THE IMPLEMENTATION OF A FIRST-YEAR ENGINEERING PROGRAM AND ITS IMPACT ON CALCULUS PERFORMANCE

Sheryl A. Sorby[1], Amy J. Hamlin[2]

Abstract *— In the fall of 2000, Michigan Tech implemented a common first-year program for all engineering students. The curriculum in the new first-year program naturally includes required courses in math and science. In addition, students enroll in two required engineering courses in each of their first two semesters at Michigan Tech. Hallmarks of this program are "cohort" scheduling of math/science/engineering courses and an emphasis on collaborative learning in the engineering courses. In addition, our Mathematics Department instituted changes in placement within first year math courses. We have examined the calculus grades of students who were in an engineering cohort and compared them to the grades received by similar students who were not in a cohort. This paper examines the performance of students in Calculus at Michigan Tech prior to and immediately after the implementation of the first-year engineering program. Conclusions will be drawn regarding the impact that this program has had on calculus performance.*

Index Terms — core requirements, freshman programs, learning communities, student success.

BACKGROUND

Engineering students must have a solid background in mathematics and science in order to successfully complete their four-year program of study. Calculus has historically been the starting point in mathematics instruction for engineering programs. Unfortunately, many engineering students are not ready to study calculus the first day they come to campus but must begin with algebra or trigonometry before going on to take their required mathematics courses. Struggles with calculus and/or science courses often lead to an overall discouragement with engineering as a field of study and possibly contribute to the higher than average attrition rate that most engineering programs experience.

Another factor that has been found to contribute to the relatively high attrition rates among engineering programs is the fact that most curricula include two years of math and science before any real exposure to engineering occurs. Students struggle to make it through these foundational courses and sometimes do not have an adequate understanding of or appreciation for engineering itself. Many engineering programs in the United States have responded to this phenomena by developing first-year engineering courses [1,2]. The purpose of these first-year courses is to introduce students to the engineering profession early in their program of study so that 1) they attain a greater understanding of engineering and how it differs from math and science, and 2) they become excited about studying engineering so that they are not so discouraged by their required calculus and science courses. Alternatively, they may find that engineering does not really interest them and they can then switch to a different major that is more appealing to them sooner.

THE MICHIGAN TECH FIRST-YEAR PROGRAM

In the fall of 2000, we implemented a common first-year engineering program at Michigan Tech at the same time that the university switched from a quarter calendar to one based on semesters. The curriculum template for the first year program at Michigan Tech is presented in Table I. (Engineering classes meet for three 1.5-hour sessions per week.)

TABLE I
CURRICULUM TEMPLATE FOR FIRST-YEAR PROGRAM

First Semester	Second Semester
Chemistry I	Physics I
Calculus I or I+	Calculus II
Engineering I	Engineering II
General Education	General Education
Physics Lab I	One Course by Major

Integration of Math, Science and Engineering

It is our intent that the first year Math, Science and Engineering (MSE) courses will be integrated wherever feasible. Examples of the type of integration that are possible include: manipulating and graphing data from Chemistry lab using computer tools in the engineering course, applying deriva-

[1] Sheryl A. Sorby, Michigan Technological University, Engineering Fundamentals Department, 1400 Townsend Drive, Houghton, MI 49931 sheryl@mtu.edu

[2] Amy J. Hamlin, Michigan Technological University, Engineering Fundamentals Department, 1400 Townsend Drive, Houghton, MI 49931 ahamlin@mtu.edu

tives and integrals learned in math to "engineering" problems, learning an introduction to statics and dynamics in the engineering course as they are learning about forces and motion in Physics. During our first year of the program (the 2000-01 academic year), the integration of math, science and engineering occurred only minimally within the engineering courses. Math and science instructors are encouraged to include engineering examples in their lectures (and some do), however, meaningful integration has not yet been fully achieved. One way to encourage more integration between subjects is to establish good communication between the math, science and engineering instructors and it is our intent to improve our implementation of this aspect of the program as we move forward from here.

Cohort Scheduling

Since the intent is that the MSE courses will be integrated in the first year, cohorts of students sign up for these classes as a "block." Therefore, students in a cohort will have the same schedule for these classes. The cohort size is generally either 20 or 24 students depending on classroom and faculty resources. Physics and Chemistry labs consist of one cohort of students while Calculus and Physics recitations consist of two cohorts. Engineering classes consist of either two or three cohorts depending on classroom availability. Chemistry and Physics lectures typically consist of around 10 cohorts of students. By utilizing cohort scheduling, we believe that learning communities will be established and that better integration of subject matter is possible. Non-cohorted sections of the MSE courses are also offered as necessary to accommodate transfer students, students with advance placement credit, students who fail one or more of their MSE courses, or students who get out of sequence for some other reason.

