Engineering Undergraduate Persistence and Contributing Factors

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Abstract - The engineers of 2020 must be technically sound in their disciplines, global citizens, as well as aspirational, ethical leaders. To foster a new generation of engineering talent, modern curricula must advance strong analytical skills, teamwork, professionalism, and leadership. However, new curriculum with poor student retention cannot be deemed successful. We believe we possess the key components of a successful program, such as well-designed curricula, dedicated faculty and strong support services, yet many students leave our School. There is widespread speculation about the reasons for leaving, including financial need and lack of academic preparedness. To address these national and local retention phenomena, an evaluation process was designed to obtain quantitative information about why our students leave. The study assessed student attitudes associated with educational experiences in their new major contrasted to their engineering experiences. Thus, information gained could be a basis for decision making for future processes and proposed improvements. Engineering is committed to the challenge of developing solutions to increase the overall retention rate and diversity of engineering graduates to meet both internal and external pressures for accountability and industry demands. This paper will address some of the viable solutions to counter the problems identified in our study as well as a discussion of how they have been implemented in our school.

Index Terms - Assessment, Advising, Curriculum, Engineering education, Climate, Persistence, and Retention.

INTRODUCTION

The Fulton School of Engineering is one of many institutions concerned with the problem of attracting and retaining the best and brightest of our young citizens. Nationally, engineering programs are losing top performing students, whereas research has shown that retaining students is less expensive than recruiting new students. Furthermore, Wankat [1] asserted that higher retention rates more than pay for the costs of redesigning courses. Administrators have argued that first year persistence and graduation rates are standard measures of academic quality as well as measures of institutional effectiveness. They have called for increased examination of issues and interventions. Our research added local, but not necessarily unique, information about our specific problem. Reasons for leaving can be grouped into four main categories of dissatisfaction: Academic and Career Advising; Engineering Structure, Curriculum, and Culture; Faculty; and High School Preparation. More specifically, our findings indicated that when compared with their new major, most students had greater language difficulties with international faculty. Students felt that faculty members were less approachable regarding academics and advising while engineering was their major. Additionally, a majority of students experienced poorer recitation support, more conceptual difficulties, and problems with class size. They also reported low morale due to the competitive culture and lack of peer support. Students were less satisfied with engineering advisors and career counseling1 and were less likely to agree that the career options and rewards were worth the effort to pursue engineering. Finally, some students felt they lacked adequate high school preparation for the engineering major in terms of mathematics and science education. In total, the responses given by former undergraduate students who remained at the university are consistent with the national literature on the subject of retention and why students leave engineering.

Our report is organized in the following manner. Each section includes a summary of national and local data identifying factors contributing to engineering attrition. At the close of this report, we use national research, best practices, and local assessment results to suggest a general set of recommendations

ACADEMIC AND CAREER ADVISING

Nationwide, students have identified academic advising and career counseling as critical needs that have not been successfully met. Specifically, students suggested that departmental advisors should provide advice on academic and career alternatives and how best to pursue them and accurate information on required courses and appropriate sequencing in order to fulfill particular degree requirements.

1 Former engineering data were compared to “new major” data; findings represent significant differences between the two majors. Our research focused on why students left engineering to pursue another major rather than why they dropped out of the university.
In one large study, inadequate advising was mentioned as a concern by 81% of engineering switchers and inadequate advising was an issue raised by 53% of all non-switchers \(^2\). One of the most difficult freshman problems was learning the campus system of advising and counseling services in order to prevent small problems from becoming large ones. Students believed that advisors provided inaccurate information about course requirements and lacked information about special programs, sources of financial aid and career opportunities. Moreover, advisors were typically too overwhelmed with student load to provide adequate care \([3]\). Our survey responses are consistent with national findings and highlight lack of satisfaction with engineering and career advising when compared with the new majors. Students were less satisfied with advising regarding both academics and career education. In addition, they were less likely to agree that the career options were worth the effort. Some argue that the engineering field is relatively invisible in the mass media or poorly depicted \([4]\).

