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Studying the Engineering Student Experience: Design of a Longitudinal Study

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Abstract

There is a need to study how students become engineers, and how they learn engineering and design concepts. The Center for the Advancement of Engineering Education (CAEE) is conducting critical research in this area. The objective of the study described in this paper is to discover what the student experience is during their undergraduate engineering education. The research includes a series of longitudinal studies of students at four universities: Colorado School of Mines, Howard University, Stanford University, and the University of Washington, and involves students during their undergraduate education and entry into the engineering workplace. The series of longitudinal studies is referred to as the Academic Pathways Study (APS). This paper describes the research design of the APS, including sampling decisions and survey design, and illuminates the potential impact of study findings on engineering education.

Introduction

A number of studies have been conducted on how to make undergraduate education more effective. But there is a critical need to investigate engineering education from the student's perspective, to understand how students identify themselves as engineers, how they overcome the significant challenges during the educational process, and how they transition into a professional engineering career.

Research by engineering educators has largely focused on broad curricular issues, or specific disciplinary reforms, and only recently have studies been done with an emphasis on engineering student learning.[1,2,3] Regarding transition into professional practice, professions such as architecture and medicine have a body of research delving into the nature of practice.[4,5] But the few studies focused on engineering practice describe a working environment which differs significantly from the concepts and practices taught to students during their education.[6,7,8]

This paper describes an in-depth, longitudinal study into the student experience during their undergraduate engineering education, and transitioning into professional practice. The study is part of research by the Center for the Advancement of Engineering Education (CAEE) into engineering teaching, learning, and educational leadership, and is called the Academic Pathways Study (APS).

The APS is being conducted across four universities to provide a more comprehensive model of engineering education: Colorado School of Mines, Howard University, Stanford University, and the University of Washington. Involving multiple institutions illuminates factors from these institutions which may be significant contributors to the process of becoming an engineer, such as an engineering-only institution (Colorado School of Mines), or one with a predominantly minority student constituency (Howard University).

Building on Research

This study builds on previous studies into the undergraduate student learning experience, several of which are summarized below:

Richard Light conducted in-depth interviews of more than 1600 Harvard undergraduates to determine how to help students succeed in the educational environment.[9] Light's findings have several implications for increasing effectiveness of higher education. Implications that are relevant to engineering education include:

1) Courses should be highly structured, include many quizzes and short assignments, as well as frequent feedback from the professor and an opportunity to revise and change work.
2) Study groups should be encouraged, or even arranged, because students who learn from other students are more successful in their college education.
3) Students' best experiences include interacting in-depth with faculty, as well as participating in small group tutorials, seminars or one-to-one faculty-supervised work.
4) Diversity is a key factor in learning to think more widely about subjects, as students encounter and learn to understand alternate viewpoints to their personal perspectives.

The study results also recommend the acquisition of such specific skills as learning time management, getting help when needed, teaching students to think like professionals, teaching the use of evidence in making decisions and evaluating policies, and making use of interdisciplinary ideas in educational experiences.

Alexander Astin has conducted research using surveys with 200,000 or more students, into student development in higher education. Astin surveyed freshmen for over twenty years, and has concluded that level of student involvement is directly proportional to higher student learning. His work emphasizes increasing student involvement, which he defines as the amount of physical and psychological energy devoted by a student to their academic experience.[10]

Rather than a traditional approach of simply providing educational resources, such as libraries, distinguished faculty, and a prestigious campus, he recommends that institutions focus on what the student does during their college experience, and that student involvement translates into higher achievement. The practical application of this approach is for faculty to strive to get students as involved as possible in their educational experience: heightening student interaction with faculty, tailoring examples to student experience, involving students directly in classes.

