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Broadening the Appeal of Engineering—Addressing Factors Contributing to Low Appeal and High Attrition*

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The declining number of graduating engineers necessary for the long-term economic growth and well-being of the US is becoming a serious challenge. We discuss national and international trends towards a decline in engineering enrollment and the consequences of further decline of engineers to the nation; data on a minority of women and persons with disabilities participating in the profession are examined in a historical context and the reasons for their relatively low numbers are evaluated, as are issues and causes related to student retention and low appeal of engineering in American universities. Input from key engineering educators (engineering school deans) has been analyzed and presented to understand the factors contributing to the low appeal of engineering among the general public and high attrition among students. A generalized preference index model is developed to address these two crucial issues; example use of preference indices is also presented. Based upon research and data, strategies are proposed that can be implemented to improve recruitment and retention.

Keywords: Engineering appeal, student recruitment, student retention.

INTRODUCTION

SCIENTISTS, ENGINEERS AND TECHNOLOGISTS drove the technical revolutions, product innovations and productivity gains that fostered the economic growth and prosperity of the United States in the 20th century. Future economic growth and prosperity will flow to countries that attract and nurture sufficient technical professionals to generate the 21st century's technological and product advancements.

National and international trends

Technologically advanced—and advancing—economies have developed an enthused population that understands the important relationship between technology, economic growth and enhanced quality of life. This motivates an increase of the participation in, and rigour of, their academia and workforce.

In contrast, the US consistently experiences a disparity between the number of individuals interested in a technical profession and the number required to sustain technical and economic leadership for the United States. Three trends have caused this disparity and threaten the US's economic status.

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1) Disinterest among young people persists in science, engineering, and technology. Figure 1 below [1] demonstrates the impact of motivating young people to pursue math- and science-based careers. China, South Korea and Japan show a remarkably large percentage of first university degrees in science and engineering. Science and engineering degrees made up 56% of degrees conferred in China in 2004 and 63% in Japan in 2003. The number of first university science and engineering degrees awarded in South Korea and the United Kingdom more than doubled between 1985 and 2005, and those in China more than quadrupled over that same period [2].

In contrast, the US has experienced distinguishable deficiencies in science and engineering graduates and their participation in the US workforce. Since the 1970s, science and engineering degrees have made up roughly 33% of US bachelor's degrees, but the distribution among the disciplines has changed. In 1985, 35% of the total science and engineering bachelor's degrees were awarded in engineering or computer science, and engineering alone comprised 23% of the science and engineering degrees. By 2005, engineering and computer science comprised only 25% of the total science and engineering bachelor's degrees, and engin-

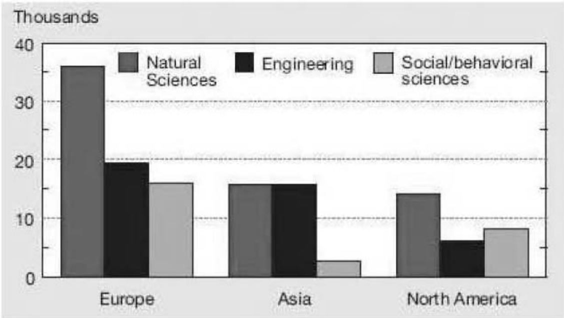

Fig. 1. S&E doctoral degrees in Europe, Asia and N. America, by field (2004, most recent data).

eering alone was only 14% of the total. During that 20 year period, the absolute number of science and engineering bachelor's degrees awarded grew 40% as the absolute number of engineering declined 14% from the record high in 1985 of 77,571 [3].

2) Declining contributions of US-trained foreign nationals. US-trained foreign nationals traditionally have been enticed to become permanent US residents, and often ultimately citizens, by finding the best job prospects and quality of life in the US. Improving opportunities and growing economies in many regions of the world increasingly encourage contemporary foreign nationals to complete their education and return to their home country, with a short-term and temporary contribution to the US economy.
3) Limited participation in US engineering education and profession. The capacity of the US's technical workforce is constrained by the country's inability to attract women, people of colour and people with disabilities to careers in science, engineering and technology. By 2025, less than 30% of the US college-age population will be from the white, male demographic that dominates engineering classrooms and earned 57% of the engineering degrees in 2006 [4].

Relevance to engineering education

'Today, the US economy is largely technology-based, and until we learn to attract students and keep our young people engaged in engineering we will continue to import engineers', said Frank Huband, Executive Director and Publisher of *ASEE* [5]. By developing the technical talents and leveraging the diverse perspectives of those severely underrepresented in engineering and science, the US will have the numbers and richness of talent required for a pre-eminent technology-based economy.

LITERATURE SURVEY

Uniquely, input has been sought from a group of engineering school deans who are the key engineering educators at universities. In addition, based upon this input, a generalized model was developed to enhance the appeal of the engineering profession and also to reduce attrition. This model provides a generalized approach to address paper topics in a way that is relevant to the needs of the institution.

Engineering undergraduate attrition and contributing factors [6]

The current work environment requires engineers to be global citizens as well as aspirational, ethical leaders. To foster this new generation of engineering talent, modern curricula must advance strong analytical skills, creativity, professionalism and leadership. However, a new curriculum with poor student retention cannot be deemed successful. The key components of a successful curriculum appear to be well-designed academic programmes, dedicated faculty and strong support services. At the Ira A. Fulton School of Engineering (FSE), we believe that we possess these key components and yet approximately 65 per cent of enrolled 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 attrition-related phenomena, a survey was designed to obtain clear quantitative information about why students leave FSE. During the fall 2005, students, who over several years transferred from engineering to a different school within ASU, were asked to complete an online survey. The hope was that information gained could be a basis for decision making and assessing proposed improvements for increasing retention. The aim of the study was to discover factors with the greatest bearing upon the decision to leave engineering. This research elicited student attitudes concerning educational experiences in their new major contrasted to their engineering experiences. The key questions investigated in this research were: what factors contribute to the decision to leave FSE? How does the student experience in a new major compare to experience in engineering? What factors in our programmes promote loss of student talent?

