Retention and Success of Engineering Undergraduates: A Discussion of Retention-related Initiatives at the University at Buffalo

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Abstract

The retention and success of undergraduate engineering students has received somewhat greater attention in recent years owing to declining enrollments during the 1990s as a result of a decreasing number of college-bound high school graduates. Engineering programs have been affected by these enrollment trends and have become sensitized to the issue of retention.

Two of the major potential reasons for freshmen encountering academic difficulty or leaving engineering stem from insufficient academic preparation for the curriculum or unrealistic expectations. Conventional university admissions criteria, such as high school average and SAT score, correlate with academic success only in a broad sense. These metrics are unreliable in identifying individual at-risk students. An accurate method for predicting academic success of an individual student has recently been developed based upon a detailed analysis of the student's high school performance in mathematics and science. This insight provides a means of directing students to appropriate-level courses and special programs and establishes realistic goals to be achieved in order for the student to succeed in the program.

Other important retention-related student needs include providing students with a realistic vision of the engineering profession, a sense of belonging to the program, imparting self-management skills for academic success, providing opportunity for peer interaction, and providing a framework for the processing of the transition experience from high school to college.

A student success (retention) program has been recently instituted by the School of Engineering and Applied Sciences at the University at Buffalo. Components of the program include a new model for admission decisions, faculty mentoring for engineering freshmen, academic small group sessions in support of first-year technical courses, a case-studies course for entering freshmen, and the establishment of learning outcomes between engineering and the service departments in other academic units. The results of this program, along with some of the formidable obstacles affecting engineering retention, are presented.

Introduction and Background

High attrition rates in engineering programs have been long standing. It has been generally felt that high attrition is to be expected in engineering as a consequence of the intellectual rigor and time demands of the engineering program. It is often further assumed that, in the United States, the early academic preparation at the elementary and high school levels has been in decline and has not always been of a sufficiently high standard for students entering a technical program such as engineering.

During the 1990s many regions of the country experienced a decrease in the number of college-bound high school graduates. Consequently, most colleges and universities witnessed declining enrollments in their traditional engineering degree programs. This prompted many institutions to place a higher priority on recruiting and retention. Despite substantial research and the implementation of numerous initiatives, high attrition rates continue to pose an extremely vexing challenge.

Engineering student attrition at most schools generally occurs in the first two years. Once a student reaches the junior year they have generally acquired a level of maturity, academic preparation, study skills (level of college thinking, problem solving ability, time management practices, etc.), and motivation that enables the remainder of the program to be completed with a high degree of success. The dilemma for most engineering schools is related to the fact that the curriculum in the freshman and sophomore years involves very little direct contact between the engineering student and the school. The curriculum in the lower division is primarily comprised of mathematics, physical science, and general education courses taught by faculty from several departments outside of engineering. In moderate- to large-size schools, such as the University at Buffalo, the few engineering courses that are encountered at the freshman and sophomore level often tend to be large and potentially impersonal since the content is typically general and not discipline-specific (e.g. mechanics, thermodynamics, etc.). As a consequence, the educational experience and needs of the lower division engineering student have tended to fall outside of the purview and attention of the school. The high attrition observed in this population has frequently given rise to questionable assumptions or conclusions, such as those stated in the first paragraph.

It is our contention that the lower division presents an excellent opportunity for impacting the quality of the educational experience and preparation of the student for academic success within engineering or elsewhere. A system that is thoughtfully oriented towards the welfare of each student has the potential for yielding substantial benefits in the form of improved student and alumni satisfaction, enhanced program quality, and higher student retention.

STRUCTURING THE PROBLEM

Student Needs

Our view is that students are not typically *driven away* from a program or institution due to strong *dissatisfactions* (although many students will articulate dissatisfactions if asked), but rather they often tend to *fall or drift away* because important needs have not been met. They therefore leave because they are *unsatisfied* and *lack reasons to persist.* Although based directly on our own empirical experience, this view is not inconsistent with currently influential retention models[1].

