AC 2008-906: ACADEMIC PATHWAYS STUDY: PROCESSES AND REALITIES

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Academic Pathways Study: Processes and Realities

Abstract

Amid concerns that U.S. educational institutions are not attracting and graduating sufficient numbers of science, technology, engineering and mathematics (STEM) students with the skills and knowledge needed to tackle the technological challenges of the 21st century, the National Science Foundation granted funding in 2003 to the Center for the Advancement of Engineering Education (CAEE), dedicated to advancing the scholarship of engineering learning and teaching.

The largest element of the CAEE is the Academic Pathways Study (APS), an in-depth, mixed methods exploration of the undergraduate student experience and the graduate's transition into professional practice. The APS addresses the following research questions:

1. How do students' engineering **skills and knowledge** develop and/or change over time?
2. How does one's **identity** as an engineer evolve?
3. What elements of engineering **education** contribute to the students' skills/knowledge and identity? What elements contribute to students' persistence in an engineering major and persistence in the engineering profession?
4. What skills do early career engineers need as they enter the **workplace**?

Given the scale of the APS investigation with multiple schools and student populations, the answers to these questions will allow us to identify educational practices that contribute to students persisting and thriving in engineering, and potential strategies for attracting more students to the study of engineering.

This paper describes the evolution and implementation of the Academic Pathways Study (APS), a five year, multi-institution study designed to address these questions and implications for academic practices. As such, this paper is a "welcome mat" or introduction for those interested in learning more about APS. Components of the paper address questions researchers designing new studies may have about the organizational and technical infrastructure that supported this project, or about the quantitative and qualitative research methods, tools, and protocols used. Other components of the paper address questions that researchers and engineering faculty and administrators might have regarding how to explore the findings and insights that are emerging from this extensive longitudinal and cross-sectional study of students' pathways through engineering. Research findings to date are summarized in a companion paper entitled Findings from the Academic Pathways Study of Engineering Undergraduates, by Atman, et al[4].

1. APS Background and Goals

The past two decades have witnessed an ongoing national dialog about the lack of gender, race and ethnic diversity among those studying and practicing engineering[1] and the adequacy of students' preparation for today's engineering challenges[2]. Further complicating the discussions are worries that U.S. educational institutions are not attracting and retaining sufficient students in the science, technology, engineering and math (STEM) fields to keep up with the country's demands. In response, the National Science Foundation set out in 2002 to establish Higher

Education Centers to promote exemplary education in these fields[3]. One of the centers created by NSF is the Center for the Advancement of Engineering Education (CAEE). CAEE consists of three research elements: Scholarship on Learning Engineering, Scholarship on Teaching Engineering, and the Institute for Scholarship on Engineering Education. These elements bring together a team of scholars and experts from an array of backgrounds, disciplines and universities to collaboratively accomplish the mission of improving the knowledge and practice of engineering teaching and learning.

This paper focuses on a major undertaking of CAEE's Scholarship on Learning element, the Academic Pathways Study (APS). The paper begins by situating the APS in the existing knowledge base of engineering education and goes on to describe the study's organization and execution, starting with the research team and leadership, followed by the study design, research cohorts and methods. The paper closes with a discussion of the research challenges, implications for engineering education, and possible future research. APS results are reported in separate papers as they become available, with findings to date summarized by Atman, et al[4].

The Academic Pathways Study aims to improve educational effectiveness by developing a rich understanding of the engineering student experience. To that end, APS addresses the following student-centric research questions:

1. How do students' engineering **skills and knowledge** develop and/or change over time?
2. How does one's **identity** as an engineer evolve?
3. What elements of engineering **education** contribute to the students' skills/knowledge and identity? What elements contribute to students' persistence in an engineering major and persistence in the engineering profession?
4. What skills do early career engineers need as they enter the **workplace**?

The first of these questions addresses cognitive outcomes, the second deals with affective learning, and the third cluster of questions examines the interplay of outcomes and environmental factors critical to student success. Taken together, these questions align with the highly durable and influential input-environment-outcome (I-E-O) model of college impact, first proposed by Alexander Astin over thirty years ago[5,6,7]. Furthermore, the APS research questions seek to explore the evolutionary nature of outcomes and environmental influences, tracing their development and change over time. Inherent in the research questions is the anticipation that the study will generate recommendations for improving educational practices to enhance the student experience and persistence in engineering studies, as well as suggesting potential strategies for attracting more students to the discipline.

This is certainly not the first study of the engineering student experience; there is solid prior work to build on. A few of the studies that have influenced and informed the APS design deserve note.

Seymour and Hewitt conducted a three-year study of 460 students at seven institutions, investigating why students leave or persist in science, mathematics and engineering (SME) majors[8]. Using ethnographic interviews, Seymour and Hewitt studied attrition among SME majors, with the aim of deriving a set of testable hypotheses from student reflections. They evaluated how students weighed numerous factors in deciding to leave SME for non-SME majors or, conversely, to persist in SME majors despite challenges and setbacks. Seymour and Hewitt's work suggests that students are leaving engineering not for lack of ability, but because of structural and cultural factors such as inadequate teaching, overly competitive grading, and lack of identification with the associated careers. Seymour and Hewitt's findings illustrate the complex nature of deciding to study or not study in SME fields, leading APS researchers to include a broad range of questions and prompts in APS research tools so as to not prescribe responses.