Making engineering appealing for girls: programmes for grades 6–12 [7]

The Rochester Institute of Technology's Women Engineering programme (WE@RIT) developed a continuous series of outreach programmes to stimulate an interest in engineering as a career for girls in grades 6–12. Events include: Park and Ride, a 6th and 7th grade amusement park design programme; Expanding Your Horizons, an 8–10th grade engineering and science conference; the SWE Overnight and Shadow Programme, an introduction to Engineering at RIT for 11th grade women; Colleges and Careers, a summer recruiting workshop for 12th graders; and WE@RIT Weekend, a three-day experience for young women who have been accepted to RIT, but who have not yet decided whether or not to enroll. In addition, WE@RIT developed and piloted several travelling engineering activity kits (TEAK) to bring engineering experiences to students unable to come to campus for an organized workshop. Although these programmes are still new and limited, long-term survey data have been collected; preliminary results show that the activities do help girls to take a broader view of what engineers do and portray RIT as a friendlier engineering campus.

Using sustainability education to enable the increase of diversity in science, engineering and technology-related disciplines [8]

Science, engineering and technology (SET) are critical to achieving and maintaining a high quality of life, economic growth, global competitiveness, a clean environment and effective governance for the public good and some of the key characteristics of sustainability. A nation's ability to meet these goals significantly depends on the capacity and competency of its workforce to develop innovative products, processes and services that advance prosperity while maintaining and restoring environmental systems. In order to continue towards this paradigm shift, advance sustainability in the long term and supply of a skilled and knowledgeable workforce to both the private and public sectors, educating the next generation in sustainability is critical. Engaging women and underrepresented groups in SET will build additional capacity in these fields that are critical to advancing economic, environmental and societal goals. There is an increasing amount of anecdotal evidence which shows that students are remarkably enthusiastic about education for sustainability and are engaged at many levels both within and outside the classroom. There may be several unique characteristics to the ideas and visions of sustainability that may contribute to making this concept especially attractive to women and underrepresented groups.

Exploiting design to inspire interest in engineering across the K-16 engineering curriculum [9]

One approach to addressing the dilemma of poor mathematics and science performance of US students on standardized tests and lagging enrollment in US engineering colleges is engineering outreach to the K-12 community. Engineering outreach has been a core mission of the Integrated Teaching and Learning (ITL) programme since its inception. Team-based design spans the entire K-16 hands-on learning curriculum, integrating maths and science fundamentals through creative, self-directed learning. Experiencing design provides a context for undergraduates to develop advanced technical skills, and motivates youngsters to pursue an engineering path.

Thinking inside the box: self-efficacy of women in engineering [10]

We describe an initiative to investigate how institutional practices implementing information technology can promote retention of women in engineering through enhancing their self-perceptions and motivations. The initiative uses the self-efficacy theory to implement teaching techniques designed to promote educational attributes: greater motivation, effort and persistence. The particular method we chose was to design and teach a course to educate women in the area of computer problem diagnosis and repair. Continued demonstration and reinforcement of the proficiency attained by the women throughout the course in computer technology distinguished them among colleagues and established an environment conducive to enhancing students' feelings of self-efficacy and associated control beliefs.

Expanding education horizons [11]

The education of engineers is undergoing considerable changes at an increasing rate. The institutions providing that education have a responsibility to respond to needs of their profession and industry. The changes cover the entire spectrum of engineering education and practice. There is a broad range of academic programmes offered by the Faculty of Engineering of the Dublin Institute of Technology. The DIT has implemented formal quality assurance procedures for its courses. These procedures are designed to assist the educators in responding to change whilst maintaining academic excellence. The procedures incorporate input from the professional bodies, academic institutions and industry. The recent development of taught postgraduate programmes that form part of the commitment to lifelong learning includes courses designed to offer engineers the opportunity to maintain or develop new skills within the framework of accredited learning. The faculty views research and development as being an essential component of providing engineering education. The consolidation of the research activity is augmented by a comprehensive staff development policy. All staff members are offered support and encouragement in pursuit of further studies

Status of women in engineering education [12]

The participation of women in engineering education has been a subject of many engineering education studies. The statistical data gathered in the Faculty of Engineering at Monash University over the last 30 years indicate that the rate of participation of females in engineering courses at undergraduate level is still unsatisfactory. More work is needed throughout the entire education system, beginning at the primary and secondary levels, to increase the entrance number of females in engineering at the tertiary level.

Importance of engineering to the US

As the global competition for science and engineering talent increases, our reliance on attracting a significant portion of the technical workforce from other countries may, in retrospect, hinder our ability to compete in the global-market. 'Top-ranked foreign students who once came to the United States to work no longer need to leave home because offshoring is increasing job opportunities in their native countries', says Ben Streetman, Dean, University of Texas College of Engineering [13]. It will be increasingly difficulty to compete for such talented foreign individuals to join our economy as other economies—especially those of their native countries—are able to provide appealing technical opportunities and quality of life. As we realize the effects of such continued reliance on imported talent, the US must focus on strengthening its recruitment and education of domestic engineers.

