations, acted as "sponsors" and provided students with internships, extra coursework and social networks in which to get to know other engineers.*

- Students can encounter different images of engineering knowledge over the four years of their engineering education: these include differences between early and late career coursework and differences between internships in professional engineering firms and university coursework (Stevens et al., JEE 2008).

→ *Changes in what counts as engineering (accountable disciplinary knowledge) and how students respond to these changes are important elements in understanding how they become engineers.*

- Most APS students had completed at least one internship or co-op before graduation.
- Internship experiences varied widely from company to company and were also quite different depending on the point at which a student's internship coincided with their year in the program.
- For many students who completed an internship or co-op, the experience shaped their expectations and experiences when they returned to school, often providing a measuring stick against which to judge the authenticity of their school experiences or offering a set of tools to use in their schoolwork (Stevens et al., 2005).

## 4. Beyond Graduation (The Picture from the Broader National Sample and Selected Details from the Workplace Cohort)

### Future Plans: Broader National Sample (APPLES) Results

#### Plans for the future

- Eighty percent of graduating seniors say “yes” to engineering work, and 20 percent are leaning away; this number is consistent with prior findings (Sheppard et al., 2001).
- The number of seniors who are “unsure” about their plans to enter into engineering work is less than 10 percent, but approximately one-quarter of seniors are “unsure” about their plans related to engineering graduate school, non-engineering jobs, or non-engineering graduate school. In other words, one in four seniors is considering how these options might fit into their future.

→ *As seniors, many are still figuring out their interests, what job opportunities are out there, and what new opportunities might emerge. A question for all of us who advise these students, and design the programs and infrastructures that support their education is—are we equipping them with the tools and skills to productively question, define and navigate their professional pathways?*  
→ *If we are concerned with the quality and quantity of new engineers entering professional engineering work, then we need to identify and respond to the reasons why students who committed four+ years of college work to the study of engineering decide not to pursue an engineering career*

*Top predictors among seniors going to engineering graduate school plans are self-reported GPA and intrinsic psychological motivation, and the top negative predictor is confidence in professional and interpersonal skills.*

#### Planning for graduate work

- The top predictors among seniors going to engineering graduate school plans are self-reported GPA and intrinsic psychological motivation, and the top negative predictor is confidence in professional and interpersonal skills.
- Engineering graduate school plans differ between URM and non-URM students. Particularly among first-year students, URM students express significantly more interest in

attending engineering graduate school than do non-URM students (65.3% vs. 37.8%) and URM status is a predictor of engineering graduate school plans. By the senior year, this is no longer a predictor when other factors are controlled, though “by the numbers” almost twice as many URM seniors express plans to attend engineering graduate school.

→ *What is feeding these differences in students’ interest in engineering graduate school? How is the higher social confidence and lower self-reported GPA of senior URM women (as described in (Sheppard et al., TR-09-02 2009)) coming into play? And why isn’t the increased interest in engineering graduate school among seniors translating into actual graduate school enrollment.*

#### A combination of plans

- About one-third of seniors see themselves as “engineering only” focused, and upwards of 60 percent of them are considering some combination of engineering and nonengineering jobs and/or graduate school.
- Similar percentages of women and men are planning on engineering and nonengineering work and graduate school. However, men are slightly more likely to focus on engineering only.

→ *Even though students' career trajectory is becoming more defined by their senior year there is still a fair degree of uncertainty as to their paths. Alternately, we could interpret this as students' career trajectories are still being formed.*

### Intrinsic Psychological Interest/Motivation an important factor

- Intrinsic psychological interest/motivation (deriving personal satisfaction from doing engineering work) is an important variable that “lights up” on all four senior regression models looking at the relationships between demographics and college experiences (independent variables), and post-graduate plans (dependent variables). It positively predicts heading toward engineering options, and negatively predicts heading toward nonengineering options.

→ *This makes sense. Individuals who are excited by engineering want to keep doing engineering. Where does psychological interest and motivation come from? What can K12 education and families do to promote enjoyment in engineering thinking? How might engineering be conceptualized in ways that invite certain groups in?*

### Confidence in Professional & Interpersonal Skills an important factor

- Confidence in professional and interpersonal skills is an important variable that also “lights up” in all four senior regression models, but in the opposite way to intrinsic psychological motivation. Findings indicate that heading-towards-engineering options are predicted by lower social confidence (all other factors being equal), whereas heading-towards-nonengineering options are predicted by higher social confidence.

→ *We are left wondering whether students with higher social confidence move away from engineering because they perceive that engineering does not value/need this “special skill” they have? Are they seeing that other arenas will value it? If students with lower social confidence are more likely to pursue engineering, does this continue to promote stereotypes of engineers and engineering work?*

## **Transition to the Workplace: Details from the workplace cohort studies**

### Learning on the Job

- Students entering the workforce often encountered a steep learning curve and felt a need to learn things on their own
- Use of math: most math was “done” for them in the workplace by spreadsheets or other software applications
- Having begun in the third and fourth years of school to use “engineering specific” language, many new hires reported having to learn a company or industry-specific language that was absent in school.
- Many early career engineers felt less in control of deadlines and workload compared to school.

### Teamwork and Communication

- Teams changed from relatively small groups of engineering students (perhaps taking on different roles) to much larger teams that frequently included non-engineering members
- Communicating with non-engineers was a sometimes unexpected and often stressful part of the job
- Recent engineering graduates were often weak in skills relating to communication, teamwork, and understanding organization contexts and constraint
- Integrating into the social context of the workplace was an important part of beginning an engineering career.

