AC 2008-1307: MOVING FROM PIPELINE THINKING TO UNDERSTANDING PATHWAYS: FINDINGS FROM THE ACADEMIC PATHWAYS STUDY OF ENGINEERING UNDERGRADUATES

Cynthia Atman, University of Washington

CYNTHIA J. ATMAN, Ph.D., is the founding Director of the Center for Engineering Learning and Teaching (CELT) in the College of Engineering at the University of Washington and the Director of the NSF funded Center for the Advancement of Engineering Education(CAEE). Dr. Atman is a Professor in Industrial Engineering. Her research focuses on design learning and engineering education.

Sheri Sheppard, Stanford University

SHERI D. SHEPPARD, Ph.D., P.E., is a professor of Mechanical Engineering at Stanford University, a Consulting Senior Scholar at the Carnegie Foundation for the Advancement of Teaching (CFAT), and a Senior Research Fellow at the Clayman Institute for Gender Research. She is first author on the soon-to-be-published CFAT report "Educating Engineers: Designing for the Future of the Field," and is co-principal investigator of the NSF- funded Center for the Advancement of Engineering Education (CAEE), along with faculty at the University of Washington, Colorado School of Mines, and Howard University. Within CAEE, she leads the Academic Pathways Study. Before coming to Stanford University, she held several positions in the automotive industry, including senior research engineer at Ford Motor Company's Scientific Research Lab. Dr. Sheppard's graduate work was done at the University of Michigan.

Lorraine Fleming, Howard University

LORRAINE FLEMING is professor and former Chair of the Department of Civil Engineering at Howard University. Dr. Fleming serves as the Co-PI of a National Science Foundation HBCU Undergraduate Program grant designed to increase the number of underrepresented minorities who pursue degrees in engineering, mathematics, and science. Additionally, she is a Co-PI for the Center for the Advancement of Engineering Education. She serves as the Principal Investigator of an NSF grant designed to study the post baccalaureate decisions of high achieving Black STEM students. She is also a 2005 Scholar at the Carnegie Foundation for the Advancement of Teaching. Most recently, Dr. Fleming is the recipient of the 2008 National Society of Black Engineers Educator of the Year Award.

Ronald Miller, Colorado School of Mines

RONALD L. MILLER is Professor of Chemical Engineering and Director for the Center for Engineering Education at Colorado School of Mines. He earned degrees in chemical engineering from the University of Wyoming and Colorado School of Mines. Dr. Miller has received three university-wide teaching awards and has held a Jenni teaching fellowship at CSM. He has received grant awards for education research from the National Science Foundation, the U.S. Department of Education FIPSE program, the National Endowment for the Humanities, and the Colorado Commission on Higher Education and has published widely in the areas of engineering education assessment, pedagogy, and curricular design. He has won the Helen Plants award for best non-traditional session at the FIE conference (1995, 2006), the William H. Corcoran Award (best paper in Chemical Engineering Education, 1999), and the William Elgin Wickenden Award from the American Society for Engineering Education for best paper published in the Journal of Engineering Education (2005).

Karl Smith, University of Minnesota

KARL A. SMITH is Cooperative Learning Professor of Engineering Education, Department of Engineering Education, and Fellow, Discovery Learning Center at Purdue University West Lafayette. He has been at the University of Minnesota since 1972 and is in phased retirement as

Morse-Alumni Distinguished Teaching Professor of Civil Engineering. Karl has been active in the Educational Research and Methods Division (ERM) of the American Society for Engineering Education (ASEE) for over 25 years and has served in many capacities, including Chair of the Division. His Bachelors and Masters degrees are in Metallurgical Engineering from Michigan Technological University and his Ph.D. is in Educational Psychology from the University of Minnesota. He has co-written eight books including Cooperative learning: Increasing college faculty instructional productivity; Strategies for energizing large classes: From small groups to learning communities; and Teamwork and project management, 3rd Ed.

Reed Stevens, University of Washington

REED STEVENS is an Associate Professor in the College of Education at the University of Washington. He specializes in ethnographic and comparative approaches to studying how people learn, especially in disciplines related to mathematics, science, technology, and design. He is currently co-leading two NSF Centers working on issues related to how people learn—the LIFE Center and CAEE.