In profiling the US indicators for innovation in the Global Competitiveness Index, the World Economic Forum ranks the US 12 out of 131 countries for availability of engineers and scientists, although the US does maintain the top overall ranking [14].

Data on minority, women, and persons with disabilities participation in engineering

As we struggle to attract more individuals to the engineering profession, women, minorities and those with disabilities cannot be overlooked as a largely untapped source of potential engineers; they encompass more than two-thirds of our workforce. Unsurprisingly, engineers in the US have always been predominantly white, male and without disabilities [15]. Although there is no inherent difference in the abilities of members of the under-represented groups from the majority, the profession continues mostly to attract members of the distinct, stereotypical group who dominate engineering in industry, academia and government. Women, minorities and those with disabilities who embark on engineering studies or enter the workforce drop out at higher rates than their majority counterparts as they encounter obstacles in their engineering studies and later in careers in academia and industry in which they are overwhelmingly outnumbered.

Women enter engineering programmes with high levels of self-confidence, but this declines during the first year of study. Although their self-confidence increases in later years, it never reaches the same level as when they began the programme. According to the *Final Report of the Women's Experiences in College Engineering (WECE) Project*, women's perceptions of the change in their self-confidence, the environment of their department and the classroom environment were all related to their persistence in the major. More negative perceptions in any of these areas were significantly associated with an increased risk of leaving engineering in every undergraduate year [16].

A common misconception is that women leave engineering because they are unable to grasp the material. Actually, women may be negatively interpreting grades that may be quite good. 'Women compare themselves unfavorably to their male peers and judge themselves more harshly than the men judge themselves' [17]. It is important to note that this self-assessment is not consistent with their actual academic performance as women historically and generally receive better grades than men. The WECE study found that 44.7 per cent of women who had left engineering were earning As and Bs in their engineering classes the year before they left [18]. Among the suggested common reasons for low appeal of, and thus, enrollment of women in engineering include [19]:

- Isolation
- Not seeing the relevance of highly theoretical basic courses, negative experiences in laboratory courses
- Classroom climate
- Lack of female role models.

The feeling of isolation is a normal response for a woman when she is one of a small number of women in her programme. This situation is exacerbated when male peers exclude women from some teams, either deliberately or unintentionally [20].

Gender-role stereotyping impacts the self-concepts of children and adolescents. Girls typically segregate from boys because they play with different toys and at different types of games. From a young age, girls are not as exposed to engineering concepts or competition as boys are. Without this prior exposure, women have difficulty translating engineering textbook concepts into practical applications. Messages from parents persuade girls and women to attribute maths success to hard work and corresponding failures to lack of ability; boys and men are more likely to attribute their successes to natural talent combined with effort [21]. As men bring knowledge acquired through childhood exposures to the lab, they are more prepared for hands-on activities and know more of the 'associated jargon'. Rather than recognizing that different background experiences provided prior knowledge for her male lab partners, it instead reinforces the self-perception that the female's success to date was due to effort rather than talent. She will tend to take a more passive role, deferring leadership positions to others in her group, further distancing her from the very experiences she needs to complete her foundational knowledge.

Role models from under-represented groups help overcome the stereotypes that prevail. However, most schools of engineering have small numbers of faculty members from under-represented groups who can provide inspiration and a motivational support system for aspiring engineers. Improvements need to be made not only to increase the influx of women, minorities and people with disabilities into engineering but also to sustain their interest to pursue graduate studies so they can become role models as faculty and professional engineers.

Although white males were approximately 31 per cent of the college age population in 2005, and earned approximately 31 per cent of the bachelor's degrees awarded in 2005, they earned 57 per cent of the engineering bachelor's degrees. The slow increase in the number of students from ethnic/racial minorities in engineering, coupled with a 31 per cent decrease in the number of white students earning engineering degrees from 1985 to 2005, has contributed to the decrease in the participation rate of white engineers from 79 per cent in 1985 to 64 per cent in 2005. Based upon a 1999 estimate that 34 per cent of the college-aged population is a member of a minority group, it is anticipated that minorities will account for approximately 52 per cent of the college-aged population in 2050 and 45 per cent in 2025. Figure 2 [22] below provides data on the distribution of race in the US, including an anticipated decline in whites as the population of minorities increases. Similarly, Figure 3 [23] below reflects an increase in minority undergraduate engineering students [24]. We, therefore, in the coming decades, will rely heavily on minorities as the driving force behind the growth of our technologies as the demographics of the United States change. To respond to this demographic shift, there are currently more incentives such as scholarships and clubs being offered in engineering education to underrepresented populations to encourage individuals to explore a career in engineering.

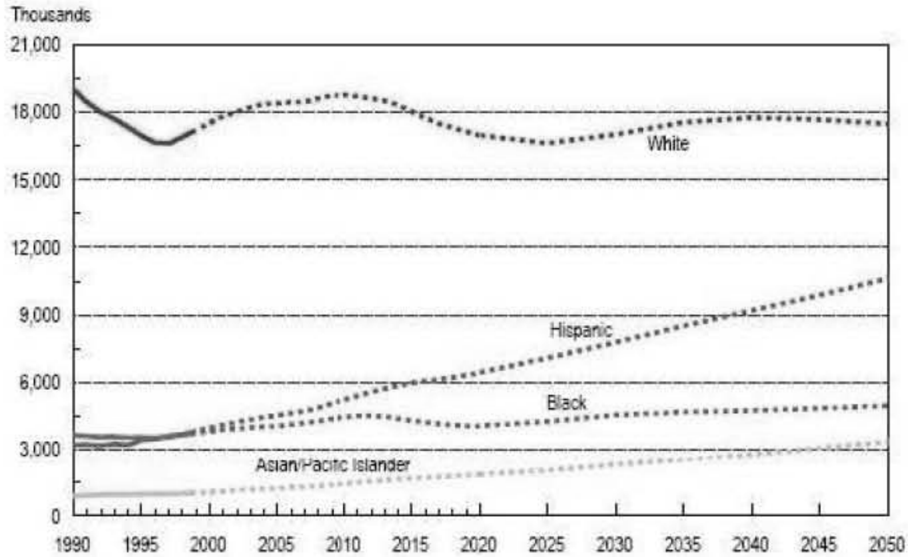

Fig. 2. US Population 18–24 years old, by race/ethnicity: July 1990–1999 and projections to 2050.