Elaine Seymour conducted a three-year study of 460 students at seven institutions, investigating why students leave or persist in science, mathematics and engineering majors.[11] Using ethnographic interviews, Seymour studied attrition among science, mathematics and engineering (SME) majors, evaluating how students weighed factors leading to abandoning SME majors for non-SME majors, or persisting in SME majors despite challenges and setbacks. Her research aimed to derive a set of testable hypotheses from student reflections. This study's findings include a number of factors specific to engineering, as well as science and math majors:

1) Students who chose to discontinue an SME major were not "different kinds of people" from those who succeeded in an SME major.[11] Those who switched out of SME majors were not necessarily less qualified to master the necessary technical concepts, but their evaluation of the SME-major academic experience was highly dissatisfactory, either due to a perceived lack of success, or to a dissatisfaction with the way courses were taught.
2) Both persisters and switchers reported experiencing the same problems in the educational experience. But for switchers, these problems led them to abandon the SME major. Persisters seemed to have developed successful strategies to overcome the challenges in an SME major, or sometimes an intervention by a faculty member, at the right moment, turned their experience around.
3) Most of the factors causing students to abandon SME majors resulted from "structural or cultural sources" rather than because those students could not meet the academic requirements.[11] Examples of such factors include inadequate teaching, excessively competitive grading systems, and a lack of identification with SME-major careers.

The study describes issues which indicate a vital need to reevaluate how engineering, math and science are taught. Without this reevaluation, students who are capable of succeeding in an SME major will continue to be lost from academic programs.

Richard Felder conducted a five-year longitudinal study of 123 Chemical Engineering students at North Carolina State University to determine the effects of nontraditional instructional techniques on academic performance and retention.[12] The alternative teaching practices included active in-class learning exercises, collaborative team-based learning in class and homework assignments, and use of open-ended questions and problem formulations. Using these techniques, a sequence of five chemical engineering courses were taught to the same students from freshman through senior year. Students in a comparison group two years later were taught the same five chemical engineering courses, using traditional methods.

Students in the study group reported high ratings on the cooperative learning aspects of the experimental courses. By their junior year, students in the experimental group indicated stronger within-group bonding than for the comparison group. Although the evidence was not strong enough to conclude whether the experimental group performed at a higher academic level or achieved greater skill levels than the comparison group,[13] this study, along with those described above, laid a foundation for future longitudinal research into engineering education from the students' perspective.

The Academic Pathways Study draws on previous research on how students learn, as well as what factors influence attrition in science, math and engineering majors. However, this study extends previous research in a number of fundamental ways:

1) It is a longitudinal study, following the same students from freshman through junior years, and other students in career transition into engineering practice.
2) It is specific to engineering students, rather than all majors or combined science, math and engineering majors.
3) It is cross-institutional, involving students from four campuses, each campus having a slightly different set of factors which may be significant in the findings.
4) It employs multiple research methods: ethnography, in-depth interviews, and widely distributed surveys.

In summary, the Academic Pathways Study builds on the foundation of existing research. But it focuses on engineering majors only, it is conducted over multiple institutions, it takes a longitudinal approach to students from entry into college through entry into the workplace, and it encompasses multiple research methods.

Objectives of the Study

The primary objective of this study is to conduct research on the engineering learning experience. Research findings will provide a comprehensive account of how people become engineers, providing insight into key questions in engineering education. Specific goals include:

1) Generating a comprehensive understanding of the work patterns, strategies, and learning trajectories of students as they progress through their engineering education.
2) Exploring how misalignments between university and workplace practices impact preparation and retention in the engineering professions.
3) Describing how participants' learning and working environments intersect with engineering, how their engineering knowledge changes over time, and the context of those changes.
4) Understanding how engineering learning and educational experience vary across populations and institutions, identifying significant factors related to gender, ethnic and geographic diversity.

The study addresses the following research questions, that can be categorized in four primary areas:

1. Skills: How do students' engineering skills and knowledge develop and/or change over time? How do the technological fluencies of engineering students compare with those found in professional engineering settings? What concepts are difficult for students to learn? How can we measure students' understanding of those concepts? Why are these concepts difficult to learn?

2. Identity: How do these students come to identify themselves as engineers? How does student appreciation, confidence, and commitment to engineering change as they navigate their education? How does this in turn impact how these students make decisions about further participation in engineering after graduation? What communities do engineering students belong to? How does belonging to a community contribute to their identity?

3. Education: What elements of students' engineering educations contribute to changes observed in questions one and two? What do students find difficult and how do they deal with the difficulties they face?

4. Workplace: What skills do early career engineers need as they enter the workplace? Where did they obtain these skills? Are there any missing skills?