Astin's research on student development in higher education relied on large-scale surveys conducted with over 200,000 students[7]. His surveys of first-year and fourth-year students over a twenty-year period led Astin to conclude that the level of student involvement is directly proportional to student learning. Astin defines student involvement as the amount of physical and psychological energy devoted by a student to the academic experience. An environmental factor that Astin identifies as being highly influential is the student's major. He concludes (page 371) that "Engineering produces more significant effects on student outcomes than any other major field." Majoring in engineering was positively correlated with the development of strong analytic skills (page 237) and job-related skills (page 240); it was negatively correlated with overall satisfaction with the college experience, satisfaction with curriculum and instruction, and developing a diversity orientation (page 306). Astin's findings led APS researchers to design a study that examines the effect of an engineering major over time, looks at engineering students relative to others, and considers a variety of institutional factors.

Adelman studied engineering undergraduate careers by drawing evidence from the 11-year college transcript history of the High School & Beyond/Sophomore Cohort Longitudinal Study, as well as the high school transcripts, test scores and surveys of this nationally representative sample[9]. Adelman introduces the idea of *curricular momentum*, which can reinforce student trajectories within engineering and establish preferred pathways for students leaving engineering, as well as boundaries for students who might be interested in entering the engineering field. Adelman's work shows the importance of curricular factors in influencing how students explore and choose majors. His findings illustrate the need to have enough fidelity in research instruments to capture the subtle dimensions of navigating and defining an academic pathway.

These studies and others–such as the National Survey of Student Engagement (NSSE) [10] and the Pittsburgh Freshman Survey[11]–along with the expertise of APS researchers, suggested that multiple methods and multiple student cohorts were needed to fully capture the engineering student experience. To this end, the APS research design included:

- Both qualitative and quantitative methods. Qualitative methods allow for exploration of how students arrive at the decision to major in engineering and how they navigate the educational process, whereas quantitative methods elicit information from larger numbers of students on a broad, but defined range of issues, such as degree of academic engagement, perceptions and attitudes about engineering, and motivations for pursuing an engineering major.
- Multiple student cohorts across multiple institutions to explore the overarching temporal, individual and institutionally specific components of the engineering experience.

Expecting to see diversity of experiences, APS researchers sought to capture the range of experiences for a variety of schools and student sub-groups.
- A multidisciplinary research team, with backgrounds in engineering, education, psychology and more, so as to bring multiple perspectives and areas of expertise to the design of instruments and the interpretation of findings.

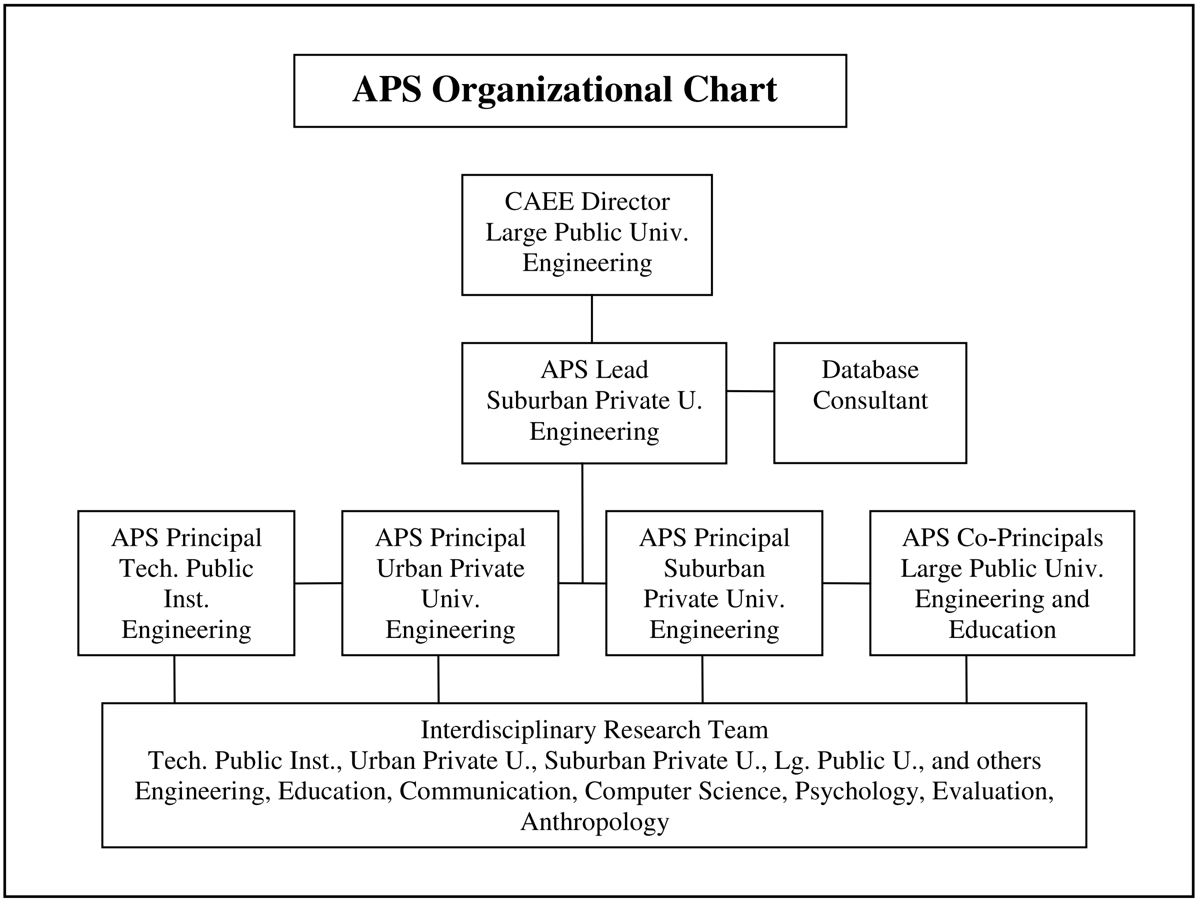
Furthermore, APS researchers aimed to design a study of which the results could inform educators, academic advisors and administrators, researchers, engineering professionals, and policy makers with a tapestry of information to improve their understanding of how engineers are educated.