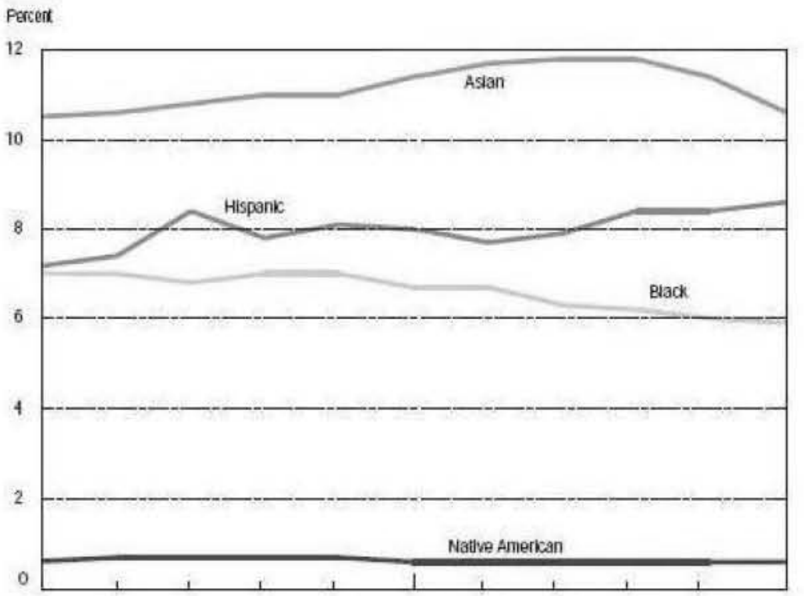

Fig. 3. Minority undergraduate engineering students by race/ethnicity: 1995–2005.

Understanding the low appeal of engineering

Most individuals have devised basic assumptions of engineering often based solely on uninformed premises developed as an adolescent. Surveys show the public has a generally poor understanding of the role engineering plays in improving quality of life and a negative view of engineers' engagement with societal and community concerns, at least in comparison to scientists [25]. Additionally, a majority of people are unaware of the extent to which engineering has contributed to economic growth and the quality of life we enjoy. Even fewer people realize the important leadership role engineers play in industrialized countries. Today, more S&P 500 CEOs have undergraduate degrees in engineering than any other field, which has an unquestionable effect on the everyday lives of individuals in the United States and abroad [26].

Arguably, problems leading to the low appeal of engineering are most likely due to the limited exposure that children receive in their early development and education. As naturally curious beings, children are not provided with the knowledge of engineering that can stimulate thought and discovery. Although some K-12 programmes include engineering and technology classes (with Massachusetts as the only state that includes engineering in the K-12 education standards), most students learn maths and science with minimal opportunity to apply these new concepts. Beyond exposing young people to engineering, practical applications of new maths and science concepts are needed to facilitate a deeper comprehension of the subject matter. As children progressively develop an understanding of engineering, it will be embedded in their minds similar to their knowledge of the medical and legal professions. Most children have less exposure to lawyers than they do to engineers, yet children are more familiar with the career of a lawyer because of the popular media. Perhaps a television show or movie with engineers and engineering accomplishments might bolster the appeal of engineering.

A recently released documentary film, *The Innovators: Designing the Future*, by the Public Broadcast Service [27], is an excellent example of broadening the exposure of engineering. This extraordinary documentary spotlights exciting new breakthroughs in science and technology. The programme, hosted by author and Emmy-winning executive producer Helene Lerner, introduces three visionary engineers tackling the challenges of modern American life—from using robots to study the effects of global warming, to employing nanotechnology in the treatment of cancer, to designing cutting-edge consumer products. The documentary also explores why the United States produces fewer scientists and engineers than other industrialized nations, and profiles an innovative engineering and high school outreach programme at the University of the Pacific, School of Engineering and Computer Science.

Engineering is a rigorous field of study with an extensive regimen that discourages many students from entering the field altogether. Some students are intimidated by the mathematics and science requirements that engineering studies require. The engineering profession and popular perceptions increase this intimidation by focusing messages on the difficulty of engineering studies rather than the tangible and intangible rewards of an engineering career. What needs to be emphasized is that with enough discipline and studying, engineering can be grasped by almost anyone. Nonetheless, there will always be some students that have to dedicate more time to studying than others. The pool of individuals capable of pursuing an engineering degree is only limited by the allotment of a sufficient amount of time for their studies. Thoughts of an inability to complete such a rigorous regimen should not be a student's primary deterrent from engineering.

Some students find other majors appealing because they see their social and ethical relevance. Students are familiar with the impacts of particular majors related to medicine, physical science, psychology, justice and our environment. The impacts of engineering on our well-being are not apparently obvious to most individuals. Our sources of entertainment and technology such as computers, television, cell phones and the Internet are products created by engineers. The structures that provide shelter, the roads we drive and the water we drink would be nonexistent if not for engineers. We all utilize the very resources that engineers have introduced to us, yet they are not as acknowledged for their efforts as other professionals.

