Effective Retention Strategies for Engineering Students

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Abstract – **Engineering Programs in the US have been working to improve retention rates of students for many years. Today universities in Europe and other countries are becoming increasingly interested in improving retention and student success. Improving retention rates is especially important in order to increase the number of students who obtain engineering degrees. Many of the programs developed in the US have been implemented from a Student Services perspective with peer mentoring and counseling prominently featured. At Michigan Tech, a number of academic programs have been implemented aimed at improving student retention and success. A first-year engineering program which features active-collaborative learning and the development of learning communities has been implemented. In addition, a companion course to pre-calculus with the goal of introducing engineering applications of algebra and trigonometry topics and providing students with a "real-life" context for the topics from mathematics they are learning has been developed. Finally, a course aimed at engineering students who have demonstrated a weakness in 3-D spatial visualization skills has also been offered. This paper describes these introductory courses and provides data illustrating their effectiveness in retaining engineering students.**

Index Terms – first-year engineering, introductory courses, student retention, student success

INTRODUCTION

As noted by Tinto [1] in 1993, institutions in the United States have come to view the retention of students as the only reasonable course of action in response to shrinking enrollments. This is especially true in science, technology, engineering, and mathematics where enrollments continue to decline nation-wide. Clearly, the causes of withdrawal and drop out are varied and many and no single intervention strategy alone is enough.

Michigan Technological University has approached the issue of retention in a multi-pronged approach. Following in the footsteps of numerous other U.S. universities, Michigan Tech has implemented student services-focused retention programs including peer mentoring, counseling, living communities, early warning intervention strategies, and student support groups focused on various specific target groups of students. Jolly [2] noted that it is best to assure that retention efforts are overlapping sets in each student's experience. For this reason, Michigan Tech has also instituted several academic courses and programs aimed at improving student retention. Because no one retention technique will help every student, each of these academic approaches also focuses on specific sets of student needs.

FIRST-YEAR ENGINEERING PROGRAM

In the fall of 2000 Michigan Tech created a First-Year Engineering Program. The curriculum features a community learning approach to engineering education where all entering engineering students share a common first-year experience. This approach to engineering education allows students to acquire hands on knowledge of the engineering programs available at Michigan Tech, work together in small group settings, and apply engineering principles and understanding early in their engineering education.

As noted in 2004 in *Transforming the First Year of College for Students of Color* [3], throughout the body of retention research that has emerged in the last two decades, "…one thing that is evident regardless of the view, that the first year in college represents a critical juncture for students in general…..". By focusing attention on this first year, Michigan Tech is addressing a need for students as they make critical decisions on their major and career path.

In the Michigan Tech First-Year Engineering Program, students register for classes in a cohort that consists of several courses that must be taken co-currently: Calculus, Engineering, and Physics (see Table I).

TABLE I
TYPICAL FIRST-YEAR ENGINEERING CURRICULUM

First Semester	Credits	Second Semester	Credits
Calculus 1	4	Calculus 2	4
Engineering 1	3	Engineering 2	3
Physics Lab 1	1	Physics 1	3
Chemistry 1	4	One additional class by major	1-4
General Education	3	General Education	4

The Engineering 1 course, Engineering Analysis, serves as an introduction to the engineering profession and to its various disciplines. The focus of the course is on developing problem solving skills, computational skills, and communication skills. The Engineering 2 course, Engineering Design and Problem Solving, continues to introduce students to the engineering profession and its various disciplines while focusing on problem solving, computational, and communication skills. Through active, collaborative work, students work on teams to apply the engineering problem-solving method to real-world problems. According to Swail [4] over 70% of the students studied in eight different colleges indicated they learn better through hands-on projects and real-world application than through classroom or textbook instruction. In support, Shuman [5] states that learning can be strengthened through collaboration and is shaped by the context in which it occurs.

In addition to allowing students real-world engineering experience in their first year of college, the common first year curriculum allows students to develop a cohort of students that they know and feel comfortable with. This familiarity enables a natural support system that can often be difficult for first-year students to develop early in their academic career. There have been many studies on the benefits of working in groups, with the understanding that often times the whole becomes bigger and better than its parts, as noted by Reklaitis [6]. In her book on small groups in engineering she recognizes that through the group process, as students observe and take part in discussions, they realize they are not alone in their struggles; this is often a very freeing insight for first-year students who feel they are the only one experiencing this loneliness or concern.