<table>
<thead>
<tr>
<th>Survey Item</th>
<th>ENGR New Major</th>
<th>Difference</th>
<th>p-value</th>
</tr>
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<tbody>
<tr>
<td>Q3 Quality of Advising</td>
<td>2.75</td>
<td>3.91</td>
<td>1.153</td>
</tr>
<tr>
<td>Q22 Satisfaction with career counseling</td>
<td>2.40</td>
<td>3.64</td>
<td>1.238</td>
</tr>
<tr>
<td>Q6 Career options worth the effort to get degree</td>
<td>3.25</td>
<td>4.33</td>
<td>1.09</td>
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According to the National Academy of Sciences \([5]\), students frequently believe that engineering classes are too time consuming, without realizing that the rewards are worth the effort. Researchers at the University of Washington conducted a longitudinal study of female undergraduate students in engineering and science. They found awareness of career opportunities in science and engineering to be a freshman persistence factor \([6]\). Some engineering students fail to see the potential benefits of engineering or where it fits into the big picture in society \([5]\). If engineering could make its societal value explicit, it would help attract and retain future students and significantly increase the persistence of women and minorities \([7]\). Females value human interaction, yet engineering is not perceived to offer that exchange \([4]\). Engineering needs to convey a message that it places a high priority on helping society, fosters teamwork, and employs diverse interpersonal skills.

**ENGINEERING STRUCTURE, CURRICULUM, AND CULTURE**

Issues that factor into student attrition are from a common set of problems experienced by both switchers and non-switchers \([2]\). Problems stem from engineering structure, curriculum, and culture, which contribute to attrition more than individual inadequacies or appeal of other majors. National studies have compared issues reported by students who switch and those who do not. Both groups reported poor teaching and difficulty in getting help with academic problems. About 40% of switchers and non-switchers reported inadequate high school mathematics and science preparation \([8]\). What distinguished the survivors from those who left was not the nature of their problems, but whether they were able to assess problems accurately and find resources quickly enough to survive. Faculty intervention also played a large role during a crisis point in the student’s academic or personal life. Introductory science courses at the university level are often held in large lecture classrooms in which students may feel isolated and uncomfortable interacting. Seymour \([3]\) found that science, math, and engineering switchers and non-switchers indicated that large classes contributed to the poor quality of their learning experiences and in addition, the competitive engineering culture contributed to student decisions to leave \([2]\).

Local survey respondents reported more conceptual difficulties with subjects, issues relating to class size, and poorer recitation support by teaching assistants in engineering compared to the new major. At ASU students take few engineering courses during their freshman year and must take math and physics taught by other departments for which engineering has little influence. Students also indicated they experienced low morale and little peer support due to the competitive culture in engineering.

**TABLE II**

<table>
<thead>
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<th>Survey Item</th>
<th>ENGR New Major</th>
<th>Difference</th>
<th>p-value</th>
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<tbody>
<tr>
<td>Q8 Conceptual issues</td>
<td>3.11</td>
<td>1.95</td>
<td>1.16</td>
</tr>
<tr>
<td>Q15 Problems related to class size</td>
<td>2.72</td>
<td>1.89</td>
<td>.83</td>
</tr>
<tr>
<td>Q14 Poor recitation TA’s</td>
<td>3.13</td>
<td>1.76</td>
<td>1.37</td>
</tr>
<tr>
<td>Q12 Low morale (competitive culture)</td>
<td>2.75</td>
<td>1.72</td>
<td>1.03</td>
</tr>
<tr>
<td>Q18 Peer support –major</td>
<td>2.66</td>
<td>4.03</td>
<td>1.37</td>
</tr>
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The NAE recommended that engineering curriculum should employ the iterative process of designing and predicting performance, building, and testing in the first year. It is imperative for programs to engage students in courses that connect engineering design and solutions to real-world problems \([5]\). Using teaching techniques that focus on social and global contexts help attract and retain more diverse students, who are not learning under the standard lecture-style, large-class system. Our School has in part addressed these issues by introducing a revamped curriculum that reduces the required credit hours, increases life-sciences studies, and introduces freshman and sophomores to more engineering courses.