Additionally, engineering is a broad subject that encompasses many facets with fundamental applications which most Americans do not even understand. A recent study by the National Academy of Engineering and the National Research Council has concluded that most Americans are not technologically literate. Technological literacy is defined as: 'one's ability to use, manage, assess, and understand technology' [28]. With the ability to make technology user-friendly, we are finding technology is becoming inevitably 'invisible'. Americans are using 'technology with a minimal comprehension of how or why it works or the implications of its use or even where it comes from' [29]. As Americans, we are accustomed to the availability of technology and we rarely see an individual to credit for these everyday pleasures and the critical task of such developments. From the 'starchitects' of grand architecture, to high profile attorneys, to fictional medical heroes on television, most professions have a human face. In contrast, the appeal of engineering is not as strong as other professions due to a lack of popular media coverage.

The appeal of engineering for most engineers is 'the wonderful intellectual challenge of research and discovery; the life of the mind in which fundamental puzzles of nature and the cosmos can be addressed; (and) the potential to develop exciting and useful new technologies' [30]. This infectious appeal of engineering amongst engineers is truly difficult for other individuals to fully grasp for it can only be fully comprehended through rigorous academic training, research, and professional practice. For these reasons, it is important to transfer this appreciation to young individuals so they consider entering such a fulfilling field of study because the payoffs are lifelong, exciting and socially relevant.

A survey was conducted to provide a baseline for why people select any profession. Based upon the information received from 27 key respondents in the engineering profession (engineering school deans), the items identified to be crucial while making this decision and their relative importance are provided in Tables 1 and 2 for the majority and underrepresented (minority) population.

Similarly, a survey was conducted to focus on factors contributing to the low appeal of engineering. Results of survey analysis are presented below.

The various factors that contribute to the low appeal of engineering are made even more complicated by the views that stem from the majority group and the minority groups, as seen in Tables 3 and 4. (Average Score is represented based on a 1–10 scale with 1 being least important and 10 being most important.) The obvious conclusion is that university engineering school deans feel that majority and minority students have differing viewpoints regarding what deters them from a future in engineering. Particularly notable is that a lack of role models is a major factor for minorities. Also notable is that the minority population finds the high cost of education a larger deterrent than the majority. An additional conclusion is that the effectiveness of teaching—how engineering courses are taught—has a major impact on those considering the pursuit of an engineering education. An introspective look at this, though not easily embraced by many of us who teach and have taught, would be salutary.

Table 1. Factors impacting an individual's selection of a profession—engineering deans' perspective

	Majority Population	**Average Score***
1	Career Advancement Opportunities	7.67
2	Economics: Compensation, Jobs, Cost of Education	7.26
3	Image of Profession	7.15
4	Informal Advising—Parents and Teachers	7.07
5	Knowledge About the Profession	7.04
6	Academic Advising—High School and Grade School	6.78
7	Social Relevance	6.26
8	Work Conditions	6.23

* Ranked on a scale of 1-10; 10 being most important

Table 2. Under-represented (minority) population

	Minority Population	**Average Score**
1	Economics: Compensation, Jobs, Cost of Education	8.07
2	Image of Profession	7.63
3	Social Relevance	7.30
4	Career Advancement Opportunities	7.11
5	Academic Advising—High School and Grade School	7.07
6	Informal Advising—Parents and Teachers	7.04
7	Difficulty Transition from High School to College	7.00
8	Knowledge About the Profession	6.26

Student retention

It is difficult to keep students in engineering programmes because it is easy to become discouraged with the demanding curriculum. The estimates of undergraduate students who begin studies in engineering and either change majors or drop out range from 40–70 per cent, depending on the institution and beginning student considerations [31]. Since it is difficult to get students initially interested in engineering, it is critical to address the factors that impact on their persistence in engineering schools. Therefore, in order to retain students, it is important for faculty to address issues related to teaching style and motivating and inspiring the students about the profession.

An attempt was made to contact some key engineering educators (engineering school deans) to see what would be the most crucial factors contributing to high attrition rate among the engineering students. Findings from this study, and the key factors thus identified, are described and discussed below.

Institutions are allocating a considerable amount of effort and resources to their retention rate as it has become one of the principle measures of an institution's reputation and effectiveness.

Table 3. Factors contributing to low appeal of engineering—engineering deans' perspective

	Majority Population	**Average Score**
1	Requires High Aptitude in Math and Science	7.70
2	Effectiveness of Teaching for Students	7.70
3	Poor Academic Advising—High School and Grade School	7.26
4	Economics: Compensation Not Worth the Effort	6.15
5	Poor Image of the Profession	6.15

Table 4. Under-represented (minority) population

	Minority Population	**Average Score**
1	Requires High Aptitude in Math and Science	8.59
2	Effectiveness of Teaching for Students	8.33
3	Lack of Role Models	8.22
4	Poor Academic Advising—High School and Grade School	8.04
5	High Cost of Education	7.41

Student attrition raises questions about the institutional priorities and programmes, particularly those of teaching and student mentoring. In the last 20 years, there have been of the order of 3,000 studies conducted relating to retention [32]. Findings have initiated advancements and have focused attention on many institutional approaches to this issue.

Main reasons behind attrition

Some students enter engineering because they are particularly good in maths and science or are attracted by the high salaries that engineers earn. While these may be reasons to enter a profession, they are not always sufficient to maintain student interest in the field. As with any major, there will invariably be students that will find engineering does not suit their career ambitions. Nonetheless, students are dropping out of engineering at an alarming rate of, on average, roughly one half. In a survey of seniors in science and engineering programmes, 26.1 per cent said that they were dissatisfied with their educational experience [33]. Institutions must evaluate the reasons behind the high attrition rate.

