2006-933: INTEGRATED PRE-FRESHMAN ENGINEERING AND PRECALCULUS MATHEMATICS

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Integrated Pre-Freshman Engineering and Precalculus Mathematics

Abstract

Engineering curricula share a reliance on mathematics as the prerequisites for nearly all science and engineering courses. As such, it's not surprising that student success in mathematics is highly correlated to retention of engineering students. As part of an effort to improve retention in engineering, a new course was offered to freshmen in the College of Engineering at Boise State University. This course, which incorporated many elements of our Introduction to Engineering course, was designed to be taken concurrently with the 5-credit Precalculus course which many of our students must pass before they can move on to Calculus I. In addition, the standard Introduction to Engineering course was modified to more directly support students concurrently enrolled in Calculus I. Preliminary results indicate that students who concurrently enroll in an engineering course along with the Precalculus or Calculus I achieve higher success rates in their math class.

1.0 Introduction

There are a variety of factors influencing student retention and success in engineering. One of these factors is strongly linked to mathematics education in both high school and in the freshman year.[1] In fact, success in the first semester mathematics class at Boise State University is the most effective predictor of freshman retention among Engineering majors. The odds of being retained increases by close to 50% for each letter grade increase in the first semester math class, according to an analysis by the university's Office of Institutional Assessment. Surprisingly, this correlation between performance in their first math class and retention overshadowed the relationship between student retention and the level of mathematics at which students began their studies. In other words, it mattered much more that students did well in their first math course, regardless of the level. Motivated by this situation and by the positive results of supporting math learning among freshman engineering students presented by Carpenter, et al.[2] a freshman precalculus engineering course, ENGR 110, was taught in fall 2005 at Boise State University geared specifically toward increasing student success in the Precalculus math class. Although offered previously as an ENGR 197 course,[3] this offering was substantially different in that the new course utilized a web-based tutorial program, ALEKS,[4] engineering modules and advising that included instruction in time-management principles as methods to increase student retention and reduce student attrition. This paper reports on the revised course organization of ENGR 110, its impact on student success in Precalculus, and on student perceptions of the course. Also reported are the effects of modifying the freshman engineering course (Introduction to Engineering, ENGR 120) taken in conjunction with Calculus I by including ALEKS as a major component of the course activities in the first ten weeks.

2.0 Description of Freshman Engineering Courses

In fall 2005, 371 students enrolled as freshmen in the College of Engineering at Boise State University in majors that included undeclared engineering, civil, electrical, materials science, mechanical, computer science and construction management. This paper presents results obtained from two subsets of these engineering students; those who enrolled in Precalculus (118 students), and those whi enrolled in Calculus I (94 students) These two groups constitute 57% of the freshmen engineering population, and are a critical group with regard to attrition in engineering. Of the engineering precalculus group, 17 enrolled in the pre-engineering course, ENGR 110 (Coreq: Precalculus), which was targeted toward helping students "survive" Precalculus. Student enrollment in the course was obtained through personal advising sessions with engineering faculty which took place in the freshman summer orientation programs for incoming students. Of the engineering Calculus I group, 31 were enrolled in ENGR 120, Introduction to Engineering (Prereq: Precalculus). ALEKS was extensively used in ENGR 120 in the first ten weeks of this course and students were required to work 4 hours per week on ALEKS. Time spent on this task as well as progress on ALEKS was monitored by the instructors and points were awarded weekly.

ENGR 110 met for approximately 5.5 hours weekly, 3.6 of which were devoted all semester long to supplemental math instruction, primarily through the use of a web-based tutorial program, ALEKS (Assessment and LEarning in Knowledge Spaces). This web-based program was developed and implemented as an assessment and teaching system based on Knowledge Space Theory; see for example, Falmagne, et al.[5] Developed at the University of California, Irvine and supported initially by the National Science Foundation, ALEKS offers individualized mathematics tutoring that identifies what the individual student already knows, via assessment technology, and what is ready to be learned. Based on the results obtained from Carpenter et al.,[2] students were given the goal of at 3 hours on ALEKS per week while showing at least 6% progress each week. The requirement of weekly progress precludes students logging into ALEKS and hitting the keyboard now and again, without putting in real effort.