**FACULTY**

National studies reveal that science, math, and engineering students are generally dissatisfied with faculty advising and academic support \([2]-[3]-[5]\). Both switchers and non-switchers indicated that advisory systems were poorly organized and often, faculty did not keep their office hours.

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\(^2\) A switcher is a student who enrolls in a non-engineering major, whereas a non-switcher is a student who persists in engineering.

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In addition, counseling on academic matters was ineffective [9]. Problems often stemmed from students assuming a broader role for faculty advisors than faculty expected. Our students found faculty members and instructors to be less approachable and experienced greater language difficulties with international faculty and TA’s in the engineering major. Also students felt less satisfied with advising or help with academic problems and they reported a lack of research opportunities with engineering faculty.

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<th>TABLE III</th>
<th>FACULTY AND TEACHING ASSISTANTS</th>
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<tr>
<td>Survey Item</td>
<td>ENGR New Major</td>
</tr>
<tr>
<td>Q3</td>
<td>2.77 3.34</td>
</tr>
<tr>
<td>Q13 Language difficulties</td>
<td>3.60 1.71</td>
</tr>
<tr>
<td>Q6</td>
<td>1.93 3.23</td>
</tr>
</tbody>
</table>

The local findings are consistent with national data. Poor teaching in STEM classes has been the most common complaint, mentioned by the majority of those who left engineering [10]. Furthermore, students perceived that instructors were too busy to meet with them. In one study, 12% of men and 20% of women indicated that professors had no time for students [11]. Yet many professors challenged this and complained that very few students came to office hours. An instructor's willingness to provide help is not the only factor influencing student behavior. There are often other issues that deter students from getting the help they need, such as faculty or instructor approachability and language barriers.

LACK OF HIGH SCHOOL PREPARATION

At national roundtables university presidents have noted the below-average school system outcomes and suggested that turning a blind eye to neighboring troubled schools is deplorable. Teaching degrees mean little if graduates are not equipped to properly educate primary and secondary school students. One president pointed out that the problem is completely within the scope of the university [12]. Nationally, students’ accounts of under-preparation were of two types: deficiencies of curriculum content and subject depth and failure to acquire appropriate study skills or habits and time management. Switchers had received little high school teaching in calculus, or described the content and depth of their high school science or math as insufficient. Our data are in alignment with national findings.

RECOMMENDATIONS BASED ON BEST PRACTICES

The following information includes strategies to improve persistence rates at the undergraduate level in engineering and other science, technology, and math-related programs.

I. Academic and Career Advising

Advisors should recognize their key role in student success and participate in any retention efforts underway in their academic area. To shed a positive light on engineering, advisors, faculty, and teaching assistants can show applications of the coursework so the students can connect what they are studying to the "real world." A critical concept is for learners to understand the impact of engineering solutions in a global and societal context. The perceived relevance of scientific process and engineering problem solving in the context of everyday life experiences is a factor in science and engineering interest and persistence at the pre-college and undergraduate levels [13]-[14].

Provide diverse role models. Many undergraduates cite the importance of their male role models or mentors in assisting them in pursuit of a science career. Although men have been important advocates, role models, and mentors for women scientists, students need more exposure to females who are successful in engineering fields. ASEE national data showed that just six percent of full professors, 12 percent of associate professors, and 18 percent of assistant professors are women [4]. Because women look to faculty members as role models, the low numbers could reinforce the lack of interest women show in engineering [4]. Ultimately, the best solution is to hire and retain female faculty who can serve as role models. A study at the State University of New York, [15] found a correlation between retention of undergraduate female students and percentage of science and math credits taken with female instructors. They also found that a greater percentage of female students in those classes lead to increased female retention. No significant relationship for male students’ retention rates was found. They concluded their results provided support for gender-based programs for hiring in specific disciplines. Some found that the percentage of women on the faculty at coed institutions to be positively correlated with students’ satisfaction with faculty [16]. According to the National Resource Council, the presence of women faculty at all ranks would be a sign to female students that they will be respected and treated fairly [17]. We have addressed several these issues by instituting advisor training, creating an intervention program for struggling students, and providing a new career center offering career coaching and internships.