Additionally, the courses encourage the exploration of all of the different engineering disciplines, helping to guide students towards the engineering discipline that best suits their individual strengths and preferences. The goal is that upon completion of the first year of courses students will be confident and ready to make their most important career decision, declaring their major with certainty. As noted by Tinto [1], "…when individuals are more certain as to their futures, they are more likely to finish college."

The First-Year Engineering Program at Michigan Tech was implemented in the fall of 2000 meaning that fall 2001 retention data is the first year that will show the impact of this implementation on student retention. As can be seen from the data presented in Figure 1, through the last few years, and most noticeably 2 years after inception of the First-Year Engineering Program, the Michigan Tech College of Engineering (COE) first to second year retention rate experienced consistent increases.

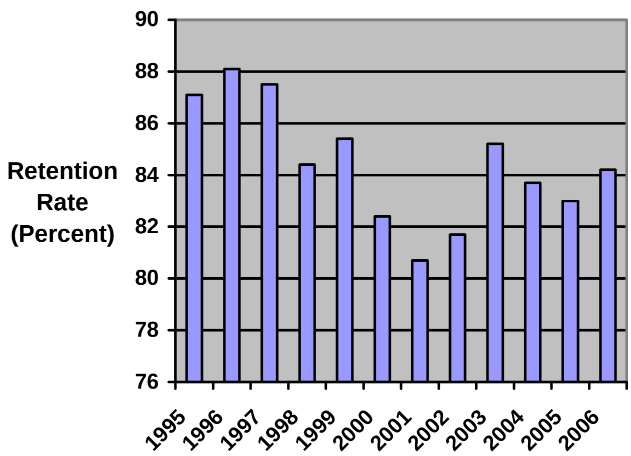

FIGURE 1
MICHIGAN TECH COE FIRST-YEAR RETENTION HISTORY

In addition to the positive impact on student retention, the first-year program appears to have had a positive impact on student success in terms of reducing the number of students who are eligible for dismissal after their first two semesters. Campus wide, the percent of first-year students that are now eligible for dismissal from Michigan Tech after spring of their first year, defined as maintaining a GPA$\leq$ 2.0 after spring semester, has decreased from a high of 13% after spring 2001 to 7% for both spring 2005 and 2006 (Table II).

TABLE II
MICHIGAN TECH STUDENTS ELIGIBLE FOR DISMISSAL AFTER SPRING SEMESTER OF THEIR FIRST YEAR

Spring of	1999	2000	2001	2002	2003	2004	2005	2006
Eligible for Dismissal (Percent)	10.3	12.9	13.0	10.0	7.0	5.0	7.0	7.0

ENGINEERING PROBLEM SOLVING COURSE

As detailed previously in this paper, the current First-Year Engineering Program course curriculum requires that students be calculus ready in order to enroll in the typical first-year curriculum. Unfortunately, approximately one quarter of first-year engineering students at Michigan Tech are not ready to enroll in Calculus 1 during their first semester on campus. Therefore, many of these students would not be exposed to the engineering first-year curriculum until spring semester of their first year or possibly not until fall semester of their second year.

To enable these students to experience an engineering course in the fall and to expose them to many of the same benefits of the other first-year engineering courses, the Engineering Problem Solving course was created. Originally created in partnership with Michigan Tech's Educational Opportunity Department and partially funded by the State of Michigan King-Chavez-Parks Initiative, the course was part of a program called ExSEL (Excelling in Science & Engineering Learning) that focused on students academically under-prepared for the Michigan Tech engineering curriculum. The course proved so successful that it was eventually incorporated into the College of Engineering curriculum and became required for all engineering students beginning their math sequence at Michigan Tech in pre-calculus. In addition, the first-year program was modified for these students so that they take the 2-credit problem-solving course in the fall along with pre-calculus and then enroll in a modified 2-credit version of Engineering 1 in the spring semester when they are enrolled in calculus (this is known as the 2+2=3 option).