Methods and Design of the Study

Research Team and Responsibilities

The Research Team includes over fifteen participating researchers from engineering, education, communication, the humanities, and the sciences. This team provides interdisciplinary expertise for conducting rigorous research across the four campuses involved in the study, and the cross-institutional, multi-disciplinary team works cohesively to develop all aspects of the study. Although specific campuses are responsible for certain areas, the team collaborates on all aspects of the study, including subject recruitment, survey and interview design, and ethnographic procedures. The collaborative nature of the study's design provides a robust research process across campuses, domains and perspectives.

Responsibility for each of the research approaches (ethnography, interviews and surveys) has been distributed in this way:

1) Survey design: Stanford University
2) Formal interview design: Howard University
3) Ethnographic design: University of Washington

Process

Using three research approaches as described above expands the work of earlier studies. An ethnography approach is used, enabling rich information-gathering about the details of student experience. Interviews and surveys, with questions designed to pursue similar questions explored by ethnography, expand the scope of the study. The research team brainstormed a large number of questions, but some of the survey questions have been developed based on other research findings, particularly Seymour and Astin.[11,10]

Each research approach is described below.

Ethnographic studies are aimed at understanding distinct cultures and the ways that the members of a culture understand and participate in that culture. Ethnography involves observation of participants engaged in their everyday activities; these observations are recorded principally as field notes for subsequent analysis. Large amounts of information of different kinds are gathered during ethnographic research (e.g. field notes, informal interviews, work products, etc.). These forms of data are then analyzed to find patterns that establish how people make sense of and participate in particular social settings. Each ethnography participant will be observed for approximately 30 hours/academic year. Particularly important will be observing students during activities that are significant in engineering education culture such as intense project work, examination periods, and while involved in extra-curricular activities. In addition, the observations will aim to document what the typical work-patterns are for each of the students.

Formal interviews allow for collection of rich, in-depth accounts of student experiences related to technical skill and cognitive development, strategies for navigating academic programs, and identity development. Each interview participant will be interviewed one time per academic year. Each interview will be approximately 2 hours in length.

Surveys allow for the investigation of a broad range of issues around, for example, students' attitudes about engineering, their confidence in their abilities, their aspirations, perceptions about the engineering education climate, and perceptions of their behaviors and experiences inside and outside of the classroom. Where possible, surveys will be patterned after surveys that have previously been used to query engineering students (e.g., Pittsburgh Freshman Engineering Attitudes Survey (PFEAS), WEPAN Quality of Engineering Education Survey, National Survey of Student Engagement (NSSE) College Student Report).[14,15,16] This allows us to benchmark the responses from our cohort against previously published data from these surveys.

Interpreted and analyzed together, ethnographic, interview and survey data will result in rich descriptions of students' academic pathways, along with broadly applicable findings on critical factors, common challenges and important strategies related to navigating these pathways.

Each of these investigative tool provides a set of insights which informs the other tools. Ethnography, while providing a wide level of information on each subject, is limited in number of participants. Findings from ethnography feed into the interview questions, drawing on a larger number of participants. Survey work extends the findings from ethnography and interviews into a much broader set of students, so that each tool encompasses a successively larger group of students in the study, allowing generalization of specific findings to a much broader population

Knowledge Attainment Measures

The development of student engineering skills will be evaluated through a combination of objective measures. Grades and transcripts are collected on subjects, and the formal interview includes a design scoping task, a design problem in which the subject is asked to list factors which they would consider in their design. The combination of these measures is designed to provide information on engineering skills attained through the process of a student's undergraduate engineering education.

Recruiting

The longitudinal study will consist of four interrelated complementary cohorts. The four cohorts, along with the research questions and methods, are described in Table 1.

Cohort 1: For Cohort 1, we will follow students *from their freshmen through junior years.* With this cohort, we will learn how incoming freshmen navigate the precarious early years of an engineering major which often include the decision to remain in or leave engineering. Cohort 1 will consist of 40 participants from each campus, as well as a control group of 40 from each campus, for a total of 160 test participants and 160 control participants. All 160 test participants will participate in surveys and interviews, while the control group will have no direct observation. Eight of the 40 participants at each campus will also be ethnography participants, for a total of 32 ethnography subjects.