This paper describes the evolution and implementation of the Academic Pathways Study (APS) as an in-depth longitudinal and cross-sectional exploration of the student experience during undergraduate engineering education and the transition into professional practice. It has relevance for a wide spectrum of readers:
- Researchers who are designing and implementing related studies are likely to find the discussions of processes and lessons learned particularly relevant.
- Those wishing to understand the context and scope of work behind the body of APS papers, findings, and recommendations can learn about the study in its entirety and the interconnection of its parts.
- People interested in locating and staying abreast of other publications stemming from APS will find pointers for doing so.

2. Research Team and Leadership

The Academic Pathways Study involved four core partner institutions: a Technical Public Institution (TPub), an Urban Private University (UPri), a Suburban Private University (SPri), and a Large Public Institution (LPub). The research was led by a senior researcher from the Suburban Private University, with the principal co-investigator from each of the four institutions serving on the leadership team. (Figure 1)

Figure 1: APS Organizational Chart



* In some APS publications the core partner institutions are referred to by the pseudonyms: Mountain Tech, Oliver University, Coleman University and University of West State.

As a working body, the leadership team had three major categories of responsibilities:

- Developing policies, standards and procedures for handling the data, reporting findings (including publication and authorship protocols), dissemination, etc.
- Coordinating the development of the research methods and their consistent implementation on the various campuses
- Leading the data collection process, including Institutional Review Board applications
- Monitoring the effectiveness and progress of the APS research team.

Each principal co-investigator was responsible for supervising the APS researchers at his/her school and championing a set of research instruments to be used across schools. In this capacity, each principal co-investigator oversaw the development, training, data processing and data analysis related to their instrument(s) for all campuses. The Urban Private University served as champion for structured interviews, the Large Public University for the ethnographic tools and engineering design tasks, the Suburban Private University for survey instruments, and the Technical Public Institution for academic transcript information.

Monthly conference calls and periodic face-to-face meetings facilitated the work of the APS leadership team.

The full research team included over 60 individuals from engineering, education, communication, the humanities, and the sciences. Participating researchers came primarily from the four core partner institutions, and also included area-experts from other institutions. Although specific campuses were designated to lead different components of the research, the team collaborated on all aspects of the project including subject recruitment, instrument design and implementation, and data processing and analysis. Teamwork was fostered by face-to-face workshops of the entire APS research team, as well as smaller targeted cross-institutional meetings and conference calls. This collaboration further contributed to the robustness of research processes across campuses, domains and perspectives.

APS employed a database consultant to oversee all aspects of data storage, organization, security and access. The database consultant participated fully with the research team to stay abreast of research activities and generally ensure the smooth functioning of all data-related systems.

3. Research Design

The APS was designed as a cross-institutional, multi-method study that would be robust enough to produce valid, detailed descriptions of engineering student pathways. Capturing diversity on the institutional and individual levels was a key objective for the APS researchers. This section describes the resulting study design, the incorporation of diversity in the study sample, and the evolution of the design over the ensuing five years of the project.

Design Overview

Persistence in engineering was a major focus of the APS research. Thus, all student subjects were either engineering or pre-engineering majors, or had interest in majoring in engineering at some time during their higher education. Inclusion of this last group–students who ultimately declared non-engineering majors–allowed investigators to explore factors that contribute to migration out of engineering.

The research was conducted in four stages, each characterized by complementary and overlapping research goals with distinct cohorts of subjects, as shown in Table 1. The research was staged to allow for the stepwise refinement of instruments and corroboration of findings with progressively larger numbers of students and institutions nationwide. Table 2 illustrates which methods were used to collect data and how they contribute to answering the basic APS research questions related to skills and knowledge, identity, education, and transition to the workplace.

Table 1: APS Research Overview

Cohort*	**Subjects**	**Research Goal**	**Methods**
Longitudinal Cohort Fall 2003- Spring 2007	160 students from four institutions, followed from their freshman through senior years	Identify and characterize student experiences and motivations, particularly relating to persistence and identity development in engineering	Series of interviews, surveys, and engineering design tasks administered over four years beginning freshman year

Broader Core Sample April 2007	842 undergraduates at the same institutions as the Longitudinal Cohort	Validate longitudinal findings with more engineering students at the same institutions	Cross-sectional survey (APPLES**)
Broader National Sample Jan.-Feb. 2008	Targeting over 5,000 undergraduates from 21 U.S. colleges and universities	Validate longitudinal findings with more students and institutions nationally	Cross-sectional survey (APPLES**)
Workplace Cohort (in process)	Early-career engineers from public and private companies	Learn about the technical and social factors/skills that contribute to successful practice by young engineers, and where/how these skills were learned	Semi-structured interview

* In some APS publications the cohorts are numbered: cohort 1 is the Longitudinal Cohort, cohort 2 is the Workplace Cohort, cohort 3 the Broader Core Sample, and cohort 4 is the Broader National Sample.
** APPLES = Academic Pathways of People Learning Engineering Survey

Table 2: Data collection methods as they contribute to APS research questions

✔ ✔ = primary data source ✔ = supplemental data sources

	APS Research Questions			
	How do engineering skills develop?	How do students build identity as an engineer?	How does education contribute to skills and identity, and support persistence?	What skills do engineers need entering workplace?
Survey	✔	✔	✔ ✔	--
Structured Interview	✔	✔	✔	✔
Ethnographic Methods	✔	✔ ✔	✔	✔ ✔
Engineering Design Tasks	✔ ✔	✔	✔	--
Academic Transcript	✔	✔	✔	--

Commitment to Diversity

Including students from diverse backgrounds was an important factor in the APS research. Historically, students from underrepresented groups report dissatisfaction with the impersonal and competitive atmosphere of traditional science and engineering courses[8, 12, 13]. To capture issues specific to underrepresented groups, researchers employed over-sampling strategies for gender (male/female) and underrepresented minorities (African Americans, Native Americans, Mexican Americans, Puerto Ricans and other Latino groups) in the Longitudinal Cohort and the Broader (APPLES) Samples.