Active Collaborative Learning

In order to achieve better student understanding and retention of material, we have adopted an active, collaborative teaching style throughout the first year engineering courses. By this method, we spend approximately one-third of each session lecturing on the topic for the day. Students then work either individually or in teams to solve problems or to "discover" the answers to questions posed by the instructor. During the time that students are actively working, the instructor and an assistant circulate through the classroom, answering questions as needed. We also spend a portion of class time on teaming with several team projects and team homework assignments given out during the semester.

Technology in the Classroom

Prior to the implementation of our first year program, most instruction in the use of computer tools within the engineering curricula was relegated to a few "computer-intensive" courses with separate computer labs staffed by TAs. In this way, most engineering students did not develop a full appreciation of the computer as a problem-solving tool until well into their junior or senior year (if ever). In our first year engineering courses, the computer is utilized as a regular part of the problem-solving process. We hope that the integration of technology in the classroom will enable our students in future years to become more adept at utilizing software tools in the solution of a wide variety of engineering problems throughout their college careers and beyond.

Engineering Explorations

As a part of their course work, students in the first of the two engineering courses are required to participate in a minimum of four hands-on activities from at least three disciplines outside of class time. These activities have been designed to expose them to the engineering majors and are 2-3 hours in duration. Every semester, each engineering discipline (mechanical, electrical, computer, civil, environmental, materials, biomedical and mining) develops a schedule for when their labs/rooms are available to conduct these activities and staff them with either graduate students, non-academic staff or faculty as they deem appropriate. Students in the first engineering course sign up for four of these activities through the semester over the web. Sample titles of the engineering explorations include: 1) Concrete: Sexier Than You Think, 2) Are Some Civil Engineers All Wet?, 3) Material and Manufacturing Choices in Bike Frame Construction, and 4) Geological Engineering of Water Wells. At the conclusion of the explorations, 79% of the first year engineering students reported that they were prepared to select an engineering major.

Calculus I/I+

Prior to our switch to semesters and the adoption of our first-year program, only about one-third of our entering engineering students were ready to take calculus from their first day on campus. Most students began their programs of study with a Pre-calculus course and went on to take their first quarter of calculus during their first winter quarter. Some students were not even ready for pre-calculus and spent two quarters taking remedial math courses--College Algebra and Trigonometry-before enrolling in calculus in the spring quarter. With the switch to semesters and the development of the first-year engineering program, our Mathematics Department developed two separate courses: Calculus I and Calculus I+. Upon successful completion of either course, students can then enroll in Calculus II during their second semester.

This difference between these two courses is that Calculus I meets for 4 hours per week whereas Calculus I+ meets

for five hours per week. During this extra hour of class each week, topics from pre-calculus are incorporated as necessary, the pace is slowed down, and students are able to solicit additional help as needed. At the end of the first semester, the student who enrolled in Calculus I+ have had an equivalent experience when compared to students from Calculus I and are thus ready to move forward through the curriculum. By instituting this one small change, we now admit two-thirds of our students directly into calculus (compared to only one-third historically). We feel that this change alleviates feelings of discouragement that students may have felt when told that they were not ready for calculus and were thus "behind" in their course of study from the first day they arrived on campus.

First Semester Calculus Performance

There is some evidence that suggests that students in learning communities perform better than those who are not in such an environment [3]. With cohort scheduling and with active, collaborative learning in our first-year program, we believe that we have provided our engineering students with a learning community of sorts during their transitional year. For this reason, we examined whether or not the changes we instituted had any impact on student success, especially with regards to calculus performance. Analysis of our data was complicated by the fact that we made several, simultaneous changes in our curricula and programs, however, this paper presents our findings to the best of our ability, given the circumstances.

In first analyzing our data it became apparent that we would have to group our students based on their math ability in order to make valid comparisons. In doing so, we noted that we could divide our students into five distinct tiers for math preparation that were based loosely on Math ACT scores. Table II lists these tiers for math placement and outlines the courses that these students would have enrolled in under our quarter vs. our semester system. It should be noted that historically the Math ACT placement criteria was a bit more flexible than it was in fall 2000, hence, some students in Tier 3 prior to fall 2000 may have actually been placed higher or lower within this structure.

