Persistence in Engineering: Does Initial Mathematics Course Matter?

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Abstract

This study is situated within a larger project that seeks to understand how students that start in precalculus and struggle in their math courses persist and complete an engineering degree program. The specific aims of this study are to determine 1) the extent to which students that start in precalculus persist in engineering after one year, 2) correlations between the grade in engineering students' first math course and/or the level of that course and persistence in engineering one year later, and 3) the relative number of students that graduated with an engineering degree who started in a non-college level (pass/fail) mathematics course.

Data were collected and analyzed from academic records for all first semester engineering students at a southern land grant university, including the mathematics course for which the students were registered that semester, their grade in that course, and their major at the end of the following fall semester. The results of the analysis showed that both the level and grade in students' first college mathematics course are significant predictors of retention in engineering: students starting out in a non-college level mathematics course and those making a D, F, or withdrawing from their first mathematics course are less likely to still be in an engineering program a year later than those that begin in a calculus course or those that made a C or better in their first mathematics course.

Additionally, our results showed that fewer than 12% of graduating engineers during a single semester at our institution started in a non-college level mathematics course. In contrast, nearly 40% of graduating engineering students entered the university with AP or dual enrollment credit for single variable calculus.

This quantitative study of trajectories of students who start out in non-college level mathematics was conducted to identify the subject(s) for a future qualitative study of the factors that contribute to students' persistence in engineering when they encounter difficulties in their college mathematics courses.

Introduction

At our institution, historical data shows that students who declare an engineering major and begin in precalculus as freshmen are unlikely to complete an engineering program. Most of these students will either leave the university or change majors, and will not complete their initial goal. For example, over a three year period, from 2003 to 2005, 141 engineering students at our university were in precalculus in the fall semesters, but only 68 of them were still in an engineering major just one year later. That is a retention rate of just over 46%. Of the 68 retained, 44 of them (67.69%; 31.2% of the original population of engineering students taking precalculus as their first mathematics course) finished precalculus with a passing grade. Based on this historical data, we hypothesized that both the final grade and course level for a student's first mathematics course at the university are significant in predicting retention in engineering.

Prior research at another land grant institution showed that the grade a student earns in his or her first college level mathematics course was highly significant in predicting persistence in engineering, while the mathematics course level they began in was not[1]. These researchers also found that retention for students starting in calculus was not statistically different from those that started in precalculus. Our study was inspired by this research to explore these trends at our institution. There is value in replicating studies, especially if done by independent researchers[2]. While this isn't an exact replication, we felt it was important to determine if results would be similar at our institution.

Research Methods

To meet our research aims, we conducted two quantitative studies. The first study examined academic records for first year students that declared engineering as their intended major to find how many persisted in engineering one year later and what factors significantly predicted persistence. The second study examined at what level students that graduated with an engineering degree began in their mathematics sequence.

Study One: Retention in Engineering One Year Later

For this study, to see what percentage of students were retained one year after starting at our university based on their first mathematics course, we collected data for all first year engineering students in Fall 2010 ($n = 865$). Transfer students and continuing students were not included in this study. The data were collected from the university's student information system and included their major in Fall 2010, the mathematics course they took that semester, their final grade in that course, gender, race, and declared major one year later. Students were considered retained if their major was still in an engineering discipline at the end of their third semester (one year after they completed their first semester at the university). Data was matched and collected using Panorama (a hybrid database/spreadsheet application), and then retention percentages were computed in Excel.

We chose to use data from the Fall 2010 cohort as it served the additional purpose of a retrospective study (see Study Two below) of the levels at which students graduating with engineering degrees began their mathematics course sequence. To confirm our findings from 2010, we expanded Study One to include the same data for all new freshman engineering students in Fall 2009, 2011, and 2012. We ran a chi-square test using the statistical software JMP to test if retention was the same from year to year for each course. Chi-square tests are appropriate when comparing proportions and testing for independence. Because retention was not found to be statistically different ($\alpha = 0.05$), we combined data for all four years to create a larger data set ($n = 4040$).