In addition, the APS research instruments were designed to probe the roles that diversity might play in a student's educational experience. For example, structured interviews included questions about diversity and racial identity as related to students' engineering education experience, while surveys collected demographic and socio-economic data.

The APS also encompassed diversity on the institutional level. The four core partner institutions that formed the Longitudinal Cohort and the Broader Core Sample ranged from small (3000 total student enrollment) to large (40,000 total students), with between 100 and 659 students graduating per year with a BS in an engineering field. Two of the schools are public and two are private. Three of the schools are classified in the Carnegie 2000 Classification[14] as Doctoral/Research Universities-Extensive, and one as a Specialized Institution-Engineering and Technology. The Broader National Sample institutions were selected to replicate and extend the institutional characteristics of the Longitudinal Cohort on a national level. Additional criteria used in selection of schools for the Broader National Sample included, among others, geographical diversity and representation of a wider variety of Carnegie classifications.

Evolution of the Research Design

During the course of the study, the APS research design evolved in several ways.

Longitudinal Study

The original Longitudinal Study design called for a control group of 160 students (40 per school) to determine how the study itself would affect student experience. However, not all schools were able to recruit the 80 students required to fully populate a study group and a control group. Because the study incorporated other means of detecting a "study effect"–namely, comparing academic records with the general engineering student population and the Broader Core Sample– the control group was eliminated from the study.

The difficulty of recruiting students for the Longitudinal Study resulted in another modification: delay of the fall 2003 survey deployment. All schools were able to recruit their 40 study subjects by December 2003, so surveys commenced with a winter 2004 deployment.

Finally, APS researchers decided to scale back on ethnographic field observation of the Longitudinal Cohort. Although a source of potentially rich data about the engineering student experience, conducting, documenting and coding field observations for even a subset of subjects exceeded the resources available at most of the core partner campuses. Only one campus conducted field observations throughout the longitudinal study period on a small sample of students.

Addition of a Cross-Sectional Cohort

As a result of collaborative relationships between APS researchers and colleagues at the University of Minnesota (UM), UM adopted the APS Persistence in Engineering (PIE) survey for use cross-sectionally with a cohort of engineering students there. The survey was deployed twice – fall 2005 and spring 2006 – and attracted over 200 respondents including transfer students. The Cross-Sectional Cohort provided UM with valuable data about their students[15], while affording APS researchers experience with cross-sectional survey administrations.

Broader Samples (APPLE Surveys)
The original proposal called for concurrent deployment of the APPLE Survey at the four core partner schools and at four affiliate campuses to collect data from a broader sample of students at the core schools and nationally. Two main factors contributed to the decoupling of the APPLES administrations:

1) Separating the two administrations allowed researchers to further refine the survey instrument between deployments (resulting in two slightly different APPLE Survey instruments.)
2) Staffing was not adequate to concurrently finish data collection from the Longitudinal Cohort, use the longitudinal data to inform refinements to the survey instrument, and recruit additional schools for the Broader National Sample.

Part of the planning for the Broader National Sample involved selecting a nationally representative sample of institutions, in addition to the four affiliate campuses originally slated for sampling. Based on Carnegie classifications and other factors such as geographic diversity, researchers determined that a minimum of 14 institutions with defined characteristics was required to assure a representative sample of institutions and students. Ultimately, 21 institutions participated in addition to the four core schools.

Workplace Cohort

Research around the school-to-work transition was redefined for pragmatic reasons. Whereas the original APS design called for following 40 engineering graduates into the workforce or graduate school, it proved more feasible to target early career engineers already employed in companies to which researchers had access. This realignment resulted in cross-sectional rather than longitudinal study of engineers in the workplace.

4. Longitudinal Cohort

Methods

The goal of the Longitudinal Cohort was to identify and characterize pathways by which students make the choice to become an engineer. This line of research focused exclusively on the undergraduate period (freshman through senior years). To accomplish the goal, researchers employed four main research methods: surveys, structured interviews, ethnographic methods, and engineering design tasks. Additional data came from academic transcripts and semi-structured "exit" interviews. These key quantitative and qualitative datasets intersected to answer APS research questions, as shown previously (Table 2).

The Persistence in Engineering (PIE) **survey instrument** was designed by APS researchers with the goal of identifying and characterizing factors that influence students' intentions to pursue an engineering degree and a career in an engineering-related field[16]. The PIE survey was also intended to broaden understanding of how students navigate their education and form identities as engineers. The survey consists of over 100 items comprising approximately 25 constructs that range from motivations for studying engineering, to enjoyment of and engagement with the curriculum[17].

The **structured interview** protocol adds insights to the PIE survey by exploring topics that are more suited to qualitative analysis. The interviews (averaging one hour in length and encompassing approximately 28 questions) complemented and added texture to the survey data, and contributed to refinement of the survey questions. In addition, the structured nature of the interviews allowed for collection of comparable data across all four campuses. The questions in the structured interviews ranged from definitions of engineering to skill development and attitudes about engineers. Data from structured interviews are suitable for both quantitative and qualitative analyses.