Pre-Calculus is a co-requisite of the Engineering Problem Solving course. If a student is ready to enroll in pre-calculus during fall of their first semester, their schedule looks similar to that shown in Table III. The student would then begin the calculus ready common First-Year Engineering curriculum in their second (spring) semester. For some students that are not ready to enter pre-calculus in fall of their first year, the calculus ready First-Year Engineering curriculum may still need to be pushed back until fall semester of their second year.

TABLE III
TYPICAL PRE-CALCULUS STUDENT FIRST-YEAR ENGINEERING CURRICULUM

First Semester	Credits	Second Semester	Credits
Pre-Calculus 1	4	Calculus 1	4
Engineering Problem Solving	2	Engineering 1*	2
Preparatory Chemistry	3	Physics Lab 1	1
General Education	6	Chemistry 1	4
		General Education	4

*Modified version of Engineering 1

The Engineering Problem Solving course is an introduction to the engineering problem solving method and to modern tools used to solve problems. Because pre-calculus is a co-requisite, the Engineering Problem Solving course material parallels the pre-calculus material. The pre-calculus topics are applied to engineering problems, allowing students to practice real-world applications of the math tool they are learning and understand the integration of mathematics, engineering, and science, while also giving the students an opportunity to experience an engineering course and engineering applications in their first semester of college.

Nilson noted in *Teaching At Its Best* [7], that students learn best by connecting new knowledge to what they already know, working both in groups and individually, and when they are actively engaged in a life experience. Thus, Engineering Problem Solving strives to employ all of these techniques. Students in the course work in teams of three in a high-tech computer classroom. The teams are utilized for both in and out of class assignments. In class, the teams participate in hands-on activities, work on the computer, and solve engineering problems on paper. Out of class, the teams work together on presentations, data collection, lab reports, and a semester design project. Students complete tests and quizzes of material on their own in order to show individual concept mastery.

The importance of a course that makes engineering come alive from the first day of fall semester, with high-quality, innovative courses, in state-of-the-art facilities, taught by faculty members who care [8] is paramount to the success of this course and the students who take it. As noted by Shuman [5], the future of engineering education lies in engineering problem-solvers trained in technological advances that can apply this knowledge to broader societal needs than done previously.

The Engineering Problem Solving course, along with the ExSEL Program, from which the course originated, proved very successful in retaining and increasing the academic success of students academically under-prepared for the Michigan Tech engineering curriculum. As can be seen in Figure 2, ExSEL students have experienced a consistent upward trend in first-year retention. It is important to note that the average ExSEL Math ACT score for ExSEL students is 21.9 over the years covered in Figure 2; significantly below the Michigan Tech COE average first-year Math ACT score of 27.3 over the same time period.

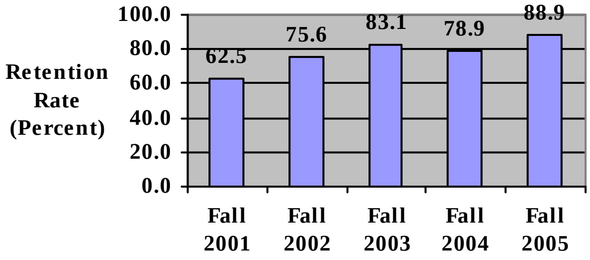

FIGURE 2
EXSEL STUDENT FIRST-YEAR RETENTION

Between fall 2000 (ExSEL Program inception) and fall 2005, the percent of ExSEL students achieving Dean’s List status after fall semester of their first-year consistently increased from 8.0% to 12.1%; spring semester increased from 4.2% to 8.7%. Since program inception, ExSEL students also experienced increased academic success in several key first-year courses as detailed in Table IV below.

TABLE IV
PERCENT INCREASE IN EXSEL STUDENTS EARNING A C OR BETTER IN THEIR FIRST ATTEMPT AT SEVERAL KEY COURSES

Course	Increase Between 2000 and 2005
Preparatory Chemistry	27%
General Chemistry	59%
Pre-Calculus	62%
Calculus 1	74%

3-D SPATIAL SKILLS COURSE

3-D spatial visualization is a skill that has been shown to be important in technological fields, especially in engineering. It is also well- documented that the 3-D spatial visualization skills of women typically lag far behind those of their male counterparts. In research conducted at Michigan Tech, [9] – [11], it was determined that, although men and women both have statistically significant gain scores through participation in engineering graphics courses, the average post-test scores for women are lower than the average pre-test scores for men.