The remaining class time in ENGR 110, approximately 2 hours per week, was spent on engineering laboratories, described further below. Other relevant components of the course included time management skills; a one hour in-class session led by a supplemental instruction student tutors; a weekly log kept by students on time spent on homework; and, early in the semester, the use of class time to self-identify student enrollment in various math sections, with the goal of forming study groups.

Engineering laboratories in ENGR 110 included a variety of freshman level engineering laboratories, geared toward conveying that engineering is fun, promoting teamwork and building basic skill levels in laboratory report writing. One duplicative laboratory (i.e. also used in ENGR 120) was a four week component on MouseTrap Cars, culminating in a competition. Two new computer aided design labs were developed for ENGR 110 as a result of a survey given in class, where students were asked what they would like to learn. These labs used SolidWorks, a 3-D computer aided design package. Once a week, over the course of three weeks in ENGR 110, students were required to run through various SolidWorks tutorials and demonstrate what they learned. The selected tutorials were chosen to help demonstrate how to:

- Create a variety of parts
- Combine various parts into a single assembly file
- Check for interference between parts
- Use proper dimensioning techniques

After completing all necessary tutorials, students were required to select a product, consisting of three or more parts, and create 3-D CAD models of each part and an assembly of the entire product. Projects selected by students ranged from simple pictures and mechanical pencils to a initial concept for a shroud that was needed to encase a router at a student's place of employment. These SolidWorks projects were very favorably received by students. A second, three-week laboratory on electrical circuits was also developed; this particular segment received a level of criticism from the students due to the write-up for the exercise not being clear enough on how to construct the various circuits. This will be improved in subsequent offerings.

Information was gathered on student perceptions of the new pre-engineering class, ENGR 110 as well as the effectiveness of using ALEKS as a supplemental math instruction tool. In addition, the following three metrics were used to assess effectiveness: (1) The grade the student earned in the Precalculus or Calculus I course, with success being defined as a grade of C or better. (2) Student scores on the COMPASS mathematics placement test. This is the test used to determine the appropriate beginning math course for incoming students. Students took the test prior to the semester (or during the first week) and again at the end of the semester. (3) The assessment reports available to instructors through ALEKS.

3.0 Results

The results obtained in this study are presented in the following five sections: Grades earned in Precalculus (taken with ENGR 110) and in Calculus (taken with ENGR 120); Statistical Analysis of Data; Attrition/Promotion in ENGR 110 and Attendance; ALEKS; and Student Perceptions.

3.1 Grades Earned in Precalculus and in Calculus I

Table 1 presents summary data obtained from all students enrolled in Precalculus and in Calculus I at Boise State University in fall, 2005. For each math class, we list the number of students enrolled, the distribution of A, B and C grades and the sum of those totals (defining success in that class). Those numbers are broken out by their participation in one of our target engineering classes (ENGR 110 or 120) and by whether or not they are majoring in engineering.

Figure 1 displays these data graphically as a percentage of each column. Note that students enrolled in ENGR 110 performed considerably better than the background population with a success rate that was 11 points higher, and 24% of these students earned an A in Precalculus. These students also outperformed the engineering students not enrolled in ENGR 110, although the gains were not as dramatic.

Similarly, Figure 2 displays the corresponding data for students enrolled in Calculus I. Again, students participating in our course performed dramatically better than their counterparts.

Interestingly, the engineering students not enrolled in ENGR 120 performed at a level that was lower than the background population, a reversal of the trend seen in Figure 1.