Calculus and pre-calculus grades for engineering students were analyzed after the fall 2000 semester with the results presented in the following. Calculus performance of Tier 1 students, who typically had AP or transfer credit for at least one semester of calculus, were not analyzed. Historical data was obtained for comparison for first year engineering students who started at Michigan Tech in the fall quarters of 1998 and 1999. In all cases, grades were analyzed only for First Time in Any College (FTIAC) students, and not for returning or transfer students.

TABLE II
Engineering Student Tiers

	Math ACT	Math Placement in Quarters	Math Placement in Semesters
Tier 1	NA	Calculus II or higher	Calculus II or higher
Tier 2	29 or higher	Calculus I	Calculus I
Tier 3	26-28	Pre-calculus	Calculus I+
Tier 4	20-25	College Algebra/ Trigonometry	Pre-calculus
Tier 5	19 or lower	Technical Mathematics	Developmental Math

Calculus Performance of Tier 2 Students

Table III presents the grade distribution in the first calculus course for Tier 2 students both before and after implementation of our first-year program. Michigan Tech uses a 4-point grading scheme with A=4.0, AB=3.5, B=3.0, etc. A grade of "W" is assigned for a student who withdrew from the class before the 9th week of the semester, there are no grade points associated with this grade designation. Typically a grade of "W" signifies that a student was struggling with the course material and did not wish to receive a letter grade.

TABLE III
Calculus Performance of Tier 2 students

Grade	Fall '98 & '99 n=468	Fall '00 n=215
A	107 (22.9%)	69 (32.1%)
AB	97 (20.7%)	39 (18.1%)
B	94 (20.1%)	33 (15.4%)
BC	42 (9.0%)	28 (13.0%)
C	41 (8.8%)	10 (4.7%)
CD	19 (4.6%)	12 (5.6%)
D	21 (4.5%)	4 (1.9%)
F	39 (8.3%)	16 (7.4%)
W	8 (1.7%)	4 (1.9%)

The average GPA for the historical data was computed as 2.80 and the average for the students in the first-year engineering program was 2.95 with the difference between the two statistically significant ($p<0.05$). In performing other statistical analysis on the data, the following observations are made:

- The difference in the percentage of students in fall 2000 who received an "A" in calculus compared to those in 1998 & 1999 was significant (p=0.01).
- The difference in the percentage of students who received DFWs, although encouraging (11.2% in fall 2000 vs. 14.5% in fall 1998 & 1999) was not statistically significant.

Calculus Performance of Tier 3 Students

Table IV presents the calculus grade distribution for Tier 3 students. Prior to the implementation of our first-year program students in this tier would have taken pre-calculus in the fall and their first calculus course in the winter quarter. In the fall of 2000 these students enrolled in Calculus I+.

TABLE IV
CALCULUS PERFORMANCE OF TIER 3 STUDENTS

Grade	Fall '98 & '99 n=557	Fall '00 n=219
A	83 (14.9%)	25 (11.4%)
AB	66 (11.9%)	24 (11.0%)
B	96 (17.2%)	33 (15.1%)
BC	64 (11.5%)	45 (20.6%)
C	76 (13.6%)	24 (11.0%)
CD	44 (7.9%)	22 (10.0%)
D	40 (7.2%)	14 (6.4%)
F	82 (14.7%)	27 (12.3%)
W	6 (1.1%)	5 (2.3%)

The average GPA for the historical data was computed as 2.30 and the average for the students in the first-year engineering program was 2.29 with the difference between the two not statistically significant. In performing other statistical analysis on the data, the following observations can be made:

- The difference in the percentage of students in fall 2000 who received a "BC" in calculus compared to those in winter 1998 & 1999 was highly significant (p<0.002). All other differences were not significant.
- The difference in the percentage of students who received DFWs, although encouraging (21.0% in fall 2000 vs. 23.0% in fall 1998 & 1999), was not statistically significant.

It should be noted, however, that for this group of students, for the fall 1998 & 1999 data, there were a total of 65 students who did not successfully complete *pre-calculus* in their first fall quarter. If these 65 students are included in the DFWs for Tier 3 students (i.e., they did not successfully complete their first quarter of calculus by the end of winter term), then the percentage of Tier 3 students not successful in calculus for fall 1998 & 1999 was 31.0% compared to 21.0% for the Tier 3 students in our first year program. The difference between these two percentages was highly significant (p<0.0005).