Cohort 2: For Cohort 2, we will follow students from the *end of their junior year through their first two years post-B.S.* With this cohort, we will focus on the critical transition from undergraduate education to either the workforce or graduate school. Studying Cohort 2 will help us identify what goes into being an engineer that is not taught or learned in an undergraduate education. Cohort 2 will have 16 participants from two of the four institutions, 8 from Howard University, and 8 from the University of Washington. Cohort 2 participants are followed from April 2005 through June 2007.

Cohort 3: Cohort 3 will include a cross-section of freshmen-alumni at the four campuses. Here, we will administer surveys based on research findings to date. The data we collect will allow us to generalize from Cohort 1 and 2 findings and compare results from a broad range of students. Cohort 3 will involved approximately 3,000 students.

Cohort 4: In Cohort 4, we will include students from engineering programs at collaborating institutions across the country. We have selected these institutions to ensure a diversity of educational experiences and student populations in our studies. Studies of Cohort 4 participants will be subsequent to the study of Cohorts 1, 2 and 3, and will focus on the same questions as these cohorts, using surveys only. The Cohort 4 studies will help us ensure that that the images we produce of how students at U.S. institutions become engineers are diverse and as representative as possible. Cohort 4 will consist of 2,000 or more participants.

The understanding of engineering education we gain from the study of any single cohort will be valuable. When the results of all studies are combined, the product will be an incredibly rich picture of the education of individuals as engineers during their four year formal education and beyond, at a wide range of institutional and professional settings.

Table 1. Research design for each cohort in the longitudinal studies

Cohort 1: Students majoring in engineering at all four institutions, followed from their freshman year through their junior year (n=40/school at all four institutions).	
How do students' engineering skills and knowledge develop and/or change?	• Periodic skill and concept-based tests and interviews with participants. • . Collection of transcripts • Ethnographic observations of students in classes and their places of work.
How do students develop an identity as an engineer?	• Periodic interviews of individual students over time, using their student work products as elicitation prompts. • Ethnographic observations of students in a range of learning environments.
What challenges do students face? What resources they draw upon?	• Ethnographic observations of students in a range of learning and work environments. • Periodic interviews of cohort students over time. •
Cohort 2: Students majoring in engineering at all four institutions, followed from the end of their junior year through their first two years post-B.S. (n=8/school at Howard University and the University of Washington only).	
What skills do early career engineers need as they enter the workplace? Where did they obtain these skills? Are there any missing skills?	• Ethnographic observations of cohort members' work over time and comparative analyses of skills and knowledge used in school and at work. • Interviews with cohort members about challenges of making transitions to post-B.S. life and ways that they were prepared well or poorly, by their educations (e.g., how cohort members integrate senior capstone design experiences into practice).
How do students develop an identity as an engineer?	• Interviews with cohort members focused on how their identification with engineering changes as they make the transition from undergraduate education (e.g., how students make decisions regarding post-B.S. endeavors; how their commitment and enthusiasm for engineering evolves).
Cohort 3: Students from freshmen-alumni at the four campuses.	
Same as above	• Surveys developed from evolving research results.
Cohort 4: Students from collaborating engineering programs at institutions across the country.	
Same as above	• Surveys developed from evolving research results.

Diversity

Students from underrepresented groups report dissatisfaction with the impersonal and competitive atmosphere of traditional science and engineering courses.[11,17,18] Including students from diverse backgrounds is a key factor in our research designs. Participants will include students that prior research shows to be more likely to remain in engineering as well as those who are have a high likelihood of leaving.[11] By comparing the experiences of people of diverse backgrounds becoming engineers, or choosing to leave engineering, we expect to further the engineering education community's understanding of student recruitment and retention.

To capture issues specific to underrepresented groups, the following has been incorporated into the study:

In Cohort 1, we will pay special attention to understanding how underrepresented students navigate their initial years in engineering education. We will accomplish that by employing oversampling strategies for gender (male/female) and underrepresented minorities (African Americans, Native Americans, Mexican Americans, Puerto Ricans, other Latino groups).

In Cohort 2, we will pay special attention to understanding how graduates from underrepresented groups navigate the transition from undergraduate education to either work or graduate school. We will accomplish that by oversampling for gender as in Cohort 1. In general, the largely contrasting ethnic backgrounds of the University of Washington and Howard University students should provide illuminating comparisons about the transition from undergraduate education to the engineering workplace.