II. Engineering Curriculum, Structure, and Curriculum

Personalize large classes and reduce class size with small group learning. The size and demographics of a university class may be different from what students experienced in high school. Research suggests that females view large classes as impersonal and isolating and thus, they are less willing to ask questions in large lecture settings [18]. In an early study in 1991, females described a good professor as approachable, friendly, and someone who wanted to get to know students. College females perceived that learning was more difficult due to lack of close contact with faculty [9].

Audiences in large classroom settings could be broken into smaller groups for short episodes of peer discussion and to work on problems, scientific inquiry, and other active hands-on exercises. Alternatively, cooperative small group learning situations could be provided during recitation sessions with graduate student teaching assistants to
compliment lecture instruction [13], with an otherwise unchanged lecture and lab pedagogy [19]-[8]-[20]. Online courses may use student groups led by a teaching assistant ‘coach’ as the main vehicle to gain mastery, and offer mini-lectures on an ‘as needed’ basis to clarify common areas of difficulty. Another technology-supported alternative is the ‘virtual classroom’ that offers student-student and student-faculty computer teleconferencing as the delivery system, with computer-generated data and examples [2].

Graduate students are often asked to lead discussion groups (also called recitation sections). However, these students have minimal instructional training; thus, in their preparation, what to teach is emphasized over how to teach [13]. As a result, students feel that they have poor recitation support by teaching assistants, a finding also evident in this current study. Suggested strategies for teaching include helping students prepare for exams; brainstorming to work through essay questions; holding post-exam discussions covering wrong answers in addition to correct answers; and employing group work [13].

It is a common belief among first-year students that introductory math and engineering classes are “weedouts.” Some faculty members think that deficits in ability distinguish those who leave from those who remain. Widespread acceptance of this theory allows schools and departments to regard student attrition as a kind of “natural selection” process [3]. In contrast, many studies have shown repeatedly that students who switch are intelligent and strongly motivated, but are discouraged by the atmosphere [22]-[23]-[24]. One research study found that 33 percent of the students switching out of a science, math, or engineering field perceived that morale was undermined by a competitive culture [9]. The NAE asserted that “accepting attrition as inevitable is both unfair to students and wasteful of resources and faculty time” [5]. Educators have realized that they cannot afford to discourage engineering students because retention numbers must improve in order to meet the country’s projected demand for engineers. Rather than functioning as gate-keeper courses, calculus and physics should be redesigned so that motivated students can master them. Courses should be developed to show the connection between subjects to improve relevance.

Use cooperative and collaborative approaches. It is recommended that faculty who teach introductory courses shift the pedagogical focus away from a competitive model to a cooperative, stimulating model to retain talented, diverse students. There are several ways to shift this focus. First, provide cooperative opportunities in introductory classes. Evidence shows that learning is enhanced through cooperative experiences [25]. Cooperative learning is an approach to learning which uses small groups of students working together to solve problems, complete a task or accomplish a common goal. Small groups provide a forum in which students ask questions, discuss ideas, make mistakes, learn to listen to others’ ideas, offer constructive criticism, and summarize their discoveries in writing [26]. In addition to improved academic achievement, there may be improvement in critical thinking, problem solving, and reasoning abilities; self-esteem; and in social skills [27]. Students can be given the opportunity to assist others’ learning through peer mentoring experiences [25].

A meta-analysis by Springer, Stanne, and Donovan [28] indicated that students who learn in small groups demonstrate greater academic performance, express more positive attitudes toward learning, and persist in STEM courses and programs more than their more traditionally taught counterparts. They suggested that the provision of small group alternatives to lecture-based instruction may significantly impact the academic achievement of members of underrepresented groups and the learning-related attitudes of women. Of particular note is that these researchers reported a 22% difference in attrition rate with small-group learning. This substantial effect upon student retention occurred across multiple postsecondary institutions with vastly different forms of small-group activities. Small group learning is often provided with peer educators. A review of colleges in the United States found that 76 to 83 percent of all higher education institutions utilize peer educators [29].