Table 1: Enrollment and Grades in Precalculus and Calculus I Fall, 2005

	Precalculus-All	Engineering students in ENGR 110	Engineering students not in ENGR 110	Non-engineering Majors
Total Students	326	17	104	205
A	36	4	15	17
B	50	3	13	34
C	63	3	26	34
A, B or C grade	149	10	54	85
	Calculus I - All	**Engineering students in ENGR 120**	**Engineering students not in ENGR 120**	**Non-engineering Majors**
Total Students	251	28	68	155
A	25	6	7	12
B	38	4	10	23
C	64	12	16	36
A, B or C grade	127	22	33	71

3.2 Statistical Analysis of Data

Success of the ALEKS participants compared to the other groups was assessed using two measures: mean grade and proportion passing the course. To assess the differences between mean grade for the three groups, an Analysis of Variance (ANOVA) was performed. Differences in the proportion passing the course with a "C" or better were assessed using Chi-square. An alpha level of 0.05 was used to assess statistical significance in both cases.

Statistical findings for Precalculus:
Although the performance of students by group suggests that having ALEKS supplemental instruction improves average grade and passing rate in Precalculus, the small number participating in ALEKS made it difficult to obtain statistical significance, see Table 2. Neither a comparison of the means ($F(2,323)=1.35$, $p=0.26$) nor a comparison of the proportions passing the course ($\chi^2=4.29$, $df=2$, $p=0.12$) resulted in statistical significance using an alpha level of 0.05. Comparison of the two groups of engineers also failed to reach significance.