Ruth Streveler, Purdue University

RUTH A STREVELER is an Assistant Professor in the Department of Engineering Education at Purdue University. Before coming to Purdue she spent 12 years at Colorado School of Mines, where she was the founding Director of the Center for Engineering Education. Dr. Streveler earned a BA in Biology from Indiana University-Bloomington, MS in Zoology from the Ohio State University, and PhD in Educational Psychology from the University of Hawaii at Manoa. Her primary research interest is investigating students' understanding of difficult concepts in engineering science.

Christine Loucks-Jaret, University of Washington

CHRISTINE LOUCKS-JARET is a Technical Communication Specialist with the Center for the Advancement of Engineering Education at the University of Washington, providing technical writing and editing services to the CAEE team. Tina has an MS in Technical Communication from the University of Washington. She is currently a member of the American Society for Engineering Education and the Society for Technical Communication.

Dennis Lund, University of Washington

DENNIS LUND joined the CAEE team in 2003 and is currently the Assistant Director. Prior to joining CAEE, he worked in a variety of roles in the aerospace industry, including electrical engineering design, engineering management, business development, and field account management. He has a Bachelor of Science in Electrical Engineering from Oregon State University and a Master of Library and Information Science from the University of Washington. He is currently a member of the American Society for Engineering Education and American Solar Energy Society. He previously served on Society of Automotive Engineers technical committees for Aircraft Lighting and for Aerospace Electrical Power and Equipment.

Moving From Pipeline Thinking to Understanding Pathways: Findings from the Academic Pathways Study of Engineering Undergraduates

Abstract: The Academic Pathways Study (APS) is part of the Center for the Advancement of Engineering Education (CAEE), an NSF-funded higher education Center for Learning and Teaching that is in its sixth year. The APS consists of longitudinal and cross-sectional studies of engineering students' learning experience and the transition to work. APS research questions are focused on student skills, identity, education and the transition to the workplace to investigate what skills engineering graduates are bringing with them into an increasingly complex world. The study relies on multiple methods and data sources including surveys, structured interviews, semi-structured interviews, an engineering design task, academic transcripts, and exit interviews. Overall, the preliminary findings to date indicate a large variation in student pathways and institutional influences. A range of factors affect the educational pathways traveled by engineering students: reasons for their choice of major, heavy workloads and competition in their programs, little vision into engineering in the first two years when they are taking math and science courses outside of engineering departments. Reasons for leaving include a fear of losing scholarship support (that dictates choice of classes), lack of confidence in math and science skills, and the perception that engineering is too "narrow" a field. Reasons for staying include sponsorship of student strengths and skills, satisfaction of completing a rigorous course of study, the desire to contribute to the public good, and a vision of the potential for a comfortable lifestyle following graduation. In many cases, students have very different perceptions of diversity and its role in their education. Some of these factors affect the quality of the student experience, whereas others affect commitment to the field. Many of these factors influence men and women in different ways and change over time.

Introduction / Background

While engineering educators have engaged in many endeavors aimed at advancing engineering education and practice, much of this work has focused on broad curricular issues. Few studies focus on what it means to be an engineer or the process of what it takes to *learn to engineer*. In the last decade have engineering educators begun to focus on developing the research base with an emphasis on engineering student learning[1,2,3]. Other professions, such as architecture and medicine, have a body of research delving into the nature of practice[4,5]. The few studies that have focused on engineering practice describe a work environment that differs significantly from the concepts and practices taught to students during their education[6,7,8,9]. A recent article summarizes the limited published research on engineering work[10]. Employer surveys also highlight these gaps[11].

Further, people with different backgrounds bring valuable perspectives, experiences, and knowledge to the engineering profession. Unfortunately, students from non-majority groups are still at greater risk of not completing engineering undergraduate programs despite significant ability[12,13]. Students from underrepresented groups report dissatisfaction with the impersonal and competitive atmosphere of traditional science and engineering courses[13,14,15]. Women who leave engineering perceive that it is not compatible with their dominant interests because they often lack exposure to the connection between engineering and society and/or the natural environment[16].