The importance of spatial visualization in engineering was noted by Michigan Tech already in 1993, when a course aimed at first-year engineering students with weak 3-D visualization skills was developed through support from the National Science Foundation. Students were selected to participate in the course based upon the Purdue Spatial Visualization Test: Rotations (PSVT:R) that was developed by Guay in 1977 [12]. In 1998, a second grant was obtained from the NSF to develop multimedia software and a workbook for use in the spatial skills course.

Since graphics is a significant part of the first-year engineering courses, the PSVT:R spatial visualization test has been administered to all entering engineering students since fall 2000 (previously the test was administered to students only in selected majors). In fall of 2000 the course was also revised and offered as a 1-credit course meeting for one two hour lab session each week. During the revised course the faculty member delivers a 10-15 minute mini-lecture at the beginning of the class session to introduce the course topic for the day. Students then work in pairs to complete the corresponding multimedia software module. For the remainder of the session, students complete assigned pages from the workbook, either individually or in pairs. This opportunity for both individual and group work, along with hands on learning in a high-tech classroom is highly supported as an ideal learning situation [4] – [6], [7] – [8].

Since 1993, several longitudinal studies have been conducted for students who participated in the spatial skills courses/training [13]. The first of the studies was conducted in ~1997. The subjects in this study were the participants in the pilot offering of the course. For this study, the experimental group (EG1) was defined as those who failed the PSVT:R during orientation and enrolled in our course and the comparison group (CG1) was defined as those who failed the PSVT:R and did not enroll in our course. It should be noted that these students were all randomly selected.

The second and third longitudinal studies were conducted in 2000 and 2004 respectively. For these studies, students in the experimental groups were again those who had failed the PSVT:R and enrolled in the spatial skills course (EG2 & EG3); the comparison groups were made up of students who had failed the PSVT:R and not enrolled in the spatial skills course (CG2 & CG3). For the second longitudinal study (EG2 and CG2), the students enrolled or did not enroll in our original 3-credit lecture-based quarter course between 1993 and 1998. [Thus, the students from the first longitudinal study were a small subset of the students in this longitudinal study.] For the third longitudinal study (EG3 and CG3), the students enrolled or did not enroll in our 1-credit semester course that was based on the multimedia software and workbook between 2000 and 2002. For both of these studies, the students were self-selected, i.e., all students who failed the PSVT:R were invited to enroll in the course but only a fraction of them did so.

Grades in follow-on engineering courses were higher for the experimental group than those of the control group for each of the studies. Additionally, retention was positively impacted for most of the experimental groups [13]. Particular attention was paid to retention rates by gender, since overall success of women was of particular interest. Tables V and VI present the data from this analysis by gender (shading signifies random selection). Note that students were deemed "retained" if they were still enrolled or had graduated from the university at the time the transcripts were obtained. Students who had left the university (other than for co-op positions) were considered to be not retained.

TABLE V
RETENTION RATES FOR MALE SUBJECTS

	EG1	CG1	EG2	CG2	EG3	CG3
Enrolled	13	40	85	200	82	120
Retained	9	28	64	138	63	84
Retention Rate (%)	69.2	70.0	75.3	69.0	76.8	70.0

TABLE VI
RETENTION RATES FOR FEMALE SUBJECTS

	EG1	CG1	EG2	CG2	EG3	CG3
Enrolled	11	32	90	161	87	53
Retained	9	23	80	110	76	38
Retention Rate (%)	81.8	71.9	88.9	68.3	87.4	71.7

For study groups 1 and 2, the retention rates *within* engineering were also examined (retention rates in Tables V and VI were university retention rates). Table VII presents data regarding engineering retention rates. Shading signifies random assignment. For study 2, the differences in engineering retention rates for women were statistically significant ($p<0.0002$), but for men, the differences were not significant. This finding is especially important as we strive to improve diversity in engineering.