Although a long list of needs can be readily developed, our prioritized list given below is based upon our experience with students and tracking their outcomes over time, the published retention literature, and practical constraints on time and resources which limit our focus to needs that could have a significant impact on student outcomes. The target list of needs for our student population is:

- Processing of academic experience
- Development of college-level thinking skills
- Connection with a peer group
- Developmentally-keyed pedagogy
- Informed vision of engineering
- Sense of belonging to the School of Engineering and Applied Sciences

Although these needs are shared by many college students, we find that engineering majors experience them in a most pronounced fashion – similar in degree to student populations that are designated "*at-risk*" in less technical majors. We have elaborated in some detail on each of these needs elsewhere[2] and therefore only a brief discussion will be provided here.

The processing of academic experience refers to the manner in which students interpret their situation when they experience academic difficulty. In general, students find themselves in academic difficulty either because their academic skills (academic preparation and/or college-level thinking skills) are not sufficiently developed or they do not possess the minimal academic behaviors (study skills, time management, use of resources, etc.) that are requisite for success. Most engineering majors have been accustomed to doing well in courses with relatively little hardship or effort throughout their high school program. Inability to complete homework assignments, poor grades on tests or exams, and the volume of work required, are new and typically puzzling experiences. The first encounter with academic difficulty draws a number of responses: some students ignore it and hope it won't recur, some become discouraged and gradually disconnect from the program, some resolve to study harder but have no idea of how to study differently, and some will decide that engineering is not for them (despite the fact that they have had virtually no exposure to actual engineering courses). In all cases, a seasoned professional can be pivotal in helping a student draw accurate lessons from the experience and make meaningful adjustments.

The need for matured thinking and higher-level problem solving skills is particularly acute for engineering majors. Students experience a rapid transition from simple scripted problems towards less well-defined problems involving combinations of novel concepts and approaches, multiple-step procedures, and intuitive insights. Courses tend to be fastpaced and offer little opportunity for recovery due to the building-block structure of mathematics, science, and engineering courses. Students may experience instructors teaching "over their heads" or at "too fast a pace" whereas instructors will view students as being under-prepared or lacking the appropriate prerequisite knowledge. Yet, with some adjustments in pedagogy, many students experiencing difficulty can learn to grasp the course material without any compromise to the level of rigor of the course.

Connecting with a peer group is especially important for engineers. It is important for students to realize that the academic difficulty, workload, and effort required is not unique to them, but is common among their engineering peers. They will be better able to realistically assess the transition they are experiencing and will not fall prey to a social isolation that could magnify their stress, disorientation, and lack of confidence. An informed vision of engineering can provide meaning to the necessary academic struggle as well as provide guidance to students in discerning their academic path.

It is our view that instilling a sense of belonging should be a high priority for an engineering program. Except at small institutions, most lower division classes (calculus, chemistry, physics, etc.) tend to be large and impersonal. These required courses are also typically outside of the engineering school. Consequently, students feel little sense of community and shared experiences. In addition, the perception among many students (and others) is that these courses are designed to "weed out" intended engineering majors.

Obstacles and Challenges

The needs described above have been widely recognized. Some of the factors that make these issues particularly resistant to change include the following:

- Specialized nature and high level of rigor of engineering programs
- Students most in need of support are least likely to engage in it
- Success skills are not easily acquired by those who need them most
- Lower division student experience falls largely outside of engineering
- Needs far exceed available resources

Except at the most highly selective institutions, the specialized nature, high level of rigor, and rapid pace of engineering programs, from their outset, may prove beyond the capabilities of some students. Approximately 80% of the students that leave engineering at our institution have a poor academic record in the core engineering courses. This is partly an issue of student ability, but also commitment: some students are unwilling to commit the time, effort, and level of frustration that might be necessary to succeed in engineering.