Research on the interplay between specific issues (such as gender, race, ethnicity, socioeconomic status, and the quality of the engineering educational experience) should be set in a broader framework of research on students in higher education in general[17,18,19,20,21].

For example, a University of Washington study of undergraduates found that a student's educational experience is shaped in every way by the academic discipline the student chooses[20]. Pascarella and Terenzini[21] have shown that the more students are engaged in activities that reinforce and extend the classroom experience (e.g., library and writing experiences), the more they will learn, and that involvement in non-classroom social and extracurricular nonclassroom interactions with peers and faculty appear to have the most consistent positive impact.

The findings of the National Survey of Student Engagement (NSSE) are particularly useful in framing issues of undergraduate engagement. Since 2000, NSSE has been surveying freshmen and seniors at 1200 U.S. universities and colleges to explore the various ways that students engage (or do not engage) in their education. NSSE[22] reports that students who took part in one or more "high-impact" practices (such as a learning community, research with faculty, or study abroad) reported greater levels of deep learning and greater gains in learning and personal development. At the same time, first-generation and transfer students were much less likely than other students to participate in such high-impact activities. It is also surprising that half of all seniors did not write a paper or report longer than 20 pages and one in ten (9%) did not write a paper longer than five pages.

Another dimension to any study of today's engineering students is considering changes in college students over the last decades. To this end, the trends in U.S. incoming college freshmen over the last forty years, as tracked by the Cooperative Institutional Research Program (CIRP), provide important contextual data for any study on engineering students. In Pryor et al.[23], we see that more of today's college freshmen report coming late to class than forty years ago, and interaction with high school teachers has declined. Also disturbing is that today's college freshmen are increasingly coming from wealthier families. At the same time, more students come to campus reporting having frequently used a personal computer and done internet-based research or homework, and in less need of tutoring or remedial work in college (even in such engineering-important areas as mathematics and science).

The Academic Pathways Study (APS) was designed to build on and add to this prior and ongoing research to investigate the engineering undergraduate learning experience and the transition to work. The APS is an extensive, multi-institution research project that is looking at how people become engineers over the course of their undergraduate education and upon entry into the engineering workplace. It is part of the Center for the Advancement of Engineering Education (CAEE), an NSF-funded higher education Center for Learning and Teaching. The APS, the focus of this paper, is complemented by several other Center projects that are exploring components of engineering knowledge and practice, including decision making practices of engineering educators[24], and methods to build capacity and community in engineering education scholarship[25].

The APS is comprised of *longitudinal* and *cross-sectional studies*. It relies on multiple methods and data sources including surveys, structured interviews, semi-structured interviews, an engineering design task, academic transcripts, and exit interviews. The APS team is using these tools to study the development of engineers from a diverse set of institutions. The study focuses on how participants' engineering knowledge changes over time and the context of those changes. This allows identification of the factors and experiences that influence change (either positively or negatively). By including multiple institutions with diverse populations, the team is able to compare findings across populations and institutions. The results from the APS are building an account of how people become engineers and giving insight into key questions in engineering education. This research will enable an understanding of how engineering students navigate their educations and explore how misalignments between university and workplace practices impact preparation and retention.

This paper presents recent research results on the engineering student learning experience from the multiple campuses involved in the study. These summarized results—from the students' perspective(s)—present initial conclusions about significant themes. In the longer run, these themes will be synthesized across the results of this large study. Among other ideas, these results question the veracity of the pipeline metaphor that has been used to describe students' navigation through their education. The "leaky pipeline" metaphor has also been questioned by others, including Watson and Froyd[26] recently, who are calling for an alternative view in order to adequately address the challenges of educating future engineers and diversifying the engineering workforce. In the concluding section, this paper outlines some questions based on the data that address potential recommendations for improving the engineering undergraduate learning experience.

Methods

The APS research questions focus on four primary areas for investigating what engineering graduates need to succeed in an increasingly complex world. These include the development of skills and knowledge; development of identity as an engineer (including student confidence, and appreciation of, and commitment to, engineering); the elements of students' engineering educations that contribute to changes in skills, knowledge, and identity; and identification of the skills needed by early career engineers as they enter the workplace.