Cohort 3 will include all students who have declared engineering as their major, students with undeclared majors who have expressed interest in engineering, and engineering alumni. In addition, declared majors in disciplines that complement and contrast with engineering will be included for comparison's sake. When identifying participants among the students with undeclared majors, special emphasis will be shown in contacting underrepresented students through math and science classes, and engineering-related, community-based societies and organizations.

Cohort 4 will include students from engineering programs at collaborating institutions across the country. Collaborating with these institutions will help to ensure that that the portraits of how students at U.S. institutions become engineers produced in the study are diverse and as representative as possible. By comparing the experiences of people of diverse backgrounds becoming engineers, or choosing to leave engineering, the engineering education community's understanding of underrepresented student recruitment and retention will be advanced.

Key decisions related to Cohort 1

Survey design

The study begins with freshmen in Cohort 1. It was decided to administer two surveys in the first year of Cohort 1: the first in January 2004, and a second survey in April 2004. The second survey will be based on the initial survey, but will also include questions and constructs suggested by findings from the interview and ethnographic research. After the first year, one or two surveys will be administered to Cohort 1 as they move through the study. These surveys will be extensions of the first-year surveys. Cohort 1 surveys will be leveraged to design a survey for the broader subject bases of Cohorts 3 and 4.

The initial Cohort 1 survey contains core questions, questions focused on persistence factors in engineering education and practice. The survey also contains wildcard questions, open-ended questions relating to engineering identity, experience, knowledge and practice.

Core questions are based on hypotheses related to persistence in engineering, which emerged from research findings based on a literature review of persistence factors in engineering. Existing national surveys on undergraduate education were also reviewed, to identify constructs that could be used in this survey. Some core questions also collect demographic information, such as sex, age, marital status, etc.

Wildcard questions were generated through brainstorming by campus teams in the four institutions, and are designed to capture campus-specific items, as well as to draw on the expertise of the engineering educators among the researchers to highlight issues that may be more intuitive or anecdotally-based. The wildcard questions complement the more focused, persistence factor-based nature of the core questions.

The initial Cohort 1 survey was piloted at all four institutions in October 2003, to ensure that survey questions are clear, that campus-specific differences are taken into account, to ensure that question placement, segmentation and completion time are appropriate, and to evaluate and redesign questions and constructs if necessary. Feedback was taken at the end of the survey in all four institutions, and focus groups were also held at Colorado School of Mines and Howard University, and from external advisors. Results are being analyzed and incorporated into the final Cohort 1 survey design.

Other design issues

The longitudinal nature of this study has major implications for engineering education, because it follows the same students as they move through their educational experience. Light's interviews, Astin's surveys, and Seymour's ethnographic interviews indicate key factors influencing the success of students, student development in higher education, and why students leave or stay in science, math or engineering majors, but only as "snap-shots." In contrast, a longitudinal approach raises certain key issues which arise because study participants are expected to remain in the study over a long time period (three years or longer).

Because the study is conducted across four institutions, other issues arise from the need either to standardize across campuses, or to accommodate campus-specific differences. Longitudinal issues and the cross-institutional issues are described below.

Background information collected: what types of background information should be gathered, whether SAT scores (pre-college) or course completion grades (during college), and is it the same across campuses or different for each campus? *It was decided to take what each individual campus uses as indicators, because indicators are part of the "normative map" of that campus. Campus-specific indicators are what students use to organize their applications and future work.*

Interview and survey questions: are questions in the surveys and interviews kept constant for all three years of Cohort 1, or are the cues modified based on findings along the way? *It was decided to modify interviews and surveys as the study progresses, because when significant findings are found early in the study, they will inform a redesign of survey and interview questions.*

Intervention vs. interaction: how do we differentiate between interactions as a basis for the study process, and an intervention which could influence a student's success in engineering education? How do researchers who are functioning in their professional roles as advisors and faculty continue to provide guidance to students without unduly influencing results of the study. If findings emerge which will aid in student persistence, can we use them to provide benefit to all students without compromising the need for the study to be unbiased? *It was decided that faculty and advisors who were also researchers should continue to guide students with the best knowledge available, and that if findings from the study could be used for all students, not just participants, they would be applied when available, particularly for the next year's incoming freshman class. Additionally, participants would not be identified to faculty or other students as much as possible, so that new interventions would be given to all students, rather than just to a select group, and findings will be consciously fed back into interventions or improvements for subsequent groups of students.*