The **ethnographic methods** used in APS included semi-structured interviews, field observations and informal conversations. Semi-structured interviews lasted anywhere from one to three hours, depending on the student, and enabled researchers to glean aspects of engineering student culture and everyday life experiences through open-ended questioning. Questions ranged from how students settled on their major to how they perceived their fellow students and their educational experiences, both academic and extra-curricular. Observing participants engaged in project work and extra-curricular activities provided further insights into the student experience, as did the informal conversations between researchers and participants.

Engineering design tasks took the form of short problem-oriented questions administered at the end of the structured or semi-structured interview. Students were allowed 10 to 15 minutes to provide free-form written responses. One such question involved factors to consider in designing a retaining wall system for the Mississippi River; another tackled the problem of frequent accidents at a busy intersection. The design tasks, taken together with specific questions from the PIE survey that focused on engineering design, formed the Engineering Thinking and Doing (ETD) component of the research, whereby researchers learned about frameworks students bring to engineering problem-solving.

Semi-structured exit interviews were administered to subjects 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 opt out of engineering. The interview consisted of 10 open-ended questions exploring the student's former interest in an engineering major and tracing the experiences and feelings associated with switching.

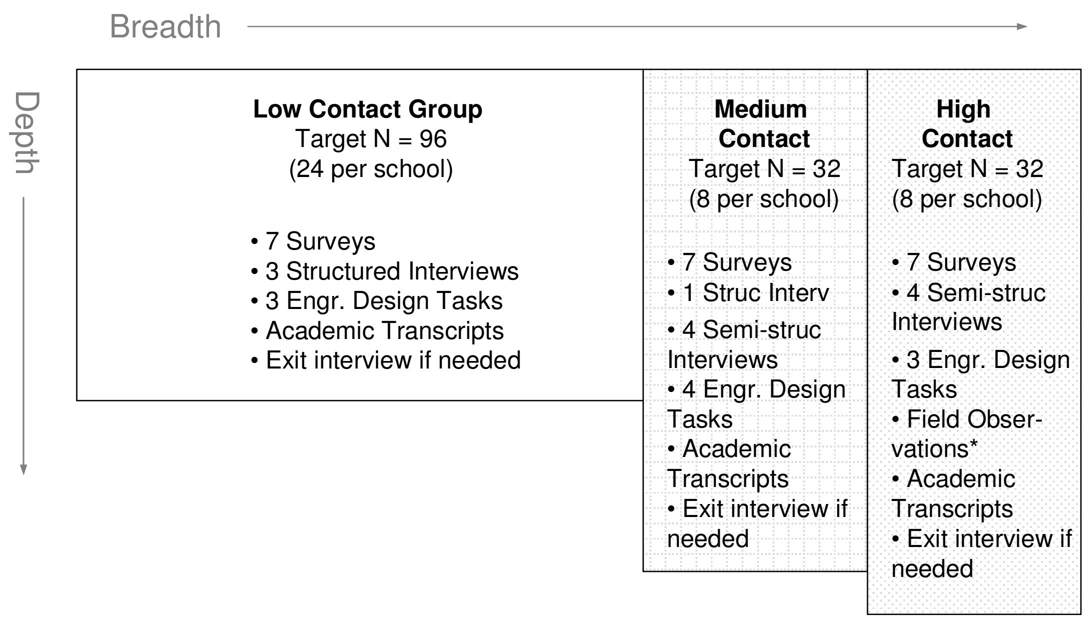
The APS data collection protocols are part of a technical report that will be available starting in June, 2008.

Study Design

Subjects in the longitudinal study were divided into three research groups: low contact, medium contact and high contact. This structure allowed researchers to build the richest datasets possible with the available resources. Figure 2 shows the target allocation of participants among study groups and the types and amounts of data to be collected from individuals in each group.

Figure 2: Longitudinal study groups and datasets (2003-2007)

See Appendix Table A-1 for sequence of data collection time points.



*Field Observations were limited after the first year

Since the goal of the Longitudinal Cohort was to describe a range of academic pathways, students were not randomly assigned to study groups. Instead, group assignments were based on a variety of factors, including gender and ethnic diversity. Assignments to study groups were made by the local researchers at each campus.

Subjects who were unique in some way or had a proclivity for sharing their stories were favored for the open-ended, semi-structured interviews administered to the medium and high contact groups. This approach was taken in order to produce a wide and rich array of personal stories. Another consideration when making group assignments was the researchers' judgment of whether the students were likely to stay in engineering (and the study itself) for the duration of their undergraduate careers. In order to achieve the goal of studying engineering student pathways, it was important to have a large majority of participants graduate with an engineering degree.

At the beginning of Year 2, 18 new participants were added as replacements for participants who left the study in the first year. All of these participants were in the Low Contact Group.

Beginning in Year 2 of the longitudinal research, semi-structured "exit" interviews were administered to participants who declared non-engineering majors. Where feasible, participants continued to take part in APS surveys and semi-structured interviews even after exiting engineering.

Recruitment and Incentives

Recruitment of students for the Longitudinal Cohort began in summer 2003 and continued through December 2003. Recruitment efforts focused on freshman students with engineering or pre-engineering majors, or who expressed interest in majoring in engineering. Researchers at each of the four participating campuses devised their own recruitment plans based on institutional processes and calendars. In general, recruitment strategies included:

- A presence at freshman orientation programs
- Presentations at engineering-related events and classes
- Targeted e-mails to engineering societies, freshman engineering lists, etc.
- Flyers/brochures at locations frequented by engineering students (such as the math department)
- Group informational sessions
- Personalized letters to freshmen with engineering majors or interests

All study participants were required to sign an informed consent form approved by the Institutional Review Board (IRB) of their institution. One partner institution did not have an IRB and was covered under the IRB of another institution. IRB approval and informed consent by students were required each year of the study.