Figure 1

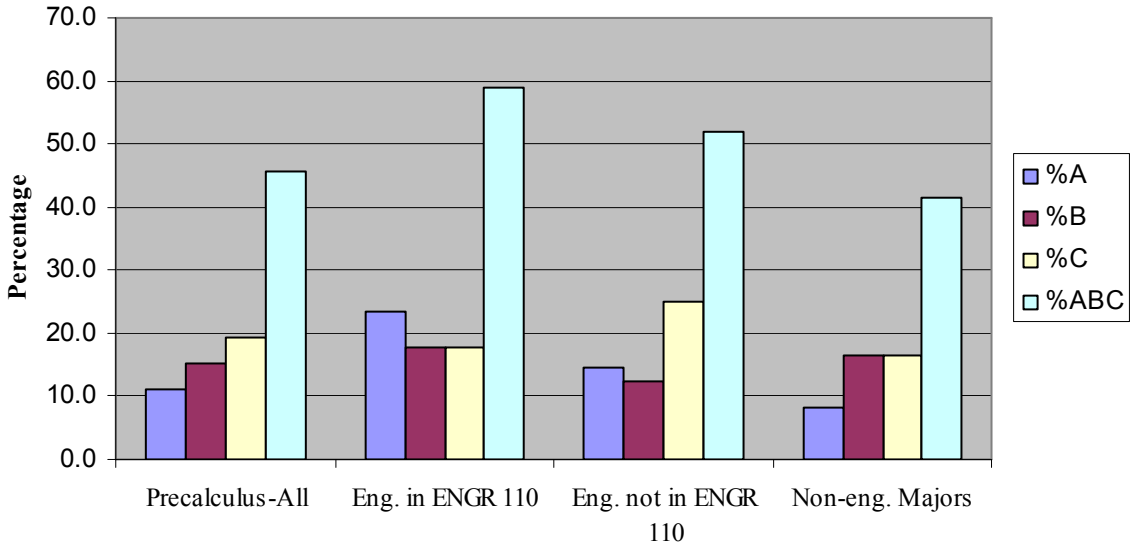

Figure 2

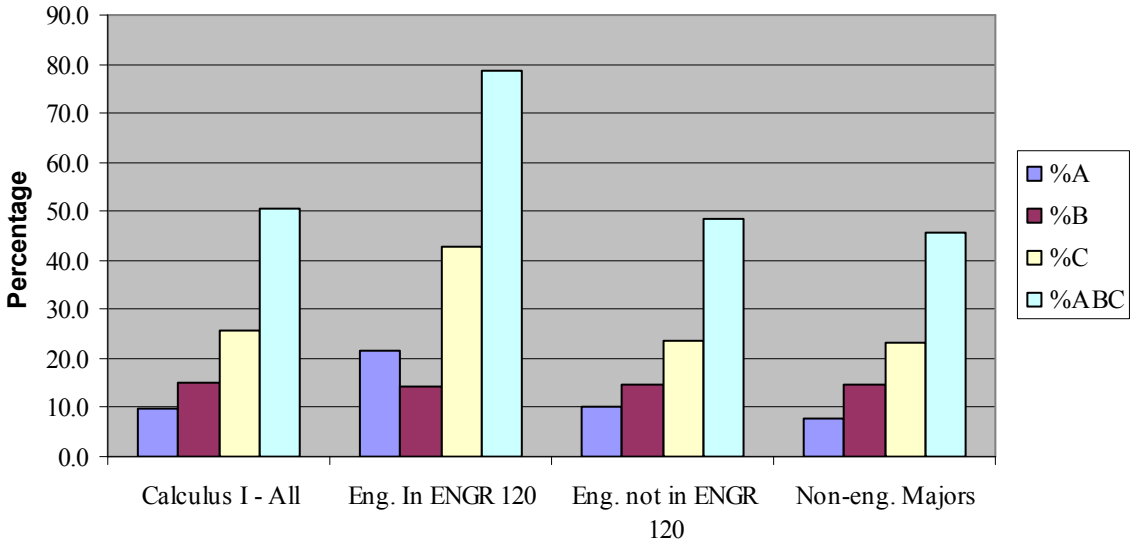

Table 2. Performance in Precalculus by Group

Group	Number in Group	Mean Grade	Standard Deviation	Percent with C or better
Engineering majors who also had ALEKS supplemental instruction	17	1.82	1.70	58.8%
Engineering majors without ALEKS supplemental instruction	104	1.50	1.50	51.9%
Non-engineering majors without ALEKS supplemental instruction	205	1.31	1.40	41.5%
Total Group	326	1.40	1.45	45.7%

Statistical findings for Calculus:
Again, although the data suggest that ALEKS supplemental instruction was effective, due to the small sample size we failed to reach statistical significance using an alpha level of 0.05 (Table 3). Neither a comparison of mean grades ($F(2,248)=2.12$, $p=0.12$) nor proportions passing the course (($\chi^2=4.09$, $df=2$, $p=0.13$) resulted in statistical significance. Comparison of the two groups of engineers also failed to reach significance.

Table 3. Performance in Calculus by Group

Group	Number in Group	Mean Grade	Standard Deviation	Percent with C or better
Engineering majors who also had ALEKS supplemental instruction	28	1.93	1.41	67.9%
Engineering majors without ALEKS supplemental instruction	68	1.47	1.40	50.0%
Non-engineering majors without ALEKS supplemental instruction	155	1.34	1.39	47.1%
Total Group	251	1.44	1.40	50.2%

In summary, although a trend is noted that appears to indicate that the ALEKS supplemental instruction is efficacious, a larger sample size is needed before concluding that this result is statistically significant.

3.3 Attrition/Promotion in ENGR 110; Attendance

Of the 17 students enrolled in Precalculus, 11 students were "successful," meaning that they qualified to take Calculus I, via either Precalculus grade (10 students), or via COMPASS result (9 students), see Table 4. Four students received an "A" grade, three, a "B," and three a "C." Student 7 received an "F", yet qualified for Calculus I via his COMPASS score. This student's college algebra and trigonometry scores, when compared with the other students, clearly show his ability in these subjects. When queried at the end of the semester about this disparity in performance, the student indicated that the underlying reason for the Precalculus grade, was:

> "I believe I had a semi-unfair instructor, I can see the reason why she graded and taught the way she did, I'm just not used to it, and I wasn't really expecting it either. I feel that I

understand everything that I was taught, I just had some trouble on the tests and I believe I am ready for Calculus. The thing that I wasn't used to, nor prepared for was that she graded for how I got my answers, not if the answer worked."