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Most Women in Science and Engineering (WISE) programs include formal mentoring in which upperclassmen serve as role models for freshmen. These mentors help with homework, give advice, and ease the college transition [30].

Moving from "survival of the fittest" to "cooperative competitiveness" is designed to increase student success in meeting and exceeding course objectives. Giving students leadership roles in enhancing the level of overall class achievement can be important for development of their future professional career and management skills. This concept is widely practiced in robotic competitions such as the FIRST competition founded by inventor Dean Kamen.

To provide more stimulating curricula, design introductory courses that are more discovery-oriented and explore interesting topics while teaching the basics. When projects are problem-based, the students become active learners who are motivated to seek knowledge and skills to solve problems [20]-[31]. Currently there is a nationwide emphasis upon developing more conceptual and exploratory-learning curriculum for undergraduates [32]. Resources exist to assist in the implementation of active learning experiences and team-based learning. Some have described typical undergraduate student reactions and faculty concerns regarding adoption of such activities [33]. Others provided a method to account for individual effort in cooperative teams [34]. Ingram et al. created student-centered activities to foster inquiry outside of laboratory settings [35]. Similarly, some initiated research workshops were developed for students to practice formulating research questions and experimental protocols [19]. Two instructors described thematic case-based learning to integrate course content with industry context [36]. Smith et al. summarized methods to engage students, particularly with cooperative and problem-based learning, and gave suggestions for redesigning
engineering classes and programs to include them [37]. Also, there has been discussion of problem-based learning and teamwork at the university department level [38].

Also, many programs have incorporated engineering design, building, and testing into freshman curriculum. One example is the Engineering Division of Lafayette College’s first-year engineering course [39]. Others emphasize the social relevance of engineering, such as Smith College’s Picker Engineering Program [40]-[41]. University of Nevada has emphasized an interdisciplinary approach, which partners with business [42]. Educators at Northwestern University’s School of Engineering and Applied Science emphasized the need for future engineers to develop and implement sustainable technology, benign manufacturing processes and expanded environmental assessment tools to maintain both healthy economies and environments [43].

III. Improve Student Climate with Summer Programs, Cohort Groups, Peer Mentors, and Housing

The more integrated a student is in the social activities of a campus environment, the more likely the student is to persist in college [44]. Four types of programs that improve student climate include summer programs, cohort groups, peer mentors, and designating residential communities. First, a community-building experience is the summer program. Increasingly all freshmen, in addition to underrepresented populations, are invited to attend classes for several weeks as a college orientation. Data support the value of these summer programs in increasing retention. A compelling example has been Syracuse’s retention program as the four-year graduation rate within the college of engineering and computer science has risen approximately 11 percent overall and 18 percent for females [7].

Second, some schools build community by creating learning cohorts. Cohort students are enrolled in the same basic classes each semester. In 1993 Texas A & M began their “Learning Communities” cohort program. Typically, they have over 15 groups of 100 freshmen who learn together in the same sections of calculus, chemistry, and physics. Cohort learning was believed to be valuable for students transitioning from a rural background to a large university setting [7]. In the University of Oregon and the University of Washington, student cohorts attend classes with 300 other students, but stay together for small discussion sections of up to 30 students lead by graduate or upper-level students [31]. Students in learning communities create their own peer groups, which support them both academically and socially. Locally, we are refining our cohort model adding variations of cohorts and involving peer leadership.

Third, the use of peer educators can improve the learning atmosphere. A review of US colleges found that approximately 80 percent of all higher education institutions utilize peer educators [29]. Small-group learning is effective in a variety of contexts [28]. At Northwestern, implementing a peer-facilitated science workshop resulted in higher retention. Evidence suggested particular benefits for minority students in the program [20]. Most WISE programs include formal mentoring in which upperclassmen serve as role models for freshmen women. The mentors help with homework, give advice, and serve as role models during the freshman year, which can be the most taxing [30].