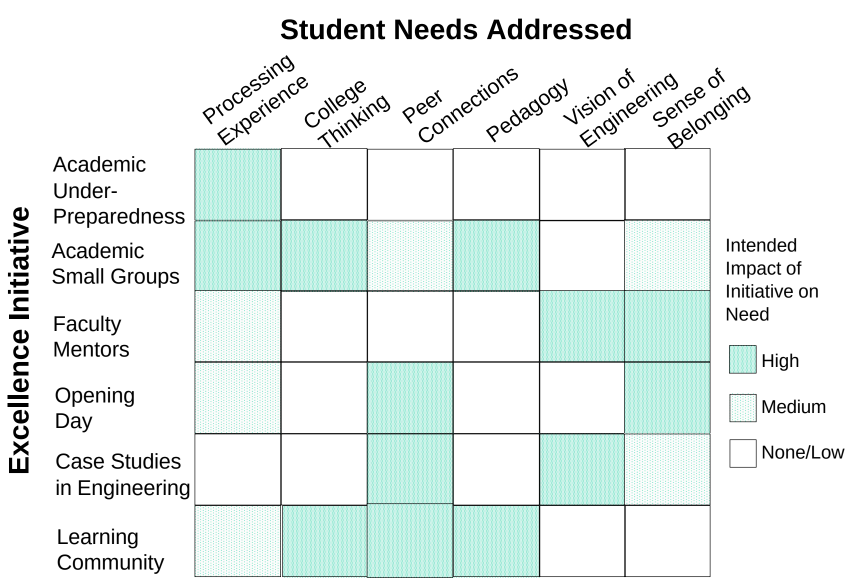
It is common knowledge that tutoring, recitations, review sessions, workshops, etc. are typically utilized by motivated students that are already "on the ball" and looking to improve themselves further. Students in greatest need are least likely to avail themselves of these resources. Even if such students are compelled to attend, they are least likely to seriously engage in the effort and benefit from the experience. These underlying characteristics are often the reason why such students find themselves in academic difficulty in the first place. Motivated, self-directed students readily integrate available tools and resources in order to successfully navigate the curricular challenges. Unstructured, perhaps under-prepared, students have great difficulty with this process since it entails major behavioral change on their part, and self-esteem issues are more frequently in play.

The question becomes how can an engineering school address these obstacles given the limited range of influence and resources available. Priority must be given to the deployment of resources and actions that can have the greatest impact. Our experience indicates that retaining all students is unrealistic. Students will choose to leave engineering for reasons that are right for them, be it interest in another field of study, lack of aptitude for the program, personal life demands, etc. The aim of our initiatives, to be described below, embodies the philosophy to be welcoming to all entering students, to provide the support and encouragement to engage *hesitant* students, and to permit actively *resistant* students to pursue their own inclinations.

THE EXCELLENCE INITIATIVES

The Excellence Initiatives are aimed at the *Student Needs* and are structured to overcome the *Obstacles and Challenges* described above. Figure 1 highlights how the *Initiatives* to be presented below span the range of targeted needs, and do so with significant redundancy. This redundancy creates a broad and layered support net, with the result that a student's full set of needs is more likely to be addressed, and addressed in significant depth. This is important because leaving students are often influenced by a constellation of factors. To change the outcome for an individual implies meeting the set of needs with which he or she is struggling.

Figure 1:
Each Targeted Student Need is Addressed by Multiple Initiatives



Academic Under-preparation, Admission to Engineering, and Follow-on Support

A detailed analysis of the historical data on the academic performance of engineering students at our institution had led us to conclude that the conventional university admissions criteria (high school average and SAT scores) were unreliable in being able to identify individual at-risk students. Instead, we have found that a model based on the detailed academic record, particularly in technical subjects, has a very high degree of reliability in being able to identify students that will be in serious academic difficulty right from the outset. The model incorporates high school average, SAT scores, and New York State Regents Exam scores in Math I, Math II, Math III, Chemistry, and Physics. The model measures student risk using a threshold procedure based on the above data and is described in more detail elsewhere[2]. The standardized nature of the New York State Regents exams is helpful in filtering the variability in grades across high schools. We have employed this model for admission decisions to engineering since Fall 2000. The result is that approximately 8% of freshmen applicants were declined admission to engineering that would otherwise have been accepted under the traditional criteria. It is our sense, based on the analysis of the historical data, that virtually all of these students would have ended up leaving engineering in serious academic difficulty.