At our university, all incoming students take the Clemson Math Placement Test (CMPT). For the population of students in our study, the CMPT was offered online and consisted of 25 algebra and 25 precalculus questions. Students were required to take the test before registering for their first mathematics course. Based on their scores and AP/transfer credits, freshmen engineering majors were placed in either precalculus, long calculus, calculus I, calculus II or calculus III. For students seeking an engineering degree at our institution, precalculus is the lowest level math

course in which they can begin. It is a five hour pass/fail course with no prerequisites. Students scoring slightly higher on the CMPT but not high enough to be placed in calculus have the option to begin in "long calculus". Long calculus is a two semester sequence course, where the first semester is a four hour pass/fail course that spends approximately a third of the semester reviewing precalculus material. Calculus I material is introduced, and almost twice as much time is spent on each topic than in regular calculus I. The second semester is a four hour graded course that continues the calculus I material. Students passing both semesters of long calculus are given credit for calculus I. Students scoring high enough on the CMPT can be placed in calculus I. However, students may only start in calculus II or III if they have AP/transfer credit for the prerequisite course. Calculus I – III are all four hour graded courses. Precalculus and the first semester of long calculus are considered non-college level courses, because they are pass/fail and cannot satisfy a general education mathematics requirement.

To identify what factors are predictive of a student persisting in engineering, we used the statistical program SAS to run a stepwise logistic regression, with race, gender, grade in first mathematics course, and course level as potential predictor variables. While our other tests were run in JMP, we specifically chose SAS for the regression model as it does stepwise regression. We felt this was the best way to determine which variables should be left in the model. The default significance levels (0.05) for entry and stay were used.

Study Two: Where Graduating Engineers Began Mathematically

We wanted to determine the level at which the students began at our university in their mathematics courses. In our second study, we collected data for students that graduated in Spring 2014 with a degree in an engineering discipline ($n = 432$). We only included students that began as freshmen at our university, so no transfer students were included in our study. Our data included students' majors, as well as the level of the first mathematics courses they enrolled in at our institution. Given that relatively few students transfer into engineering from other non-STEM (science, technology, engineering, and mathematics) majors[3,4], we only included students that started in one of our mathematics courses required for STEM majors (those discussed in Study One).

To increase the size of our cohort, we collected the same data for graduating engineers in Spring 2013. We ran Fisher's exact tests to compare the enrollments in each course and found that there was not a statistical difference in course enrollment percentages for the two different years, allowing us to combine them to create a larger data set ($n = 814$).

Results

Study One: Retention in Engineering One Year Later

Table 1 includes retention rates in engineering for students starting in different mathematics courses (combined Fall 2009 – 2012 data). These were found to be statistically different based on results from the chi-square test. The percentage of engineering students starting in non-college level mathematics courses (precalculus and long calculus) is lower than those starting in one of the calculus courses (I – III). Also, the percentage of students leaving engineering is much higher

in those same courses than those starting in calculus. In fact, nearly half of the students starting in precalculus, and almost 40% of those starting in long calculus, left their intended majors within the first year.

Table 1: Retention of students in engineering one year after starting by initial course

Course	Enrollment	Retained in Engineering	Percent Retained
Precalculus	123	65	52.85
Long Calculus	574	362	63.07
Calculus I	1667	1311	78.64
Calculus II	681	581	85.32
Calculus III	995	896	90.05
Total	**4040**	**3215**	**79.58**

In the logistic regression model with grade, course, gender and race as predictor variables, and retention after one year as the response variable, grade and course were found significant, as well as gender, at the 0.05 significance level, and were retained in the model. This means that both grade and course significantly predict retention in engineering one year later, which supported our hypothesis and confirmed our earlier findings that students starting in the lower level courses were less likely to stay in engineering. Also, students earning lower grades in their first mathematics courses were less likely to stay in engineering majors, supporting findings from other studies[1,5]. Table 2 gives the estimates for the final model, which explains the log odds of students starting in any one course or a specific grade persisting in engineering compared to a reference level, while the other variables are kept constant. Log odds are determined by calculating $e^{Estimate}$. For example, for students starting in precalculus (Course – Precalculus), by computing $e^{-2.0265} = 0.132$, we find that the odds of a precalculus student being retained in engineering one year later is 13.2% of the odds for a student starting in calculus III (the reference level for course). In terms of gender, we found that women were less likely to be retained in engineering than men, with odds for a female persisting in engineering a year after her initial mathematics course was 72% of the odds for a male. Of the 4,040 students in our study, 3595 (89%) are white, which may be why race did not prove to be significant in our model.