Calculus Performance of Tier 4 and Tier 5 Students

Students in these tiers had not attempted calculus by the time that the data for this paper had been gathered. Their progress towards graduation will be monitored and compared to historical data as it becomes available.

Calculus Performance of Tier 2 and Tier 3 Minority and International Students

The student population at Michigan Tech is primarily caucasians from the Midwest region of the United States. For this reason, most minority (i.e., African Americans, Hispanics, Latinos, Native Americans, and Multiracial) and international students have typically been "marginalized" within our campus. For this reason, we felt that it was important to determine whether or not the creation of our "learning communities" produced any positive results in terms of calculus performance. For this analysis, due to small sample sizes, we divided the students into only two categories: 1) Success in calculus (CD or better), or 2) non-success in calculus (DFW). Table V contains the results from this analysis for Tier 2 students.

TABLE V
SUCCESS VS. NON-SUCCESS FOR MINORITY AND INTERNATIONAL TIER 2 STUDENTS

	Minority Students		International Students	
	Fall 98/99 n=26	Fall 2000 n=14	Fall 98/99 n=26	Fall 2000 n=18
Success (CD or better)	25 (96.2%)	10 (71.4%)	20 (76.9%)	18 (100%)
Non-Success (DFW)	1 (3.8%)	4 (28.6%)	6 (23.1%)	0 (0%)

In performing statistical analysis of this data, the following are noted:

- The difference in success rate for Tier 2 international students was significant (p=0.0286), favoring the fall 2000 group of students.
- The difference in success rate for Tier 2 minority students was significant (p=0.0238), favoring the fall 1998 & 1999 group of students. However, one student in the

fall 2000 group was originally not admitted to the engineering program due to poor high school performance, and he was later allowed to enter the program despite our reservations about his probable success. If this person were removed from the analysis, this difference would not be statistically significant.

Table VI contains the results from this analysis for Tier 3 minority and International students.

TABLE VI
SUCCESS VS. NON-SUCCESS FOR MINORITY AND INTERNATIONAL TIER 3 STUDENTS

	Minority Students		International Students	
	Fall 98/99 n=29	Fall 2000 n=10	Fall 98/99 n=7	Fall 2000 n=3
Success (CD or better)	17 (58.6%)	8 (80.0%)	4 (57.1%)	3 (100%)
Non-Success (DFW)	12 (41.4%)	2 (20.0%)	3 (42.9%)	0 (0%)

In performing statistical analysis on this data, no statistically significant differences were found, largely due to the small sample sizes.

In combining the data for all Tier 2 and Tier 3 "marginalized" students, the following are noted:

- The calculus success rate for *all* marginalized students not in cohorts (fall 1998 & 1999) was 75.0% (n=88). For those in cohorts (fall 2000) it was 86.67% (n=45). This difference, while encouraging, was not significant.
- The calculus success rate for international students not in cohorts was 72.73% (n=33). For those in cohorts it was 100% (n=21). This difference was significant (p=0.008).

Probation rates for Tier 2 and Tier 3 Students

Another indicator of student success is the incidence of academic probation. At Michigan Tech, students are placed on academic probation in any term that their GPA is less than 2.0. Once again, however, it was difficult to fully assess the potential impact of our programmatic changes on probation rates due to our simultaneous change in our academic calendar. Table VII shows probation rates for Tier 2 and Tier 3 students for the three years under consideration. In compiling the probation rates for 1998 and 1999, probation after either fall or winter term was noted (i.e., the student had been placed on academic probation sometime during their first year at the university). Table VIII shows these probation rates for minority and international students in these tiers.