This does not imply that no high-risk students were admitted. Some high-risk students do prove able to succeed but they are admitted with conditions that are designed to safeguard their academic welfare. The goal is to enable such students to either succeed in engineering or find a home elsewhere by the end of the first year – before their academic record and confidence have been seriously damaged. The first set of conditions is strictly academic: students are required to take appropriate remedial courses and to achieve at a particular level in these courses. They are also required to use selected support resources. Even so, a high attrition rate is expected among this group, and so a second set of conditions constitutes a "safe-exit" process. Participation is required in:

- A two phase career planning activity developed specifically for this group. Students first meet in small groups with university career planning and advisement professionals to explore their own personal motivational connection to engineering. In accord with the needs assessment of these sessions, individuals are then routed to follow-on services/programs that address those needs.

- Individual *Diagnosis and Strategy* meetings with Engineering Student Services Office. At the end of the Fall semester, progress is reviewed, issues identified, and new strategies and adjustments for the Spring semester are explored. At the end of the Spring, the year's experience is brought to closure and the student's continuance in engineering is discussed.

This process aims to help students reach similar conclusions as SEAS regarding their continuance, so that those who need to be "counseled out" have come to terms with their situation, and personal contacts have already been established with other University professionals who can help them explore new directions.

Block Scheduling

The importance of connecting with a peer group is a strong theme in the higher education literature (e.g. peer groups[3], social integration[1], learning communities[4]) and is especially important for engineering students as mentioned earlier. Freshman engineering students are co-registered into a "block" of classes so that individuals travel with much of the same group through many of their courses. This also permits us to work directly with the instructors in "engineering-only" sections of math, chemistry, etc.

Opening Day

"Opening Day" is used primarily to initiate relationships of freshmen to each other, to upperclassmen, and to engineering faculty – relationships that will continue. Students progress through the day in blocks (as described above) of approximately 28 students. The people they meet are the same people they will continue to see in lab and in their other courses on a weekly basis. Each group is led by a pair of volunteer Student Leaders who serve not only as guides for the day's activities but sources of advice and guidance. Students also meet for the first time with their faculty mentor (described in more detail below). They also meet with officers and members of the many engineering student organizations and have the opportunity to become involved with these student clubs from the outset. The message of Opening Day is that, despite the size of the University, no one need make the engineering climb alone. The main components of the program include:

- An explanation of the purpose and mission of the School of Engineering and Applied Sciences.
- Interactive Ice-breakers. One a fun-oriented cooperative group task, with prizes awarded, in order to set the atmosphere. A second focused on personal sharing, first between pairs of students, then with their groups, to help students realize their common interests, concerns, and vulnerabilities. (Many students feel awkward about this exercise at first but this exercise begins to establish a sense of group identity and membership).
- Small group meeting with a faculty mentor.
- Indoor-kite building competition. As pizza is served by engineering student organization members, freshmen observe a kite flying demonstration given by a nationally renowned indoor kiting champion. Each group is then provided with a kit of basic materials (tape, scissors, plastic film, etc.) and given a short time to cooperatively design, fabricate, and demonstrate a functional indoor kite. Kites are judged and prizes are awarded. The kite-building task offers students an entertaining way to get to know each other better.
- Student leaders provide a brief tour of essential locations students need to know as classes begin such as the main lecture halls for most of their classes, nearest dining facilities, the student union, etc.
- Information session is provided on critical issues relating to policies, procedures, etc.

"Opening Day" is a pre-emptive strike on the problem of isolation and alienation that many students experience on a large campus. Our intention is to create a sense of Engineering as a home in which students have connection and membership.

Faculty Mentors

This program aims at the aforementioned "student needs" of processing their academic experience, providing a realistic vision of engineering, and imparting a sense of belonging within the School of Engineering and Applied Sciences. An important function from our perspective is that the mentors serve as a vast warning net, allowing us to be in personal contact with several hundred students.