Table 2: Logistic regression model for students persisting in engineering one year after beginning based on grade, course and gender. Each predictor variable has one degree of freedom (df=1).

Predictor Variables	Estimate	Standard Error
Intercept	1.3418	0.1807
Course – Precalculus	-2.0265	0.2739
Course – Long Calculus	-1.5967	0.2143
Course – Calculus I	-1.0537	0.1260
Course – Calculus II	-0.4045	0.1546
Grade – A	1.4914	0.1914
Grade – B	1.3151	0.1894
Grade – C	0.6959	0.1957
Grade – D	0.3919	0.2455
Grade – F	0.1231	0.2084
Grade – P	1.2672	0.2541
Gender – Female	-0.3140	0.0977

Table 3 shows retention in engineering based on grade received in first mathematics course for the four years combined. Not surprisingly, students that did well in their mathematics classes were more likely to stay in their engineering major. However, it is surprising that only 70% of those who received a grade of 'P' were retained. This means that 30% of students who successfully completed the non-college level course decided to change majors or leave the university. The percentage of these students is only slightly lower than the students that withdrew from the course that semester (33%).

Table 3: Retention of students in engineering one year after starting by grade in initial mathematics course

Grade	Retained	Not Retained	Total	Percent Retained
A	1022	133	1155	88.48
B	936	149	1085	86.27
C	442	118	560	78.93
D	121	42	163	74.23
F	240	183	423	56.74
P	326	138	464	70.26
W	128	62	190	67.37
Total	**3215**	**825**	**4040**	**79.58**

Study Two: Where Graduating Engineers Began Mathematically

Figure 1 shows the percentage of students starting in a specific mathematics course that graduated with an engineering degree from our institution in Spring 2013 or 2014.

There are very few students graduating with an engineering degree that begin in our non-college level mathematics courses (precalculus or long calculus). The majority of students graduating with a degree in engineering started in one of the calculus courses. Many of those students entered the university with AP credits and were able to start in calculus II or III. The relatively high number of students that entered with AP credits and chose engineering as their major agrees with the finding that students taking AP calculus in high school (whether or not they completed the AP exam), are more likely to choose a STEM major in college over the other disciplines, with engineering being just as popular as mathematics and the sciences combined[6].

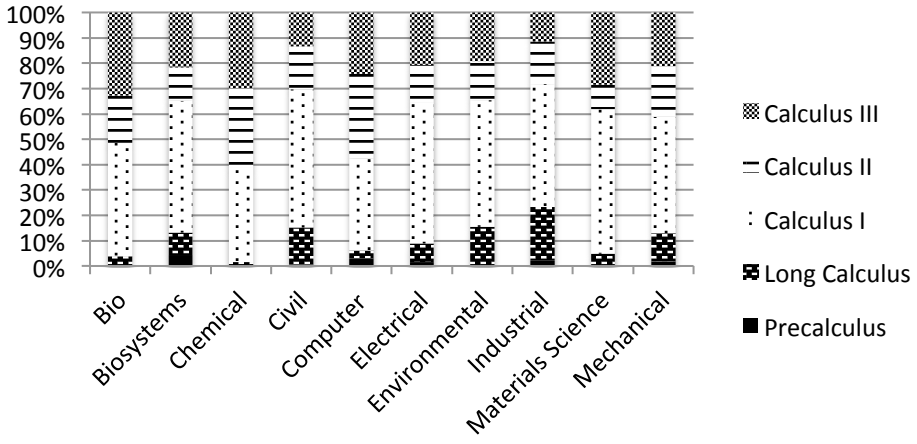

Figure 1: Percentage of students starting in different mathematics courses who graduated in Spring 2013 or 2014 by Major

Discussion

Based on four years of data, we have shown that the percentage of students retained in engineering one year later is significantly lower for those that begin in non-college level mathematics. Nearly 50% of those starting in precalculus, and nearly 40% of those starting in long calculus, either change majors or leave the university, compared to 21%, 15%, and 10% that begin in calculus I, II and III respectively. These values are at the same level as attrition rates for engineering majors over an entire college career, which are reported to be between 40 and 50 percent[3,5,7,8].

At our university, students are not eligible to take introductory engineering courses if they start in precalculus. This adds another obstacle for students that are already starting behind in mathematics. Burtner found that a student's confidence in their college level mathematics ability significantly predicted persistence in engineering[9]. If students are getting the message that their mathematics skills are too weak to take an engineering course in their first semester, many of them may choose to leave engineering within their first year.