The Academic Pathways Study was originally designed to investigate these research questions using data from four cohorts of participants[a]. In 2005, a fifth group was added (referred to as the Cross-sectional Cohort[b]) that included students not in the original design and provided cross-sectional data from all four undergraduate years.

APS Longitudinal data were collected at four pseudonymous institutions: Technical Public Institution, Urban Private University, Suburban Private University, and Large Public University. The Cross-sectional Cohort data were collected at a fifth institution (another large public university). The Broader Sampling Cohorts expanded the number of participants to over 6000 students pursuing engineering degrees at 26 different institutions. The sections below provide brief descriptions of each group of research participants and the methods used by the researchers. For an expanded description of the APS methods and the design of the study, refer to Clark et al., 2008, *Academic Pathways Study: Processes and Realities*[27].

Longitudinal Cohort

For the Longitudinal Cohort, the APS research team is using four primary data collection methods: surveys, ethnographic (semi-structured) interviews and observations, structured interviews, and short engineering design tasks (ETD activity). These methods are described in the following sections. In addition, academic transcripts are being collected for all participants and exit interviews are conducted with those leaving the engineering major.

The Longitudinal Cohort consists of 160 (40 at each of 4 campuses) undergraduate engineering students, who participated in the Study from 2003 to 2007, beginning with their first year in college and into their fourth year. Through the students' junior year, the APS team had administered six sets of surveys and conducted three full rounds of structured interviews, semi-structured interviews, and engineering design tasks. In the senior year (2006-07), a final survey was administered to all Longitudinal Cohort participants, and semi-structured interviews were conducted. In addition, structured interviews and engineering design tasks were conducted with a subset of 16 students. Numerous ethnographic field observations were also made over the years of the study.

The PIE Survey Instrument

The Persistence in Engineering (PIE) Survey given to the Longitudinal Cohort is used 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.

Structured interviews

The structured interviews extend and expand on the PIE survey with a focus on specific information related to engineering education and identity development. The structured interview protocol (lasting approximately one hour) was designed to explore variables more suited for qualitative data gathering and analysis using a pre-defined set of questions.

Semi-structured Interviews and Ethnographic Field Observations

APS' ethnographic team uses semi-structured interviews and field observations to gather data from a smaller set of participants. This portion of the Study focuses on extending understanding of both the local cultures of engineering student experience and students' pathways through these experiences. Researchers examined activities such as intense project work, exam periods, and extracurricular activities.

Engineering Design Tasks

The ETD activities (Engineering Thinking and Doing) include 10 minute "engineering tasks" designed to investigate how students approach engineering problems at various stages of their academic careers. Following the task, participants were asked about their answers as a means to better understand their approach and the reasoning behind it. These data were supplemented by responses from specific questions included in the PIE survey that related to students' conceptions of design and engineering work.

Academic Transcript Analysis

Academic transcripts from the four partner schools provide data on student course-taking patterns and major declarations. Normalized grade point averages (GPAs) are coupled to engineering design tasks or PIE survey results and used as measures of knowledge level. Transcript GPAs also provide a confirmation of student-reported GPAs on the survey.

Exit Interviews
Semi-structured "exit" interviews were conducted with most of the participants who declared non-engineering majors. The protocol for exit interviews focused on understanding the motivations and experiences that contribute to the choice of majors by students who chose not to major in engineering. Some participants continued to take part in surveys and semi-structured interviews after exiting engineering[27].

Broader Sampling Cohorts
The Broader Core School Sample consisted of over 800 students at the four Longitudinal Cohort institutions. It was a cross-sectional sample that received the Academic Pathways of People Learning Engineering Survey (APPLES) in the spring of 2007. The Broader National Sample is targeting over 5000 students at 21 U.S. colleges and universities. It is also cross-sectional and uses the APPLE survey; it is being deployed in the first three months of 2008. The APPLE Survey is a shorter version of the PIE survey that was administered to the Longitudinal Cohort. Both of these Broader Sample cohorts are targeted at engineering students, pre-engineering students, and also "non-persister" students (defined here as those who had an initial interest in engineering but who eventually chose other majors)[27,28].