A fourth method to build community is designating residence halls or floors for engineering students. Some benefits include less peer pressure to play versus study as well as increased opportunities for teamwork and peer mentoring [7]. The Ira A. Fulton School of Engineering Residential Community provides first-year students enrolled in engineering and computer science programs with an opportunity to enrich their academic experience outside the classroom. Students have access to tutoring, academic workshops on registration and time management, industry tours and social activities such as gaming night, faculty dinners and speed networking. These academic and social activities are designed to help build relationships with peers, mentors, and faculty. Additionally, students have access to peer mentors. There are two peer mentors, who are upper-class engineering students, living in the community. The peer mentors are there to serve as a resource to the residents and to assist in the planning of academic and social activities. These programs seek to ease the critical transition from high school to the university. They are increasingly being implemented to improve the student learning climate.

IV. Faculty

In a recent Prism article, authors recommended proven steps to improve the quality of instruction and approachability for engineering faculty [45]. These recommendations include identifying education objectives, employing active, hands-on and small group learning, providing encouragement, sharing enthusiasm for the subject matter, reducing time pressure on examinations, and obtaining and implementing several written suggestions from students to improve learning.

Initiating the recommendations above may affect the quality of teaching and also may enhance student self-confidence. For example, underrepresented minorities and females thrive in classes with a variety of project-based activities that require teamwork. As a result, schools are introducing design courses as early as the freshman year to give students a taste of engineering. At the University of Michigan, students in an Engineering 100 section build a greenhouse for nonprofit groups [7]. The Fulton School is refining design courses and offers the courses in small class sizes of 19 students to optimize faculty-student interaction.

At Alverno College, an all women’s college in Milwaukee, introductory courses have used collaboration, which boosted students’ self-confidence and performance [46]. This is particularly important as women are more likely to cite their own inadequacy when encountering academic problems [47]. Some have also highlighted the benefits of hands on research to increase student motivation and productivity. Research opportunities often allow students to recognize new aptitudes and get a better sense of the purpose of classroom learning. Also working with a
faculty member or other researcher provides students with the opportunity to find role models and mentors and gain insight into what engineering is all about [48]-[49]. The work habits required for success in research can carry over and help students in their class work--things like good time management, careful note taking, and the ability to discern the more substantive issues of a problem. Educators have revealed that participation in undergraduate student-faculty research partnerships, which included peer advising, positively affected retention [49]. These authors emphasized that research partnerships for undergraduates successfully combine school educational and research missions.

The School has initiated the Fulton Undergraduate Research Initiative (FURI) to encourage student research. Three programs are featured under its umbrella. First, FURI’s major component is the Research Program where students are paid to conduct their own research projects under the guidance of a faculty mentor. Students are eligible for a research supply budget and the mentor is paid a stipend at the end of the semester. This program currently has seventy-three students. Thirty percent of the students are women and about forty percent represent minority students. The number of mentors in FURI represents approximately 20 percent of the Engineering faculty. Second, FURI hosts a Research Symposium every semester for all FURI students and other undergraduate engineering student conducting research. This event draws about 200 on- and off-campus visitors. Third, the Travel Grant Program supports any undergraduate engineering student conducting student research. This event draws about 200 on- and off-campus visitors. To support both their educational objectives and their transition to college, the curriculum should include current literature on issues facing the learner population in the classroom. An innovative program in our school is being infused into first year engineering curriculum which introduces modules for student success (e.g. time management). These modules are jointly instructed by faculty, advisors and peer mentors. Since our campus is comprised of working and commuting students, with multiple demands on their time, campus offices, like tutoring and career services, are able to assist students by providing some extended hours. Finally, matching new students with peer mentors or second-year students creates peer connections and networks to discuss concerns and enables better orientation to the campus. These partnerships give new students a link to the institution through students within the population. Providing information and resources, thereby helping students to feel supported by their School or university, can increase students’ institutional commitment, involvement, and persistence. The School is committed to the challenge of developing viable solutions to increase the overall retention rate as well as diversity of engineering graduates to meet both internal and external pressures for accountability and industry demands.

Acknowledgment

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References


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