APS offered incentives for students participating in the longitudinal study. Participants received checks for $175 at the end of each academic year of participation. They also received scientific calculators, donated by a large electronics company, at the beginning of the study.

Data Collection and Participation Summary

The Longitudinal Cohort had little attrition. Of the original 160 freshman students in the study in 2003, approximately 85% were still in the study in the spring of 2007 (their senior year), with study retention rates being virtually identical between males and females. Participation by method and gender are presented in Appendix Tables A-1 and A-2. Although ethnic diversity diminished over the four years of research – from 26% to 20% underrepresented minorities – the study retained an over-sampling of underrepresented racial and ethnic groups. (See Appendix Figure A-1).

A future paper will examine the question of how representative the Longitudinal Study participants are of the general student population.

Data Analysis Processes

The Longitudinal Study generated a number of distinct data sets corresponding to the different data collection instruments, thus producing a myriad of data analysis opportunities. For all data sets, the first line of analysis was instrument-specific; only data from that instrument were used in the analysis. The champion institution (i.e., the one that had led development and implementation of the instrument) also led the instrument-specific data analysis for all four schools. Several papers reporting instrument-specific analyses have been published to date[18-25], with more in process.

A second line of analysis extends across instruments and methods, utilizing data from more than one APS data set. A workshop in September 2006 brought APS researchers together to stimulate discussion of possible analyses across instruments and institutions, resulting in a number of papers reporting cross-instrument findings[26-28]. Analyses utilizing multiple data sets continue.

Access to and sharing of data is managed through an online APS Workspace with a secure database system. Access to APS data is carefully controlled to ensure that IRB guidelines are observed and data is used appropriately.

5. Broader Core and National Samples

Goals and Methods

The goal of collecting data from broader samples was to corroborate and explore the generalizability of findings from the Longitudinal Cohort. The APPLES (Academic Pathways of People Learning Engineering Survey) instruments were used for this purpose in two stages. The first stage had limited scope, targeting additional students at the four core universities that participated in the longitudinal work. The second stage was more extensive, enlisting students from 21 other schools representing a wide array of institutional missions.

The APPLE Survey instrument was derived from the Persistence in Engineering (PIE) surveys and engineering design tasks used in the APS longitudinal research[17]. A focused subset of questions from the PIE survey comprised the APPLES instrument, which was extensively piloted and refined to be effective for a single, cross-sectional administration to engineering and non-engineering majors from all four class levels (freshman, sophomore, junior and senior.) Whereas the PIE survey took 30 minutes to complete, the final APPLE Survey took 10 to 15 minutes. Like the PIE surveys, APPLES was administered via the Web.

Participation

Although IRBs required the Broader Core Sample investigation be open to all students, recruitment efforts targeted pre-engineering, engineering and non-persister students. Based on the response patterns from the Longitudinal Cohort, recruitment efforts concentrated on posters, emails to engineering students from their dean, and ads in the student newspaper. All materials, including emails, were branded with a red apple logo, the institution's name, and the National Science Foundation name and logo. Recruitment targets were set on a per school basis[29].

The sample size for the two Broader Samples was determined based on defined respondent characteristics strata, or sub-groups, that would be used for data analysis. The primary strata were persistence, academic class (freshman, sophomore, junior, senior) and gender. Secondary strata characteristics were enrollment status (part-time versus full-time), transfer status, ethnicity and citizenship. Ethnic minority students were defined as those traditionally underrepresented in engineering in the U.S.: African American, Hispanic and Native American students[1, 30]. International students included any student not holding U.S. citizenship.

The schools included in the Broader National Sample were selected based on a variety of institutional, demographic and geographic characteristics from the pool of American universities with at least one ABET accredited engineering program. The Suburban Private University, as the lead APPLES research institution, obtained umbrella IRB approval for all of the participating institutions except those with APS researchers on staff. The two schools with APS-affiliated staff were required by lead institution's IRB to also obtain approval from their local IRBs.

Each institution had recruitment targets to ensure adequate data to run statistical tests comparing strata. Smaller institutions (<150 undergraduate engineering students) had a target of approximately 50 total participants. Larger institutions (>600) had targets closer to 150 participants. Response rates were monitored daily during survey deployment to determine if strata targets were being met. Monitoring allowed each institution to adjust ongoing recruitment to target students in strata that were falling short of their targets. Respondents were offered a $4.00 incentive paid through a popular online financial transaction company.

Participating schools developed a student recruitment plan tailored to their campuses with the help of a liaison at the Suburban Private University. Student recruitment was largely accomplished through targeted e-mails from the dean of engineering, although most institutions also hung posters and some ran ads in their student newspapers. Additional strategies included emails to members of student engineering societies, international student organizations, and minority student programs. In a few cases, ads were placed on a popular social networking website.

Data Summary

A total of 914 survey responses were obtained in the Broader Core Sample, and approximately 3000 responses are expected in the Broader National Sample (in progress at this writing). In the Broader Core Sample, 842 responses were determined to be eligible. Ineligible responses included those from graduate students or students from non-participating universities, and responses that were likely generated from fraudulent submissions in order to claim additional incentives[29]. Table 3 summarizes the participation rates for the Broader Samples.