Cross-sectional Cohort
The Cross-sectional Cohort participants were drawn from a fifth Center-affiliated institution and received the PIE survey described above for the Longitudinal Cohort participants. The Cohort targeted 160 undergraduate students distributed across their first through fourth years at one campus in 2005-2006. The survey was administered twice. In addition to the survey, six focus groups were conducted to supplement quantitative information from the survey. These focus groups included two each for non-transfer women, non-transfer men, and male and female transfer students[29].

Workplace Cohort
The Workplace Cohort is looking at the “school to work” transition and involves a small group of early career engineers who participated during 2007 and 2008. Workplace Cohort data are being gathered through structured and semi-structured ethnographic interviews and short engineering design tasks similar to that described above for the Longitudinal Cohort. Participants were early career engineers already employed in companies to which researchers had access[27].

Emerging Themes: The Engineering Undergraduate Learning Experience

This paper focuses primarily on results from the Longitudinal Cohort. At the end of the fourth academic year, approximately 113 of the original 160 Longitudinal Cohort undergraduate students were still participating in the study. Data analysis continues on each campus within each method and across methods. The triangulation of qualitative and quantitative data types and sources is allowing the APS research team to create a broad set of results that describe the engineering undergraduate learning experience in detail and paint a rich portrait of the engineering students themselves.

The interim results discussed below present an overview through 2007. A number of themes have emerged from the on-going analysis, many of which are common across campuses and some of which are specific to particular institutions. These summarized findings suggest ways that the student learning experience can be improved to better recruit, educate, and retain engineering students at the nation's higher education institutions.

The findings presented in this paper are just the beginning of the wealth of results that APS will be generating as analysis continues. Additional results are being presented concurrently in two special sessions during the 2008 ASEE Annual Conference (#1530 and #2530). The results summarized below are collected along several themes: reasons for choice of major; curriculum and skill development issues; perspectives on diversity and gender-related issues; commitment to the field of engineering; and reasons for leaving engineering. References are provided to papers that can provide greater depth for each theme.

<u>Reasons for Choice of Major</u>

Students reported that their primary motivations for studying engineering were based on a strong personal interest in applied science and math and a desire to contribute to the betterment of society[30]. In one campus sample of first year students, the survey results showed that 75 percent of participants indicated that the enjoyment of mathematics and science, and financial reward were primary motivational factors in their pursuit of an engineering education[31]. Family influences are also a factor in studying engineering; however, APS data show that nonpersisters are more likely than persisters to be motivated by family influences to study engineering[32]. The influence of family also tends to be less important after the first year[32]. In the Cross-sectional Cohort, data showed a lower level of motivation to study engineering because of financial reward for transfer students than for non-transfer students[29].

<u>Curriculum and Skill Development Issues</u>

As discussed above, the factors affecting students' choice of major(s) are varied and sometimes complex. But the complexity of navigating an education through to an engineering degree is only beginning with the selection of the major. Students' pathways to an engineering degree are affected both by an institution's curriculum and by individual academic experiences. For instance, nonpersisters reported lower levels of engagement in both engineering and liberal arts courses as first-year and sophomore students than persisters[32]. Transfer students in another sample reported a higher level of academic disengagement in their liberal arts classes than non-transfer students[29]. Results from 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[31]. Other APS results show that students have a desire for more balance (i.e., pursuits and learning projects aside from engineering studies) than their prescribed program of study will allow[33]. Transfer students experience other, often unique, curriculum challenges in addition to those experienced by students who entered as first year students. For instance, transfer students reported difficulty transferring credits, getting started in their programs, and meeting people (typically because they missed the freshman year)[30]. Possibly as a result of this, transfer students also reported a lower level of satisfaction with their overall collegiate experience than non-transfer students[29].

Students' knowledge of the engineering profession is often very low in the beginning, and increases over time[34]. In general, students' knowledge of engineering practice was limited by a lack of exposure to the profession, especially a lack of internship and co-op experiences[30]. Although students' understanding of engineering as a profession early in their academic careers is minimal in many cases, there is a perception among many engineering students that their university course work is much more difficult than that of their peers in other majors. Furthermore, the feeling that they sacrifice more often leads them to develop relatively strong "us/them" attitudes regarding themselves and other students. Over time, engineering students increasingly identify other intellectual pursuits as less rigorous and valuable than engineering[34].