Operationalizing research questions into survey and interview instruments: should we adapt existing instruments already in use, develop new instruments tailored to our specific research questions, or should we use some combination of these two options? *It was decided to generate survey and interview constructs based on our specific research questions (factors influencing persistence in engineering), but to adapt national survey questions where possible, because surveys are effective, but difficult to design well, so leveraging existing surveys which have been used previously helps minimize potential instrument problems.*

Ethnographic issues: how do we avoid bias and unwanted interventions during the ethnographic process? Because ethnography is grounded in anthropology, it is a highly specialized approach to research. *Taking care to use appropriate and sound ethnographic research methods avoids introducing bias from imposing a researcher's framework on the student's cultural experience, and also avoids undue intervention by the researcher. Researchers strive to observe participants without influencing their behavior, by getting a sense of what they do on a daily basis, by noting specific vocabulary and language they use on a frequent basis, by describing actions or behaviors without imposing an interpretation.*

Attrition and participant replacement: what happens if a participant drops out, do we replace a participant, and if so, how is that replacement recruited? *Current thinking is that if participants drop out of the study, replacements will be recruited from the control group, since background information has already been gathered for the control group. Because of the richness of the ethnographic approach, persistence factors which have already been established through previous studies will be used to try to ensure that ethnographic participants have a good chance of persisting through the study.*

Interaction of surveys, interviews and ethnography: how do we make sure that each study method does not become a study on its own? *It was decided to make sure that the scale of each method is not too large, and to continue leveraging what is learned from one method into redesign of the other methods, so that the combination of methods form an integral study design.*[19]

Implications of the Study for Further Research

Using the longitudinal research in this study, we will develop a conceptual map, or a "navigation chart" that is synthesized from individual findings of the study. This map will identify, analyze, and illustrate the various observed pathways to becoming an engineer. It will also illustrate the "dead ends" and hindrances that steer students away from becoming an engineer. This will delineate areas in engineering education where additional work is needed for improvement.

The synthesized study findings will pave the road and serve as a canonical reference framework for more targeted future research projects. Certain approaches to engineering education will be found to be highly effective, while others will be less effective. This information can be used to guide engineering education decisions, both to promote more use of effective approaches, and to discontinue use of less effective approaches. Further experimentation may be required to discover how to solve the challenges of less effective approaches.

Some results may be interesting or ambiguous, or may apply to a certain subset of subjects. These results will benefit from further investigation to determine specific strategies in certain situations. For example, married off-campus students with families may benefit from a different pedagogical method than their unmarried, on-campus counterparts.

Instruments which have been used in this study may be beneficial for use at other institutions, using the research developed through this study as a basis for evaluating and strengthening other engineering programs. These survey and interview instruments, in particular, may be part of a library or collection of evaluative instruments for general institutional use.

Conclusion: Value and Impact of Study

While a number of studies exist on undergraduate education from a student's perspective, this study is unique, because it is an in-depth, cross-institutional longitudinal study by an interdisciplinary team, with a sole focus on engineering education and transition into practice. The study also encompasses four institutions of widely varying constituencies and offerings, over three thousand students, is conducted over a period of five years, and utilizes three separate but interleaved approaches to data collection (ethnography, interviews and surveys).

The greatest contribution of this research may be in the value of contrasts: by ensuring uniformity and continuity across campuses and instruments, the results will have broad and far-reaching impact. Involving a large public institution (University of Washington), a prestigious private university (Stanford University), an engineering-only institution (Colorado School of Mines) and a predominantly minority-population, small engineering program (Howard University), this study's findings will include analysis of significant factors of student experience which would not arise in a single institution. The contrast within the research team among disciplines as well as institutions strengthens the robustness of the study. Additionally, using three research approaches provides contrast between rich ethnographic data, in-depth interview data, and broader survey data. Taken altogether, the Academic Pathways Study will show what themes and generalizations can truly be made for the student engineering population at large.

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