A recent survey of university engineering school deans discovered some very interesting and challenging issues as summarized in Tables 5 and 6 for majority and underrrepresented (minority) populations respectively.

While the most significant reason for the high attrition is the ineffectiveness of teaching, it is noteworthy that the majority and minority populations differ; minorities seem to face challenges differently from the majority. A loss of interest is a much lower attrition factor for minorities and a lack of academic support seems to be a much higher factor.

Table 5. Factors contributing to attrition—engineering deans perspective

Majority Population	**Average Score***
1 Effectiveness of Teaching for Students	7.26
2 Required High Aptitude in Math and Sciences	7.22
3 Curriculum Overload	7.07
4 Academic Advising	6.96
5 Loss of Interest	6.56
6 Other Majors More Appealing	6.52
7 Step-Up from High School to College Programs in Engineering too High	6.44
8 Reward Not Worth the Effort	6.27

Table 6. Under-represented (minority) population

Minority Population	**Average Score**
1 Effectiveness of Teaching for Students	8.04
2 Curriculum Overload	7.96
3 Required High Aptitude in Math and Sciences	7.89
4 Academic Advising	7.81
5 Step-Up from High School to College Programs in Engineering too High	7.81
6 Lack of Academic Support	7.30
7 Loss of Interest	6.85
8 Other Majors More Appealing	6.85

As mentioned earlier, institutions are allocating a considerable amount of resources and effort to their retention rate as it has become one of the principle measures of an institution's reputation and effectiveness.

Generalized preference index model

After reviewing various elements contributing to choices individuals make in selecting any profession (Tables 1 and 2), factors contributing to low appeal of engineering (Tables 3 and 4), and factors contributing to attrition (Tables 5 and 6), it is clear that we have a large number of elements or indices to deal with. Most of these elements are qualitative, and some even if quantifiable, are not in common units.

Each school of engineering has a different set of challenges in the broader institutional context it operates and the quality of students it attracts. There is also considerable uncertainty about the decisions to be taken and the resulting effects and utility functions.

A model derived from the work of Keeney and Raifa [34], which takes into account preference indices and value tradeoffs, is suggested in selecting elements that can address the problem. The decision maker can assign utility values to consequences associated with each path instead of using explicit quantifications. The payoffs, or resulting benefits, are captured conceptually by associating to each decision a consequence that completely describes its implications. This can be described mathematically [35] as follows:

$$a' \text{ is preferred to } a'' \Leftrightarrow \sum_{i=1} P'_i U'_j > \sum_{j=1} P''_j U''_j$$

where a' and a'' represent choices, P probabilities, and U utilities; the symbol $\Leftrightarrow$ reads 'such that'.

Utility numbers are assigned to consequences, even though some aspects of a choice are not in common units or are subjective in nature. This, then, becomes a multiattribute value problem. It can be solved informally or explicitly by mathematically formalizing the preference structure [36]:

$$y\,(x_1, x_2, \ldots\ldots, x_n) \geq y\,(x'_1, x'_2 \ldots\ldots, x'_n)$$
$$\Leftrightarrow (x_1, x_2, \ldots\ldots, x_n) > \sim (x'_1, x'_2, \ldots\ldots, x'_n)$$

where y is the value function that may be the objective of the decision-maker, x_i is a point in the consequence space, and the symbol $> \sim$ reads 'preferred to' or 'indifferent to'.

After the decision-maker structures the problem and assigns probabilities and utilities (as appropriate), an optimal strategy that maximizes expected utility or outcomes can be determined. When a comparison involves unquantifiable elements, or elements in different units, a value tradeoff approach can be used either informally, that is, based on the decision-maker's judgment, or explicitly, using mathematical formulation.

After the decision-maker has completed the individual analysis and has ranked various policy alternatives or projects, then a group analysis can further prioritize the policy alternatives or specific actions. A modified Delphi technique is suggested as an approach for accomplishing this [37].

Discussion of selected preference indices

Various elements and indices described in Tables 1–6 can be grouped into a smaller number based upon the characteristics, experience and history of the engineering programme and the institution. As an example, these indices were grouped into the following:

- x_1 Career advancement opportunities and economics
- x_2 Social relevance and image
- x_3 Pre-college education and bridge programs
- x_4 Effectiveness of teaching and required high aptitude in math and science
- x_5 A nurturing environment
- x_6 Curriculum overload and step-up from high school to college
- x_7 Role models
- x_8 Internships

All of which means:

x_1: Career advancement opportunities and economics

Career advancement and opportunities for engineering graduates need to be properly documented and explained. Some examples are:

- Now more S&P 500 CEOs have undergraduate degrees in engineering than any other field [38]. This clearly demonstrates excellent career opportunities for engineering graduates and their unquestionable effect on society.
- Median salaries of engineers are higher than any other graduate of a four- or five-year degree program.
- An undergraduate degree in engineering provides excellent opportunities for graduate studies beyond engineering including: law, business, and medicine.
- The job market for engineers, during times of prosperity and austerity, historically has remained strong.

x_2: Social relevance and image

Though not always understood, the work engineers are involved in is quite exciting and relevant in addressing societal needs. Some examples that can be cited are:

- Engineers generate new knowledge, working as scientists in research in universities and industry; they work as educators and practice engineering to plan, design and build technology-based projects. Their public image in all of these areas is one of the highest among all the professions.
- Science and technology embedded in engineering is the core component responsible for much of the economic growth in the US and the quality of life we enjoy.
- National Academies of Science and Engineering have identified the following twenty impressive engineering advancements that have unquestionably transformed our economy and contributed to the quality of life we enjoy [39]:
  a) Electrification
  b) Automobile
  c) Airplane
  d) Water supply and distribution
  e) Electronics
  f) Radio and television
  g) Agricultural mechanization
  h) Computers
  i) Telephony
  j) Air conditioning and refrigeration
  k) Highways
  l) Spacecraft
  m) Internet
  n) Imaging
  o) Household appliances
  p) Health technologies
  q) Petroleum and petrochemical technologies
  r) Lasers and fibre optics
  s) Nuclear technologies
  t) High performance materials
- These achievements also clearly demonstrate social relevance of the role the profession has played in serving societal needs. That role is even more important in the 21st century. The National Academy of Engineering has identified the top challenges of this century to be addressed by engineering identify what needs to be done to help people and the planet thrive [40]:
  a) Make solar energy affordable
  b) Provide energy from fusion
  c) Develop carbon sequestration methods
  d) Manage the nitrogen cycle
  e) Provide access to clean water
  f) Restore and improve urban infrastructure
  g) Advance health informatics
  h) Engineer better medicines
  i) Reverse-engineer the brain
  j) Prevent nuclear terror
  k) Secure cyberspace
  l) Enhance virtual reality
  m) Advance personalized learning
  n) Engineer the tools for scientific discovery

x_3: Pre-college education and bridge programmes

Some of the factors contributing to attrition begin at pre-college level and must be addressed there. Particularly, the issues of maths and science education must be addressed before students enter universities. Remedial classes can be beneficial and highly educational but they cannot be used as a means to prepare an entire incoming class, because students cannot complete their education in a timely manner if they are taking remedial or 'catch-up' classes.

Engineering majors require a high degree of capability in mathematics and sciences. It is to the students' advantage to have an extensive background in these areas before entering an engineering programme. Students fall behind when they enter engineering without sufficient knowledge from high school in these fundamental areas. Students are not always at fault for the shortcomings in their prior academic knowledge, as some high schools do not have access to teachers with certifications or majors within the areas they teach, nor the expenditures needed for additional maths and science learning tools in the classroom. Currently, fewer than one third of American 4th and 8th graders are performing at a mathematical level that is considered 'proficient' [41]. As struggling students enter college, remedial classes can help them to catch up to their academic counterparts but that does not serve as a long-term or a cost-effective solution. When mathematically struggling students enter engineering programmes, they may feel they are far behind in their courses, diminishing their motivation to continue with such a demanding curriculum. Thoughtful bridge programmes should be designed and implemented to assist struggling students and complement efforts at the pre-college level.

x_4: Effectiveness of teaching and required high aptitude in math and science

Some lower-level courses such as physics, calculus and chemistry are highly theoretical and are typically taught by science and maths departments with no attention to the application of the concepts. Their relevance is not readily apparent to students with engineering career goals. Students' own hard work and discipline, coupled with effective teaching, can help them to acquire maths and science proficiency.

Bloom's *Taxonomy of Learning* demonstrates the important three overlapping domains: cognitive, affective and psychomotor [42]. Cognitive domain, relevant to this discussion, refers to educational objectives which deal with recall or recognition of knowledge and development of related skills and intellectual abilities. Bloom identified a series of hierarchical skills involving the acquisition and use of knowledge that ranged from knowledge (simple recall) to application and evaluation; these skills are [43]:

- Knowledge
- Comprehension
- Application
- Analysis
- Synthesis
- Evaluation

Engineering faculty are the foremost and essential influence on students' education; students are hindered academically when professors are ineffective teachers. One issue that has surfaced in the profession deals with faculty members for whom English is a second language, which can often be laborious for students to understand. 'While the teacher might be brilliant, oftentimes, the students have a difficult time understanding the brogue or dialect' [44]. When this is a problem, schools of engineering should provide support to assist the faculty member to overcome this difficulty; most faculty members would welcome such support. Some specific suggestions to address academic issues are:

- Analyze courses where students are receiving unsatisfactory grades (C- or lower). Depending on the institution and quality of incoming class, it should be a concern if a class has more than 15–25 per cent of students with unsatisfactory grades.
- For maths and science courses, consider reforms that include team teaching or joint curriculum development that involve faculty members from maths, science, and engineering. Also, looking at Bloom's *Taxonomy of Learning*, teaching in these courses should go beyond knowledge to application, synthesis and evaluation. A similar approach should be used for other engineering courses as well.
- Try to reduce course load during students' earlier semesters.
- Provide supplementary instructors, tutorials and student study work areas and study teams. Designing an introduction to engineering course that serves to inform, motivate and inspire first-year engineering students can also be of enormous benefit. Discussions with deans of engineering indicate that such a course, if structured properly, can make a difference.
- Assist gifted faculty members for whom English is a second language with appropriate training.

x_5: Nurturing environment

Most institutions are traditionally accustomed to promoting a highly competitive environment amongst engineering students in which 'weeding out' classes are utilized, competition in the classroom is encouraged and high academic achievement is promoted [45]. An overemphasis on creating a learning environment seen as hostile by many students has resulted in low student retention while the demand for such professionals is vastly increasing.

Young engineers are motivated by the influence of engineering professionals whom they admire and respect. A majority of the most successful engineers have role models who have had some influence during the course of their career. It is becoming increasingly important for engineering professionals to reach out to future engineers as they have the potential to offer them guidance and suggestions to overcome difficulties in completing their engineering education. Each institution could develop programmes to specifically focus on this issue. Some suggestions are:

- Develop a nurturing environment for engineering students while maintaining academic excellence. Bridge programmes and tutoring can be helpful; this should not be a problem for those institutions that claim to be student-centered.