Students' pathways to an engineering degree are also affected by their perceptions of the skills and abilities they have or will need with regard to the practice of engineering. The vast majority of seniors considered problem solving, communication and teamwork among the most important competencies of practicing engineers. In contrast, almost none of these students considered knowledge of contemporary, societal or global issues to be among the most important. Students' self-ratings of their preparedness in each of these competencies corresponded to how they perceived their relative importance. The vast majority of students felt at least fairly well prepared in problem solving, communication and teamwork, but relatively few students felt as well prepared with respect to contemporary issues and context[35]. Overall, student perceptions of other 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[36]. Survey results indicated that nonpersisters report lower levels of confidence in their math and science skills than persisters (as first-year and sophomore students[32]). Interestingly, international students from one sample of structured interviews exhibited a higher level of confidence in the areas of math and science and in themselves than U.S. engineering students[37]. The ideas and perceptions that students develop and perpetuate throughout their academic engineering careers are important factors in the way they navigate their individual pathways to a degree or their pathways out of engineering into a different field of study.

Perspectives on Diversity: Gender-related Issues

Although navigating through an engineering program is a complex process that is affected by the perception and reality of students' skill development and curricular challenges, other factors can also affect the experiences of students. Much has been written about the under-representation of women in engineering. Recent statistics from ASEE[38] indicate that the number of undergraduate degrees awarded to women is at 19%, a slight decrease and the lowest it has been in ten years. APS results are pointing to multiple factors that relate to the persistence of women and under-represented minorities in engineering.

Gender-related differences in the confidence levels of men and women in their engineering skills are apparent in the data. For instance, male students in one sample exhibited a higher level of confidence in the areas of math and science and in themselves than female engineering students[37]. Women in their sophomore year reported less confidence in their design skills than men. By their senior year, this difference in confidence was less pronounced, but still present[39].

It is also interesting to note that students in another sample assembled a cultural model of admission that, for some, included the view that women have an easier time getting into the engineering major than men do[40].

However, the relatively small differences between the persistence rates for the gender or school subgroups, coupled with preliminary information regarding differences on PIE survey construct scores, suggest that the differences between persisters and nonpersisters do not arise from over- or underrepresentation of a particular subgroup[32].

Gender differences are also apparent in several aspects of engineering skill performance and development. APS data for first year students show that women were more contextually oriented than men while performing engineering design tasks. For instance, in an open-ended design task where students were asked to think of as many factors as they could in addressing a specific design problem, both women and men were equally attentive to matters of design detail, but women considered broader contextual factors to a greater degree than men[41]. Additionally, in a closed-ended task where students were asked to select from a given list the most important kinds of information needed to design a playground, women chose a greater proportion of context-oriented items than men[42]. A gender-related difference in the prioritization of certain elements of design activities was also noted. Women were more likely to consider goal-setting among the most important design activities, while men were more likely to consider building among the most important design activities. This difference persisted throughout the college years[43]. Further, when participants were allowed to brainstorm the kinds of skills they thought necessary for engineering, women were much less likely than men to mention active-experiential ways of knowing[44].

These findings demonstrate the importance that gender plays not only in how students perceive their engineering skills and abilities, but also in how gender affects their perceptions of their relative difficulty or ease of being accepted into an engineering program.

Commitment to the Field of Engineering

Students commit to the field of engineering for a number of reasons that are sometimes intertwined in a complex manner with other factors such as those discussed above that affect their pathways through, or possibly out of, engineering education. Commitment can be a subtle combination of personal and institutional factors. Survey data from the freshman, sophomore, and junior years show that persisters demonstrate higher levels of agreement with statements that relate to both academic persistence (completing their degree) and professional persistence (pursuing a career in engineering)[32]. However, structured interview data from the freshman, sophomore, and junior years indicated that many students exhibited “doggedness” – a high level of commitment to completing an engineering degree with an intention toward perseverance for its own sake and with little regard to enjoyment or satisfaction[45]. Unpublished results indicate that this aspect of "doggedness" may fade by the fourth year. Students in a different sample that used the survey and focus groups reported on the pressures associated with a highly competitive and demanding program, frustrations with competitive grading practices, and concerns with advising[29].