By running a logistic regression model on the four year data set, we showed that not only does the grade earned in a student's first mathematics course significantly predict retention in engineering one year later, but so does the level of that first math course, as well as gender. While gender isn't the focus of this study, it is well known that women are not well-represented in engineering disciplines[3,4,8,10]; identifying ways to increase the level of their first mathematics course as well as their performance in that class may help to address this disparity.

In our second study, we showed that very few students that graduate with engineering degrees start in a non-college level mathematics courses. However, based on our data it did appear that there were certain engineering majors that could be more attainable than others for those students, specifically biosystems, civil, environmental, industrial, and mechanical engineering. While our first study showed that almost half of the students starting in the lower level courses leave the major (or university) within the first year, our second study showed a pattern that suggests that very few of those that were still in engineering a year later would successfully complete an engineering degree. It is widely understood that mathematics knowledge, skills and ability (KSA) are important to being successful in engineering education[4,11–13]; students who are lacking mathematics KSA are starting out at a deficit in non-college mathematics courses before they even begin their intended engineering courses.

One limitation of this study is that precalculus and long calculus are pass/fail courses, whereas calculus I – III are letter grade courses. When we used grade as a predictor in the regression model, we kept the pass/fail courses as P's and F's, and the other courses as letter grades. It is possible that if they were on the same scale, the results may have been different. However, to test this on a subpopulation in our cohort, for Fall 2010 we were able to obtain final numeric grades for students in precalculus and long calculus, which we converted to A, B, C, D, or F. When the regression model was run for just Fall 2010 data using letter grades for all courses, both grade and course level were still significant in predicting retention in engineering one year later. Because we did not have access to numerical grades for all courses, it is not possible to compare average grades for each level of mathematics course. Thus we could not determine if, for

example, students in higher level courses earn higher grades, or if grades are evenly distributed across all levels. At institutions that record numeric grades, this would be an interesting area for future studies.

Another limitation of this study is that we did not include grade point average (GPA) in our analysis. Our population is incoming students, and as such they do not have a GPA when they start their mathematics course sequence. However, GPA after their first year in their engineering programs may have an effect on whether or not they choose to stay in engineering. Future versions of our logistic regression model should include GPA one year later as a possible factor in retention in engineering.

As stated earlier, the research for this paper was inspired by research done at another institution[1]. One of the differences between their institution and ours, is that they offer non-credit bearing mathematics courses. Students that aren't ready for precalculus would take one of their developmental algebra courses as a prerequisite. Our university does not offer such courses. Differences in course offerings could explain why our results did not match those at the other institution, and why they may be different for other institutions. If a student is not ready for precalculus and the university does not have a lower level course for them to take, this could affect retention. Another difference between our courses and theirs is that our non-college level mathematics courses are graded pass/fail, while the students in their lower level courses, including precalculus, appear to be given letter grades. It is possible students treat a course differently depending on how the course is being graded. If a student feels there is less pressure in a pass/fail course, they may not put as much effort into it, and thus may find themselves failing after it is too late to catch up, or they may only do enough to pass, not fully grasp the material, and then find themselves struggling in their subsequent mathematics courses. Both of these scenarios would affect retention.

Conclusions and Future Work

It is clear based on our research that students starting in non-college level mathematics are significantly less likely to graduate with their intended engineering degree than those that begin in a calculus course. To improve retention in engineering, further qualitative studies are needed to understand what barriers may exist for the students who aren't able to make it through engineering programs. The focus of this study is not on identifying ways to improve retention in engineering; however we seek to inform practice through results from this and future studies. We also need to understand factors that contribute to students' success in completing engineering degrees for those who start in non-college level mathematics. To that end, we will be conducting a case study of one or more of the six students that began in precalculus as engineering majors in Fall 2010 and are close to successfully completing engineering degrees. We will do interviews with these students and others that they identify as being influential in their success in completing their degree program. We will examine details about the curricula, other programs or resources that may have contributed to their success. Results from this case study will provide information that will benefit future students wanting to major in engineering, but who lack the mathematical background needed to start in a college level mathematics course. Additional work is underway in our research group that incorporates effects of self-efficacy and grit on students' persistence in engineering when faced with struggles in mathematics courses.

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