- Provide access to practicing engineers who can serve as role models or mentors.
- Assist students in defining acceptable levels of performance for success in the programme to prevent over-critical self-assessments encouraging talented students to withdraw from engineering. Remind students that average students, when they complete their education, can pursue rewarding careers. Studies show that many academically average students end up holding important leadership positions in the profession.

x_6: Curriculum overload and step-up from high school to college

The first two years of an engineer's education are crucial to academic success, encompassing a curriculum of key fundamental courses such as: calculus, physics, differential equations, chemistry, statics and dynamics. These core courses should be structured to supply students with the necessary knowledge to prepare them for intense upper-level engineering and design courses. A poor understanding and grasp of fundamental engineering concepts will affect a student's ease of learning throughout an academic career. Reducing course load for the first two years can be helpful for some students who need this extra support.

Moving from high school to college-level is academically and socially a major step. A challenging step for any student is made even more difficult by the rigorous nature of the programme. As a result, there is much early attrition among students studying engineering while they are still focused on foundational classes.

Some students find it difficult to approach professors with questions during class or even afterwards. Their reluctance, typically, stems from not wanting to reveal to a professor how much of the information presented to the class they were unable to understand or retain; this is particularly true of women and minority students for a number of reasons. Student mentors and tutors can provide reliable and useful educational support. This can help overcome some of the curriculum overload and the transition from high school to college challenges; some suggestions are:

- Keep the number of courses in the early semesters of the programme at a level that a student can handle successfully.
- Provide supplemental instructors and create other bridge programmes to assist students in overcoming the transition from high school to college.
- Provide tutors and mentors, especially during the first two years of college.
- Since tutors and mentors are often college students themselves, struggling students are less likely to feel intimidated and more likely to identify with them. Creating such programmes can assist students in being successful and thus reduce attrition considerably.

x_7: Role models

The lack of role models has been identified as an important issue for many students, but especially for women and minority students. To address this issue, activities that could be offered are:

- Provide financial and other academic support for student organizations such as Society of Women Engineers (SWE) and other multi-cultural student organizations, projects, and activities. Legitimize organizations that support students from under-represented demographics through visible and sustained support, such as personally attending major events for these students.
- Recruit faculty members who are a part of under-represented groups or faculty members who are willing to mentor and offer support for these groups.

x_8: Internships

As described earlier in Bloom's *Taxonomy of Learning*, the most profound learning takes place beyond knowledge; this is particularly true about engineering. Here, application of the concepts learned in classes, and synthesis and evaluation of these concepts to address societal needs, can make an engineering education more relevant, exciting and connected. Internships, especially on-going paid internships (commonly referred to as cooperative education programmes), implemented as an integral part of the engineering educational process, can be very effective in attracting and retaining students. Cooperative education (co-op) programmes, integrated with the educational curriculum, have proved to be very effective in encouraging student interest in engineering while bringing a real world, practical application of engineering concepts. At the University of the Pacific School of Engineering and Computer Science, our analysis of data from 2001–2006 indicates that over 95 per cent of students who completed a co-op programme graduated with a degree in engineering. Creating such programmes for engineering students can thus assist considerably in reducing attrition.

Use of selected indices: an example

Mathematical formulations, at times, can appear to be confusing and unclear; on the other hand, such a formulation can provide comprehensiveness and interconnectivity of complex elements not possible by merely providing a description of the concept. Thus, after reviewing the model, we could explicitly select those indices or their subsets most relevant for a given school of engineering that might provide the optimum value function, . As an example, we could select x' (economics), x'_3 (bridge programmes), x'_4 (teaching effectiveness), x'_6 (curriculum overload), x'_8 (internships), as indices and study results over time. This way, we can make these choices now, defer other choices and modify the preference indices as results become available. We can also assign probabilities and utilities to each index for a longitudinal study. Using items listed above, we could readily develop a specific example case relevant to the unit involved.

CONCLUSION

Expanding participation in science, engineering and technology is critical for the technological innovations that drive economic growth and enhance quality of life. Increasing technical workforce capacity in many countries, and obstacles to the recruitment and retention of young people into science and engineering careers in the US, threatens US global competitiveness.

To improve participation, this paper discusses major factors contributing to the low appeal of engineering and contributing to high attrition among students. Analysis of input from key engineering educators identifies the factors and distinguishes those that specifically impact on students under-represented in science, engineering and technology.

Contributing to the low appeal of engineering is the perceived high aptitude in math and science, the effectiveness of teaching and poor academic advice in grade school and high school. Although these are key factors for all students, the impact is greater for under-represented students. These students are also impacted by a lack of role models ('people who look like me') in the profession and the high cost of education.

With estimates of attrition rates of undergraduate engineering students varying from 40–70 per cent, the factors that impact on students' persistence in engineering schools have been discussed above. Factors for all students include the effectiveness of teaching and advising, curriculum overload and the required aptitude in maths and sciences, although again shared factors impact on minorities with greater intensity. A unique factor for under-represented populations is the lack of academic support.

Although recommendations are presented, because interrelated factors are significant and pervasive, quick fixes and singular approaches are not practical. Each school of engineering has its own characteristics, history and broad institutional contexts, so no given set of elements or indices would apply to each school. Consequently, a generalized preference index model has been developed. Selected preference indices are discussed and an example of selected indices as a model is presented for faculty to address these crucial issues in a context that is appropriate for their institution.

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