→ *Engineering programs might better prepare students for the social context of their work and organizations might manage the social context of the work group to help new engineers better integrate into the organization. The problems faced by engineers in practice are extremely complex, ill-structured, ambiguous, and dependent on the social and organizational contexts and programs that address this might provide better preparation for students (Korte et al., ASEE 2008).*

### Gender Differences

- Several of the female early career engineers from the Longitudinal Cohort who were interviewed described how they had strong working relationships with males while they were students. Yet when they entered the workplace they reported encountering clear discrimination and bias as women. They mentioned being outnumbered by men in the workplace and feeling uncomfortable because of that (Jocuns et al., unpublished data).

### Graduates Often Don't Seek Employment in Engineering

- Today's college graduates think more about their "first job" than about a lifetime career choice (Lichtenstein et al., JEE in press).
- 60% of undergraduates anticipate having multiple jobs in different fields during their working life and students who complete a major in engineering are not necessarily committed to careers in engineering (Ohland et al., JEE 2008).
- Undergraduates' thoughts about career options can be swayed by a single experience such as an internship, interactions with faculty, or advice from a mentor (Lichtenstein et al., JEE in press).
- Institutional differences can contribute strongly to the varying levels of commitment to engineering careers (Lichtenstein et al., JEE in press).
- Student decisions about their post-graduate plans often take place without the direct influence of engineering faculty and staff, who could conceivably provide valuable insights and guidance (Lichtenstein et al., JEE in press).

→ *Recognizing the fluidity of student commitment to engineering, and building more guidance into programs, could ensure that our most qualified and talented students will use their skills in engineering-related careers.*



## 5. Next Steps

The Academic Pathways Study has resulted in a rich collection of observations about the undergraduate engineering experience as students move into, through, and beyond college. The many findings resulting from multiple research methods allow us to see links between various facets of students' experiences (e.g., classroom engagement, extracurricular involvement, engineering employment, etc.) and the programs in which they earn their degrees. While there are prior studies that address college students' experiences, motivation, self-confidence, and learning and development over time, the Academic Pathways Study is unique in providing an opportunity to consider each aspect as one piece of a larger puzzle that committed engineering educators grapple with daily: *how to meet the learning needs of all students, speak to their passions, and help them develop the complex set of skills needed to meet the grand engineering challenges of 2020?*

### Looking Across Our Findings – Some Selected Examples

Looking across the methods and campuses, we see evidence of the inter-relatedness of many aspects of our findings. For example, we see evidence of how...

*...there are not many pathways into engineering.* Once students make the commitment to an engineering degree, we are doing as good (if not better) a job of keeping them as other majors. But a major challenge lies in attracting students to the major. For example, students considering engineering may not be aware of the many opportunities for engineers with diverse skills and interests. How can educators help attract students into engineering and let them know early on all the possibilities that exist for an engineering career? And how can we build and support more pathways for migration into engineering?

*...students' conceptions of engineering as a field of study and a profession are intimately tied to their confidence and motivation to become engineers.* There may be differences in how students conceive of engineering, and these differences play out in a variety of ways. For example, women from one sample in our study approach engineering design problems more broadly than men, yet there is a perception among all the students that considering context in engineering design is a low priority relative to other skills, knowledge, and behaviors. How can educators ensure that the perspectives of all students are included in the conversation?

*... engineering colleges can create different experiences for different students (men and women, URM and non-URM, high SES and low SES).* The same sets of courses can be experienced in qualitatively different ways by different students. How can we ensure that all students are learning the content, skills and attitudes they need to be effective engineering professionals?

*... there is a multiplicity of pathways through an engineering education in terms of combining coursework, internships and extracurricular activities.* Students benefit from learning experiences both in and outside the classroom (e.g., research experiences, internships, service learning, co-ops, engineering and non-engineering related extracurricular activities). How can we better support the integration of these learning experiences with what is going on in the classroom?

### Additional Questions for the Community

The findings we describe in this document give us insights into the undergraduate experience on some of the campuses in the U.S. These findings, along with those being generated by the growing community of engineering education researchers can be used as a catalyst for

conversations to guide change in engineering colleges across the country. The types of conversations that the community can engage in might focus on questions such as:

- How can the curriculum be designed to bring additional relevance to student learning when students generally take a set of courses that contain important concepts (e.g., math, science) early in their career, but without the engineering motivation and context? What is the impact if most complex design projects and team experiences come late in the curriculum?
- How can universities and engineering colleges and departments address the peripheral but crucial factors that students face that are separate from the challenges of navigating the engineering curriculum (e.g., factors such as admission to the major of their choice, keeping grades high to maintain scholarship funding, finding a place to study at night)?
- What can be done about the experience of heavy workloads in a competitive environment that leads to high stress for many students?
- How well prepared are graduating students for the next steps, whether to a job or graduate school in engineering (or not)? And how well are educators preparing students to be the “Engineers of 2020,” able to see “the big picture,” and with an understanding of such necessary skills as teamwork and communication?

### **How can you help?**

We again invite you to think about the results in this report in terms of what questions they might raise on your campus or in your classroom and what kinds of changes they might lead to. Please contact us at [caee@enqr.washington.edu](mailto:caee@enqr.washington.edu) to continue the conversation.

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