Statistical analysis reveals that differences in probation rates for Tier 2 students (10.7% vs. 18.2%) were marginally

TABLE VII
PROBATION RATES OF TIER 2 AND TIER 3 STUDENTS

	Fall and Winter '98 & '99	Fall '00
Tier 2	85/468 18.2%	28/215 10.7%
Tier 3	170/557 27.3%	44/219 20.1%

TABLE VIII
PROBATION RATES OF MINORITY AND INTERNATIONAL TIER 2 AND TIER 3 STUDENTS

	Minority Students		International Students	
	Fall/Winter 98/99	Fall 2000	Fall/Winter 98/99	Fall 2000
Tier 2	5/21 19.2%	3/14 21.4%	10/25 40%	0/18 0%
Tier 3	12/31 38.7%	3/10 30.0%	2/8 25%	0/3 0%

significant (p=0.093) while differences in probation rates for Tier 3 students (20.1% vs. 27.3%) were statistically significant (p=0.034). For minority students, differences in probation rates among Tier 2 and Tier 3 students were not significant. Differences in probation rates for international students were statistically significant (p<0.002).

Staying "On Track" to Graduation

With our new curriculum and our new calendar, we thought that it would also be helpful to examine whether or not students were more likely to stay "on track" to graduation. Historically, it has taken our engineering students 4.5 years to graduate, on average. One goal of our curricular changes was to improve the graduation rate such that more of our students would be able to graduate "on time"--in just four years of university study. Graduation rates for the students who began in the fall of 2000 will not be available for some time, however, by examining on track performance after one year of study, this may help us to determine if we are making progress towards this goal.

For this analysis, we selected a random sample of 100 students for each year from 1996-2000 and examined their transcripts. These students were those who began their studies in the fall of the respective year and who had declared some engineering discipline as a major. Entering class sizes for each of the years in question was around 700-800 students. Thus, our sample represents around 12-15% of the total population. Table IX includes the data regarding calcu-

lus progress during their first year for the students in each sample, and Table X contains similar data with regards to progress in science courses.

TABLE IX
CALCULUS PROGRESS FOR FIRST-YEAR ENGINEERING STUDENTS

	1996	1997	1998	1999	2000
No Calculus	11	13	18	17	14
Partial Year of Calculus	61	49	47	44	24
Full Year of Calculus or more	28	38	35	39	62

TABLE X
SCIENCE PROGRESS FOR FIRST-YEAR ENGINEERING STUDENTS

	1996	1997	1998	1999	2000
No Science	8	7	7	4	10
Partial Year of Science	44	46	40	65	32
Full Year of Science or more	48	47	53	31	58

During the 1999 transitional year, several engineering departments changed the way that they advised students which could account for the dramatic change in science progress during that year (they recommended that their students take only two quarters of science in their first year). If we define "on track" as one full year of calculus and one full year of science courses (the science courses could vary significantly by major prior to fall 2000), it seems that we have made a relatively large impact in calculus progress and a small impact in science progress through the curricular changes that we implemented. The gain in calculus progress is likely due to two factors: 1) a reduction in probation rates for Tier 2 and Tier 3 students, and 2) the implementation of the Calculus I/I+ courses by our mathematics department.

CONCLUSIONS

Despite student grumbling, it seems that cohort scheduling and changes instituted in mathematics courses have had a positive impact on student performance in calculus. Specifically, the following conclusions can be drawn:

- There was an improvement in calculus GPA for Tier 2 students as well as a higher occurrence of "A" grades when compared to historical data. There was also a lesser occurrence of probation part way through their first year on campus for these students.
- There was no change in the calculus GPA for tier 3 students, however, a much larger percentage of these students successfully made it through calculus in their first semester when compared to historical data. These students were also less likely to end up on probation either before or after their first calculus course.
- The impact of cohort scheduling/changes in math courses on international and minority students has been significant, and generally positive. This is particularly true for international students.
- Our curricular and programmatic changes have resulted in more students "on track" to graduation after their first year in engineering.

ACKNOWLEDGMENT

The authors would like to gratefully acknowledge the National Science Foundation for their support of this work through grant No. EEC-9872533. We would also like to thank Ford Motor Company and Caterpillar, Inc. for funds for classroom renovations that enabled us to incorporate technology in an active learning setting into our courses.

REFERENCES

[1] Al-Holou, Nizar, et al., "First Year Integrated Curricula Across Engineering Education Coalitions," *Proceedings, 1998 Frontiers in Education Conference*, IEEE, Tempe, Arizona, November1998.

[2] Pendergrass, N.A., et al, "Improving First-Year Engineering Education," *Journal of Engineering Education*, January 2001, pp. 33-41.

[3] Jacobson, Doug and Barb Licklider, "Freshman Year Learning Communities in a Computer Engineering Program," *ASEE/IEEE Frontiers in Education Conference*, October 2000, Kansas City, MO, pp. T2B-1-T2B-6.