Table 3: Broader Sample Administration and Data Collection Summary

	Dates	Institutions (#)	Respondents (#)	Response Rates*	% Claiming Incentive
Broader Core Sample	April 2007	4	842	12-34%	82%
Broader National Sample	Jan.-Mar. 2008	21	3000 (estimated)	TBD	TBD

*Percentage of undergraduate engineering majors at each school participating in survey

6. Workplace Cohort

Goals and Methods

The Workplace Cohort was designed to answer questions relating to skills and knowledge needed by early career engineers, and the development of identity as students transition into the workplace. This portion of the APS research was originally conceived to be a longitudinal, qualitative study of students from the end of their junior year through their first two years after graduation. The original research design called for ethnographic data collection methods including observation and interview. However, early experience with these methods in the Longitudinal Cohort led researchers to conclude that a longitudinal plan for the Workplace Cohort was more time and energy intensive than anticipated, and therefore unfeasible with the available resources.

As a result, APS researchers adopted a new strategy for investigating questions surrounding transition to the workplace. The reconfigured research consisted of two studies of early career engineers in the workforce: one at a large automobile manufacturer and the second involving engineers at several aerospace companies and public sector engineering departments.

At the automobile manufacturer, researchers focused on the socialization of engineers and the role of co-ops and internships in the "on-boarding" of entry level engineers. These researchers conducted structured interviews with 24 young engineers (between six and 24 months on the job) and six supervisors. All interviews took place at the worksite. Employee interviews lasted 60-90 minutes, and focused on how employees applied their technical knowledge to problem-solving, and how they learned the prevailing culture and interactions of their workgroup. Interviews with supervisors lasted 30-45 minutes, and explored the technical and social training of new employees from the perspective of the supervisor[31].

The second of the APS workforce studies is currently in process, and consists of semi-structured interviews and short engineering tasks similar to those used in the longitudinal study. Both public and private worksites are included in the investigation.

7. Challenges

Multi-institutional research has inherent challenges stemming from physical distance and variations in institutional cultures, calendars and procedures. The multi-disciplinary nature of the APS research added another layer of considerations. This section touches on the major categories of challenges APS experienced regarding its organization and staffing, internal communication, and data handling.

Organizational and Team Building Challenges

Accommodating the natural life changes of a large research team is, perhaps, inevitable in a long-term project such as the APS, which experienced a steady stream of staff turnover, sabbatical leaves, maternity leaves, and transitions to other institutions. In most cases, people were able to continue their APS involvement via the Internet, e-mail and telecommunications. Flexibility and understanding at all levels were key for maintaining the momentum and continuity of the research in light of staff transitions.

To meet the challenge of creating and maintaining cohesion among the large and diverse research team, the APS leadership supported physical team meetings once or twice a year for planning, training, updating, team-building and general sharing. The most effective and productive meetings were informal, working-oriented meetings that focused on the content of findings and research rather than on research processes, which remained anchored in specific disciplines and research methods.

Communication Challenges

Project management in the APS depended heavily on e-mail, electronic file-sharing and telephone conferencing. Regular telephone conferences with the entire research team gave way to monthly telephone meetings with the project Leads. Although these executive meetings were more manageable and productive, the discussions and decisions were not uniformly and consistently conveyed to the rest of the research team—from undergraduate research assistants to post-doc students to faculty—who were scattered across institutions and departments. With the help of the APS evaluation team, it became apparent that increased communication among researchers was needed. Resources were made available to promote face-to-face and long-distance interaction among method teams independent of the project leads, as well as among the leads themselves.

Communication styles played a role in the amount and effectiveness of communication among team members. Some researchers responded well to e-mail while others preferred telephone contacts. The leadership team and support team spent significant time working to improve internal communications, including naming a communications specialist on the leadership team.

Challenges in Processing and Analyzing Data

The sheer volume of the data collected in the APS presented its own set of challenges. Data management (security, storage, access) was a major undertaking. Given the number of researchers, institutions and types of data involved, a detailed set of procedures was necessary to ensure that data were collected and entered into the database in a consistent fashion.

Data analysis was contingent upon data access privileges that, for reasons of security and confidentiality, were not uniformly granted to all researchers. Managing access to data across multiple institutions and numerous researchers required ongoing attention and negotiation among the various research interests on the team. Furthermore, the identities of subjects had to be masked so researchers who were also teaching classes could not identify students at APS subjects.

At the outset of the longitudinal study, it was anticipated that data analysis and collection could occur concurrently. That is, researchers could be analyzing data from Year 1 while collecting data in Year 2 and beyond. Overall, this plan proved unrealistic because of competing demands on researchers to continuously collect, enter, clean and analyze data.

Data analysis across instruments was complicated by the fact that the institutions leading the analyses operated on different timelines, so data from some instruments were analyzed more quickly than others. This differential was partly due to the nature of the instrument, and partly to the resources and workload of the sub-group doing the analysis.

8. Implications for Engineering Education and Future Research

Findings and Publications

At this writing, findings from the APS continue to emerge and be reported in professional journals, conference proceedings (including two special sessions at ASEE 2008) and invited talks. Conference papers, journal articles, and various presentations related to the APS work are listed on the CAEE website at http://www.engr.washington.edu/caee/publications.html, along with other CAEE publications and presentations related to learning and teaching engineering. Overall, the APS findings indicate wide variation in engineering student pathways, beginning with their reasons for choosing (and leaving) the major, and extending to the quality of the student experience and what they encounter as newcomers in the workplace. Data indicate certain differences along gender lines, as well as differences in perceptions of diversity and its role in the educational experience[4, 32].