Other aspects of commitment to engineering (i.e., persistence) have to do with the developing identity of a student as an *engineering* student. For instance, a sample from the unstructured ethnographic interview data suggested that students' interests become differentially identified over time as either "engineering interests" or "not engineering interests" where certain kinds of interests or behavior (e.g., competitive engagement in school-based math) might be sponsored, by engineering faculty, for example, over and above others (e.g., integrating diverse perspectives into technological solutions to social problems). This sponsorship (or privileging) of certain viewpoints or approaches over others sometimes has inadvertent and undesirable outcomes in terms of who succeeds, and who does not, in gaining an engineering degree[46].

Future lifestyle and income considerations are also reasons why many students decide on engineering. Semi-structured interview data from one sample indicated that students harbor the pervasive concept of *engineering as lifestyle*—that an engineering career will result in a comfortable material existence[34]. Students also believe in *the meritocracy of difficulty*—that because the engineering major is perceived to be much more difficult and competitive than other majors, they deserve the comfortable material existence that results from earning an engineering degree[34]. The idea of a future reward for hard work and/or "doggedness" are potential factors that can keep students in engineering.

<u>Reasons for Leaving</u>

While the reasons for committing to engineering are numerous and complex, the reasons for leaving may be just as complicated. Although the persistence rate for the students in this study was 76%, the national rate for engineering undergraduates is approximately 60%. The team has posited that the higher persistence rate of those involved in the study could be related to the self-selection of survey participants[32]. Even so, many students do leave the engineering major or choose not to practice engineering following graduation. The reasons for this include the observation that students often make decisions about majoring in engineering or leaving the major based on pre-requisites and before they are enrolled in engineering courses[47]. The idea of "sponsorship" of "engineering interests," mentioned above in the Commitment to Engineering section, may also be a factor in a student's choosing to leave engineering. Understanding why students choose to leave engineering is the first step in developing ways to identify these students before they leave and in developing new ways to keep them interested and engaged in the engineering disciplines.

Summary, Implications, and Future Directions

The strength of the Academic Pathways Study lies in the collaboration of different campus cultures and perspectives on engineering student learning combined with the use of a multiple-method approach to gathering and analyzing data. When completed, the APS will have involved over 6000 participating students at five core institutions and 21 additional institutions. In total, these 26 institutions represent to a large degree the diversity in institutional settings for the study of engineering in the U.S. Data from multiple methods allows the team to triangulate results and enables a broader analysis of the engineering student experience than would be possible with only a single method. Much of this rich and in-depth data set is still being analyzed but it is already revealing important themes and insights about the ways students experience their engineering education.

These initial findings effectively challenge the long-held notion of the engineering education pipeline. This metaphor loosely assumes that all engineering students enter and exit their engineering educations at the same intake and outflow points, with some students leaving engineering through various "leaky" points along the way. A pipeline metaphor also assumes a certain level of homogeneity among engineering students and can disregard the many changes that occur during the students' undergraduate careers.

APS findings to date (based primarily on data from the Longitudinal and Cross-sectional Cohorts) indicate a large variation in student pathways to an engineering degree. This variation is demonstrated by a number of factors. The reasons students give for their choice of an engineering major include things such as future financial security, the ability to contribute to society, influence of family or mentors, and that they are good at math and science. Once in the engineering major, students pathways to or out of engineering are affected by curriculum and skill development issues such as heavy workloads and stress; a competitive atmosphere, especially in the early years; a missing "vision" about engineering; and a delay in experiencing design and teamwork until later in the engineering program. Students' differing personal perspectives on diversity and gender also play a role in determining students' pathways, as can the institutional, curricular, and skill development factors associated with diversity and gender. Pathways are also affected by a student's commitment to the field of engineering that is, in turn, affected by personal situations, learning experiences, and institutional practices. These influences can lead to students re-examining their decision to be an engineer quite often. Sometimes this results in a pathway out of engineering. The decision to leave engineering can be precipitated by a variety of factors including a lack of confidence in math and science skills; a fear of losing scholarships; and a perception that engineering is too narrow and does not offer a path to contribute to social good. However, many students remain on an engineering pathway for reasons including sponsorship of student strengths and skills, satisfaction of completing a rigorous course of study, the desire to contribute to the public good, and a vision of the potential for a financially secure lifestyle following graduation.