The challenge of a large faculty-mentoring program is to facilitate meaningful interactions. It is one thing to state that meetings should take place. It is quite another to see that this actually happens and that the meetings are fruitful – because constructive interaction does not happen spontaneously by simply placing people together in a room. As we have already noted, most freshmen, and particularly those most at-risk, are not habituated to using resources beyond the classroom or conversing with faculty. Faculty, for their part, are not generally familiar with the developmental stage of entering freshman students. They also have a diversity of preferences and aptitudes regarding mentor roles in which they feel comfortable and, of course, operate under significant time constraints.

Our current program hinges on three required meetings, positioned at critical junctures during the first semester. Each of these meetings has a particular suggested focus. Student participation is encouraged by including these meetings as a small part (5%) of the student's "Introduction to Engineering" course grade. The first meeting is integrated into the Opening Day program (described above) ensuring that contact is initiated. Students prepare a brief reflective writing exercise for this meeting that focuses on how they came to be in engineering, and on their images of engineering. These responses provide a springboard for conversation and provide mentors with an initial sense of how deeply committed and well informed each of their mentees is regarding the pursuit of engineering. The second meeting takes place about one month into the semester. The focus at this time is to identify arising issues and help connect students to appropriate support resources as needed. The third meeting is near the end of the semester. Students are asked ahead of time to reflect briefly in writing on their transition experience. The focus is to see how the student is situated in engineering, understand any needs that appear unmet, and help direct them towards their next steps in the spring semester.

These meetings are supplemented by near real-time grade updates early in the critical core courses. These inform the faculty of mentee progress in a timely enough manner that successful interventions are possible.

The program, though far from a perfect machine, has grown from a sparsely utilized service into one that generates significant interaction and is becoming part of our culture.

The very existence of such a program is one more signal to students that the School is committed to enabling their success.

Structured Academic Support

The major form of our structured academic support is small-group academic focus sessions that are provided for calculus, chemistry, and physics. The immediate goal of the groups is that students understand the material better and perform to their potential in the course. But the groups are not "tutoring". The ultimate goal is that students become trained in college-level engineering thinking and problem solving skills, so that as they move higher into the curriculum they are more strongly positioned to succeed.

These groups are conducted by a professional instructor in the engineering school, assisted by a student tutor (a high achieving veteran of a previous group). Each group is comprised of approximately 10 students and meets for one hour each week. The essential components of the material covered during that week in the corresponding course are addressed, along with the "disconnects" that we have found our students historically experience. The pedagogy is highly structured with the stated goals of the groups in mind, allotting time between development of problem-solving "maps" and use of the maps in an individualized problem-solving workshop. The format is also highly interactive, which is not only a benefit to learning, but often enables the groups to serve as a powerful vehicle for helping students process their academic experience. Students can meet individually with the tutor outside of group hours for additional help, if needed.

Multiple group sessions are offered at times that are convenient with course schedules. These group sessions are non-credit bearing and participation in the groups is voluntary. The decision to have voluntary groups was to avoid any perceived stigmatization that freshmen often associate with support services of any kind, particularly mandatory ones. Compulsory attendance is also likely to be ineffective, and even counterproductive. Ineffective, because although students can be compelled to attend, they cannot be compelled to devote the time and energy needed outside the group to bring the tools provided there to fruition. Counterproductive, because a key benefit is the creation of peer groups of motivated students working hard to succeed. This atmosphere (part of our "key student needs" list) would be lost with unwilling attendees in the room.

Students in the small groups form important connections to the School and to one another. They develop important study skills, successful strategies for approaching and analyzing engineering-like problems, and garner a deeper understanding of fundamental concepts.

Vision of an Engineering Career

It is our view that freshmen need to be provided with a realistic vision of the engineering profession that can serve to enhance motivation for their studies in courses within and outside of engineering. This perspective should also serve to inform career decision-making among the various engineering disciplines. Since freshmen are exposed to only one introductory engineering course during their first year, we have redesigned this course to present case studies that are intended to present real engineering projects in some depth and breadth. This approach differs markedly from the textbook-driven syllabus of engineering topics that had formerly prevailed. The course also provides an important opportunity for communication to the collective freshman group and enables students to form closer relationships with one another.