TABLE VII
ENGINEERING RETENTION RATES FOR SUBJECTS

	Males		Females		Males		Females	
	EG1	CG1	EG1	CG1	EG2	CG2	EG2	CG2
Enrolled	13	40	11	32	85	200	90	161
Retained in Engineering	9	25	7	17	52	104	69	77
Engineering Retention Rate (%)	69.2	62.5	63.6	53.1	61.2	52.0	76.7	47.8

RETENTION IMPACT

This broad range of both academic and extended student centered support has highly impacted retention, especially female retention at Michigan Tech. Indeed, the Michigan Tech COE first-year retention of females (Table VIII) consistently outperforms that of the COE males. Nationally, the norm in STEM disciplines is the opposite; males typically outperform females in first-year retention.

TABLE VIII
FIRST-YEAR RETENTION COMPARISON BY GENDER

	1998	1999	2000	2001	2002	2003	2004	2005
COE Female	92.1	88.8	88.2	88.2	89.9	91.7	86.1	85.8
COE Male	82.3	84.3	80.9	79.0	79.9	83.8	83.3	82.5
*STEM Female	65.6	66.0	65.5	66.4	65.6	66.0	67.3	67.4
*STEM Male	69.6	70.2	69.8	70.4	70.6	71.3	71.5	71.3

*2004-05 and 2005-06 Center for Institutional Data Exchange and Analysis (CSRDE) STEM Retention Report, University of Oklahoma Outreach, all 188 STEM Institutions, Discipline-specific.

Additionally, the Michigan Tech first-year retention rates are consistently higher not only in comparison to STEM Institutions as shown above, but also when compared to National Public 4-Year Selective Admittance University's (Table IX). Note that selective in this case is defined as admitting an ACT middle 50% of 22-27, SAT middle 50%

of 1030-1220, and the majority admitted from the top 25% of the High School class [14].

TABLE IX
FIRST-YEAR RETENTION RATE COMPARISON

	2000	2001	2002	2003	2004	2005	2006
Michigan Tech	79.5	75.5	77.6	80.8	81.0	80.3	80.7
Michigan Tech COE	82.4	80.7	81.9	85.2	83.7	83.0	84.2
National Public 4-Year Selective*	80.2	80.4	80.2	80.8	81.3	81.6	81.7

*Data compiled by ACT, Inc. from the ACT Institutional Data Questionnaire, www.act.org [14].

With an average of 65% of first-year Michigan Tech students enrolled in the COE, any significant retention improvements naturally result in University-wide increases, as can also be seen from this data. Additionally, the COE first-year retention rate has been higher than that of all of the other colleges and schools at Michigan Tech University over the previous ten years.

Retention for students academically under-prepared for the Michigan Tech engineering curriculum has also increased since inception of these courses and the First-Year Engineering Program. As shown in Table X, the first-year retention rate for students with Math ACT scores of 19-22 and 23-25, have rebounded significantly from their lowest point in fall 2001 and fall 2000 respectively. Students considered well prepared have also seemed to benefit from the outreach, as those with Math ACT scores of 26 and above are also increasing in the last few years.

TABLE X
MICHIGAN TECH FIRST-YEAR RETENTION RATE BY MATH ACT SCORE

Math ACT	1998	1999	2000	2001	2002	2003	2004
Below 19	64.3	71.4	38.5	40.0	NA*	NA*	NA*
19-22	82.8	78.5	78.0	64.9	71.0	83.6	76.6
23-25	78.6	80.1	75.0	78.8	83.1	82.9	80.8
26-28	87.9	85.8	85.8	77.8	79.5	86.7	85.1
29 and higher	89.5	90.5	87.8	88.5	87.3	86.8	86.5

*Small sample size (less than 4).

CONCLUSION

Engineering education has many gateway courses. Typically, these are thought to be calculus, chemistry, and physics. From the results of this research, it seems that engineering graphics and hands on engineering problem solving experience in the first-year classroom should also be included in that list. By developing and implementing both student services focused support and academic courses to help students improve their ability to be successful in applying engineering concepts early in the engineering education, student success and retention were indeed improved.

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