Moving from Pipeline Thinking to Understanding Pathways

The large variation in student pathways is not only a function of individual students but depends on the characteristics of institutions as well. This variation demonstrates that a "one size fits all" recommendation for addressing problems in engineering education likely will not work. Institutions must examine their own student populations to determine appropriate curricular and program changes. The APS survey and interview instruments provide tools that could be used to enable other institutions to look more closely at their students.

Furthermore, the pipeline metaphor of engineering education can also neglect the huge changes that students undergo during the course of their undergraduate years. Many of these changes are related to what students learn in courses and research or work experiences, but there are broader changes in what students think: about what it means to be an engineer; about their self-concept and identity as engineers and as members of society[20,21]; and in their overall direction and goals. As analysis of the APS data continues, and as data from the Broader Samples is included, a more complete picture of engineering students is emerging, creating a picture that reflects changes over the four years of student life.

Engineering programs and their current teaching methods should be re-examined. In addition to a further examination of student experiences, an important part of that examination is to see how well students are able to make *informed decisions* to stay or go in their study of engineering. Students need a welcoming environment that gives them the information they need, and they need learning experiences that will enable them to build their engineering knowledge and identity as an engineer with the skills needed to succeed in the global engineering work world. Our data show that often the undergraduate experience differs greatly for different groups such as men, women, and underrepresented minorities. The engineering education community, whether policy-makers, faculty, or researchers, must not only recognize the wide variety of student pathways to an engineering degree but also encourage and support these multiple paths.

Looking to the Future

In addition to the picture of undergraduate student pathways that is emerging from the Longitudinal and Broader Sampling Cohorts, the results from the Workplace Cohort will offer a portrait of engineering graduates entering the world of work. Although this current paper does not present Workplace Cohort findings, initial results based on interviews with over 30 early career engineers are being presented concurrently at the 2008 ASEE Conference[48].

As analysis continues and more results are available, the APS research team hopes to shed light on questions that are emerging about the undergraduate engineering student learning experience. Some of the compelling questions include,

→ How can the curriculum be designed to bring additional relevance to the 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 can be done about the experience of heavy workloads in a competitive environment that leads to high stress for many students?
→ What is the impact of most complex design projects and team experiences coming late in the curriculum?
→ How can universities and engineering colleges and departments address the peripheral factors that students face that are separate from the challenges of navigating the engineering curriculum (e.g., admission to the major of their choice, keeping grades high to maintain scholarship funding, finding a place to study at night)?
→ How can we best determine if those students who stay in engineering are learning the skills they need to address issues of context in their engineering problem solving?

As the results in this paper have shown, the Academic Pathways Study is providing compelling data that paint a picture of the undergraduate engineering student learning experience not only with a human face, but with a multi-faceted understanding that comes from a rich triangulation of data types and sources.

The APS team is committed to continuing this line of research on the undergraduate engineering student learning experience as a means to understand and ultimately affect positive change within engineering education programs. The Academic Pathways Study is providing a rich set of insights and tools to support these changes and ultimately to strengthen effective teaching of our future engineers.

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End Notes:
[a]The Longitudinal Cohort (Fall 2003—Spring 2007) was initially called Cohort 1; the two Broader Sampling Cohorts using the APPLE Surveys were referred to as Cohorts 3 and 4.; and the Workplace Cohort was referred to as Cohort 2 in the initial framing of APS.
[b]In some publications and planning documents this Cross-sectional Cohort was referred to as Cohort 1′. The "prime" indicates that it was a derivative of Cohort 1 in that it used the same PIE survey tool. It differed in that it was a cross-sectional study, whereas Cohort 1 was a longitudinal study.

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