Classroom Environments and Learning Outcomes

We have engaged in a substantive dialogue on educational issues and student learning outcomes with the service departments outside of engineering. This has been a significant step forward within the historical culture of our institution. Specifically we have provided input with regard to critical course objectives and content from the perspective of providing a solid foundation for engineering majors. We have had meaningful discussions with regard to course pedagogy. Recently we have begun discussions concerning the objective evaluation of student performance and attainment of learning outcomes. This coincides with the new ABET accreditation criteria and approach to the assessment of educational objectives. Proper design of tests and examinations (as well as other tools for assessing student performance) is essential in order to provide an objective evaluation and meaningful comparison over various class sections, multiple instructors, different semesters, etc. The rubric underlying this approach is still in development but thus far it has been very well received by other academic service units and has served to catalyze very productive discussions regarding course design and student learning outcomes.

Results and Assessment

We have solicited written student evaluations of various components of the program including opening day, faculty mentoring, academic small groups, and the introduction to engineering course. Course evaluation instruments are also administered in all courses. The table below summarizes student responses over the past year. These data have been fairly consistent over time. It is important to note that the survey regarding the “Opening Day” program is administered at the end of the semester rather than on the day of the program. This provides a better measure of the true impact of the program on student experience, viewed in retrospect, at the conclusion of the first semester.

Clearly small group participants experience the service in a strongly positive fashion. There is typically nearly 100% continuing participation in the small groups from the fall to the succeeding spring semester. As the table indicates, the primary academic objectives regarding the material are rated highly. The secondary, affective objectives also meet with fair success.

In terms of impact on course outcomes (not in the table) nearly two thirds of students regularly rate their work in the group as having improved their course grade at least one letter grade. These subjective assessments are roughly supported by objective data, in which we find that group participants generally outperform non-participants in calculus, chemistry, and physics course grades. This is particularly significant in view of the fact that group participants tend to constitute an equal or higher academic risk level compared to non-participants (judged by our admissions risk model). The cohort of academic group participants has also yielded a substantially higher (by approximately 20%) retention rate. Although the voluntary participation in the academic small groups makes straightforward comparisons somewhat difficult (since we do not have a controlled experiment), all these indications are strong evidence that the groups are meeting their goals.

Program	**Very Successful**	**Fairly Successful**	**Not Very Successful**	**Not at All Successful**	**Neutral**
Opening Day					
Helping to meet others	70%				
Setting a friendly tone	80%				
Communicating sense of caring	80%				
Faculty Mentoring	55%		11%		34%
Academic Small Groups					
Better understand material	78%	22%			
How to approach material	75%	25%			
Sustain motivation	53%	44%	5%		
Sense of belonging	45%	47%	3%	2%	
Case Studies Course					
Understand engineering field	40%	50%			
Help inform decision making	30%	40%			10%
Connecting with peers	60%				

Note: Evaluation scales differ among the various initiatives. The table provided here correlates them to a single scale for ease of viewing. Hence, for Opening Day for example, we do not distinguish between successful and highly successful, but simply rate success as depicted here. Because of the different evaluation scales not all entries for a given program have been incorporated into the table and percentages across rows may not total 100%.

Conclusions

The initiatives described here have been in place for only a very short time and an assessment of their full impact is still too early to measure. However, student feedback, student success rates, and a variety of other indicators are strongly positive. Better-informed admissions decisions based on a student's technical high school record, placement of students in appropriate preparatory courses, structured academic support in critical subject areas in a small group setting, providing a realistic vision of the engineering profession, and building closer relationships with the engineering school (through block scheduling, opening day programs, faculty mentoring, etc.) have dramatically reshaped the mainstream educational experience of our engineering freshmen. It is our belief that positive improvements in course pedagogy and design have been attained in several lower division courses both within and outside of engineering. We will continue to monitor and assess the impact of these initiatives on our student retention and graduation rates. However, the benefit of these programs is not solely reflected by these quantitative measures. These measures do not readily capture the improvement in performance and confidence of a moderate- or high-achieving student. We also feel that these programs have been nurturing and beneficial even for students that leave engineering. These students leave with a better awareness of alternatives, a more positive sense of confidence in their academic potential, and our support in helping them find an academic home suited to their interests and aptitude.

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Biographical Information

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