Two students who qualified for Calculus via grade of C or better in Precalculus, did not qualify via COMPASS scores, students 12 and 13. Of the six students that did not qualify for Calculus I, all received grades of F; only two of these took the second COMPASS placement exam and neither qualified. Thus, the nominal "success rate" of the students in the Precalculus engineering class, was 11/17, or 65%. The successful students are bolded in Table 4 below.

Table 4 Initial and final COMPASS scores, Precalculus math grades, and ALEKS data.

Student	COMPASS -- Initial				COMPASS -- Final				Final COMPASS Math Placement	Math Grade	ALEKS			
											Knowledge Assessment			
	Prealgebra	Algebra	College Algebra	Trig	Prealgebra	Algebra	College Algebra	Trig	Precalc (P) Calculus (C)		Initial	Final	Total Hours Spent	Hours per Week
1					87	69	55		P	F	7	38	32	2.4
2	85	47								F	18	27	10	0.7
3	90	67	51		89	79	54		P	F	13	37	37	1.9
4	93	80	28							F	12	43	32	2.1
5										F	9	32	25	2.8
6	89	71	58							F	11	34	42	3.1
7	**87**	**62**			**89**	**76**	**85**	**60**	**C**	**F**	**17**	**37**	**34**	**2.5**
8	76	64			61	93	55		P	C	13	38	49	3.2
9	88	63			99	94	74	47	P	A	14	78	83	6.1
10	**85**	**69**	**51**		**97**	**99**	**83**	**81**	**C**	**C**	**7**	**45**	**33**	**2.3**
11	**75**	**62**			**79**	**82**	**79**	**71**	**C**	**B**	**16**	**58**	**36**	**2.6**
12	**83**	**65**	**41**		**78**	**81**	**73**	**53**	**C**	**C**	**8**	**52**	**35**	**2.6**
13	**93**	**65**	**51**		**90**	**99**	**97**	**53**	**C**	**A**	**17**	**58**	**46**	**3.3**
14	**75**	**78**	**44**		**79**	**87**	**77**	**73**	**C**	**B**	**10**	**64**	**47**	**3.3**
15	**99**	**68**	**52**		**87**	**97**	**97**	**62**	**C**	**B**	**17**	**64**	**52**	**3.5**
16	**84**	**94**	**72**	**19**	**89**	**97**	**97**	**61**	**C**	**A**	**15**	**66**	**69**	**4.8**
17	**99**	**53**			**94**	**94**	**66**	**79**	**C**	**A**	**7**	**86**	**80**	**5.3**

The students that enrolled in ENGR 110 were required to take the COMPASS as part of their course requirements. Consequently, there were no COMPASS scores from the control group of students consisting of students enrolled in Math 147 but not enrolled in ENGR 110.
Although most of the unsuccessful students regularly attended the pre-engineering class, they became so "lost" in Precalculus that they stopped attending Precalculus. From information collected weekly on math class attendance, the time point where these students stopped attending class was week 5. Information was also gathered weekly on the amount of time that students

spent the previous week on math homework, not including ALEKS time. The average amount of time that the A students spent on Precalculus, was 15 hours per week. The students receiving a grade of B spent an average of 8.4 hours per week, and the C students, 7.3 hours per week. Students that failed fell into two categories, those that ceased doing any homework at all, and those that continued to do math homework. The three that continued to try, spent an average of 8 hours per week on homework; the three that ceased their efforts, spent an average of 1.5 hours per week on homework, with the majority of the effort occurring in the first four weeks.

3.4 ALEKS

For students who were successful in Precalculus, an average of 3.7 hours was spent per week making progress within the ALEKS modules, with the "A" students spending on average 4.9 hours/week; the "B" students spending 3.1 hours per week and the "C" students spending 2.7 hours per week. The five unsuccessful students spent on average, 2.2 hours per week. See Table 4.