APS Methods, Instruments and Data

The APS experience using qualitative and quantitative research methods applied longitudinally and cross-sectionally is itself a study in conducting mixed methods research. Besides setting the groundwork for future research efforts, the APS is a valuable case study for teaching research methods in the classroom. APS instruments continue to be refined for future applications.

It is anticipated that the APS dataset and data collection instruments will be made available to a broader range of researchers in the near future.

Reflections

APS research appears to be having an impact, as findings begin to affect the systems under study. For example, APS-based insights regarding the advantages of earlier exposure to engineering coursework have contributed to an effort at the Large Public University to re-evaluate its policy of delaying acceptance to the engineering school until after sophomore year. Similarly, the Suburban Private University is considering offering more engineering content to freshmen and sophomores to help them engage with the practice of engineering. We anticipate APS findings will be of great value to engineering educators, administrators and policy makers for questioning today's practices and imagining tomorrow's solutions.

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and those we work with on a daily basis. As teachers and researchers, we continuously learn from them. Our students are the reason we undertook this research.

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APPENDIX:

Table A-1: Longitudinal Data Collection Summary

This table shows the types and amounts of data collected during the four years of longitudinal research. The decline in numbers over time, reflected in the first row of the table, was mostly due to attrition although there were a few instances where participants missed an interview or survey. Academic transcripts were collected for all time points, but only reported in the final year, (lower right cell). Structured interviews were not conducted in the final year of the study, reducing the number of Engineering Design Tasks that year, as reflected in the last column of the table.

	Winter 2003	Spring 2004	Fall 2004	Spring 2005	Fall 2005	Spring 2006	Spring 2007
Surveys	156	156	155	154	144	144	126
Structured Interviews	--	128	--	95	--	76	--
Semi-structured Interviews	--	64	--	60	--	55	51
Engineering Design Tasks	--	124	--	155	--	126	51
Exit Interviews	--	--	--	16	--	15	1
Academic Transcripts	--	--	--	--	--	--	128

Note: Empty cells indicate time points when data was not collected. Figure 2 in the body of this paper shows the study groups targeted at each data collection point.

Table A-2: Gender Breakdown of Longitudinal Subjects

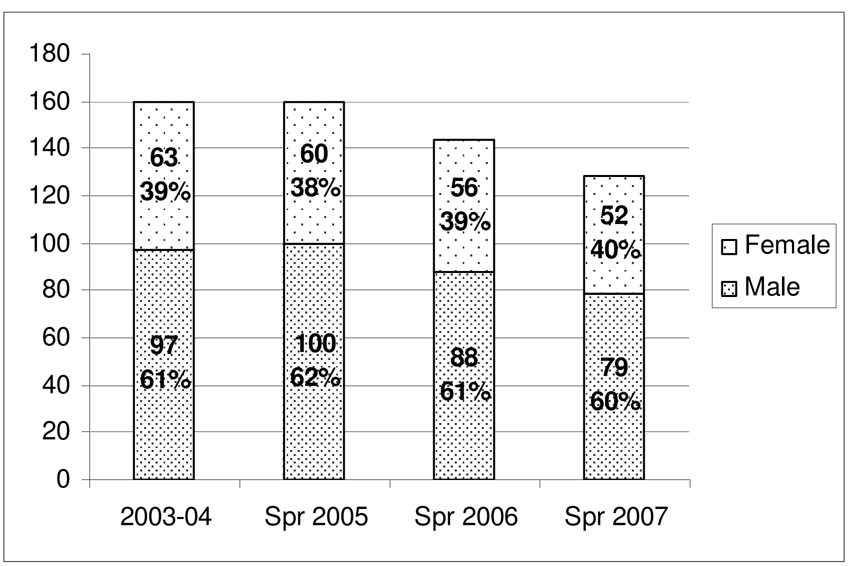
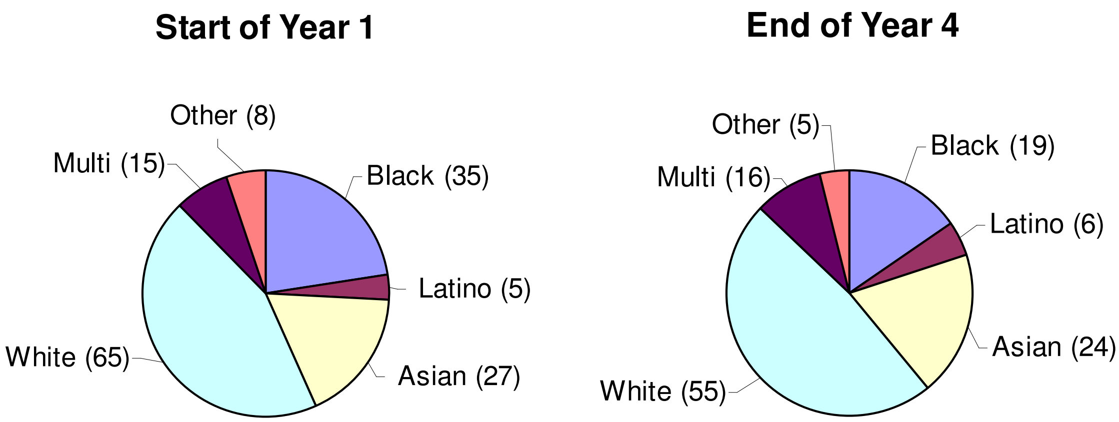


Figure A-1: Subject Ethnicities



NOTES:

- Numbers of subjects are in parenthesis
- "Multi" indicates more than one ethnicity
- Of the 160 students enrolled in the study in Year 1, 156 completed the first PIE survey and one of them did not provide ethnicity.
- In Year 4, 126 students completed the final PIE survey, including one who did not provide ethnicity.