All students received an initial assessment of their knowledge of Precalculus via ALEKS and the average of this value was determined to be 12.4% with a standard deviation of 3.9%. There was no correlation between the initial assessment score and student success. The average final assessment as determined by ALEKS for students successful in Precalculus was 58.7% of the subject matter with a standard deviation of 15.4%. Unsuccessful students received an average final assessment value of 35.2% with a standard deviation of 5.5%.

3.5 Student Perceptions

ENGR 110: An end of course survey was administered that queried student perceptions of the course. There were 17 responses collected.

- Students were asked whether enrolling in this course affected their grade or learning in precalculus. An affirmative response was obtained from 63% of students, and most of those responses indicated that ALEKS was the way in which the course impacted their grade or learning. A negative response was obtained from 37% of students with 67% of those negative responses being associated with various issues students experienced with the ALEKS software. When queried as to how to structure the course for future offerings, 56% recommended continuing to use ALEKS in a similar way, with the remainder recommending working math problems in class instead of using ALEKS.

- Only two students went to an extra math help session; both only went once.

- Questions related to the modules covered in the class devoted to engineering and advisement subjects revealed several trends. Students overwhelmingly agreed (82%) that the in-class assignment that was devoted to scheduling their class, work, homework and personal time should be repeated, even though only 23% reported that this assignment caused them to change their plan for how they spent their time that semester. A majority of students (76%) recommended repeating the use of SolidWorks for a couple of

laboratories, with the majority commenting that it was a fun break from math. The minority response indicated that it took time away from math.

- A variety of responses, with no majority trend, were obtained from the question, "What was the best part of taking this course?" Responses included: "SolidWorks, pizza, ALEKS, improvement in math, meeting other engineering students, mouse trap car." By contrast, when queried about the most annoying thing about taking the course, the majority response was ALEKS (57% of written responses).

- A clear trend emerged in 14 student responses as to what advice they would give to new students on how to succeed in Precalculus. This advice was to do your homework (11 responses) – "Always finish your homework," "Do all the homework assigned and do the practice problems the teacher assigns," "Do your homework as soon as possible after class," etc. Two students advised "Don't give up." One student advised to review a teacher's statistics before signing up.

ENGR 120: The requirement for ALEKS participation in ENGR 120 was met with mixed reviews:

- About 30% of the students were very enthusiastic in their reviews of ALEKS and asked if they could continue working after the requirement was finished. These students tended to be older students returning to school after several years.

- Approximately 35% did not have strong feelings either way about ALEKS but if pressed on their reaction indicated that it may have helped them in Calculus I.

- The remaining 35% felt strongly that ALEKS did not help and was a waste of their time. The majority of these students were further along in the math curriculum, enrolled in Calculus II or higher, leading to the conclusion that the use of ALEKS for this subset may be inappropriate.

- Uniformly, students felt that ALEKS was a terrific review and significantly improved their math performance.

4.0 Future Plans

As a result of the positive results obtained, the ENGR 110 course has been added to the Boise State University undergraduate catalog and will be offered again in fall 2006. Although taking this course does not count toward graduation, except as a free elective, it is believed that student enrollment will continue to occur as a result of advising during summer orientation. ALEKS will continue to be emphasized in ENGR 120; however, based on student responses, there will be a shift toward the first month of classes only, rather than all semester long. Also, students in more advanced mathematics courses (beyond Calculus I), will not be required to participate in ALEKS. The retention rate of students who enroll in ENGR 110 and in the revised version of ENGR 120 will be monitored, with particular attention to success in mathematics courses.

Another possible strategy the next time the course is offered would be to identify failing students after the first math exam (usually week 4), and to offer extra interventions or advise the student to transfer to a more appropriate (lower) level math course.

5.0 Acknowledgments

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