The Effects of Calculus I on Engineering Student Persistence

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I have a B.S. in civil engineering and a M.S. in structural engineering from Arizona State University. After graduating, I became a lecturer at ASU in civil engineering. During my time teaching I really became interested in engineering education and knew I wanted to pursue a graduate degree in that field. After moving to Utah and finding the program at Utah State University, I have really enjoyed diving in to the education world. I am most interested in the sophomore level courses that engineering students typically take and how changes in those courses can impact student learning and retention.

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Abstract

The number of students that start in engineering and persist to graduation with an engineering degree is continually declining with the attrition rate currently around 50%. This concern with engineering student retention has pointed to many issues including the early math requirements, specifically, Calculus I. Calculus I has often been referred to as a "bottle-neck" course for any engineering degree program, which implies that if a student can successfully complete this course then they are more likely to persist in the degree program. This study uses a longitudinal data set to determine how grades received in Calculus I along with other pre-college and demographic variables can predict persistence of engineering students. In many cases, this math course is taken prior to any technical engineering course, and this study shows how impactful the academic result of this course is for an engineering student. The results indicate the student outcomes after taking Calculus I, the grade distribution of students in the course, and a predictive model of persistence. The model considers the grade the student received in Calculus I, whether the student chose to retake the course, and other predictive variables to determine which students are more likely to persist in engineering or leave the engineering degree program.

Introduction

In the nation, the engineering retention rate is consistently reported to be below the national average for higher education retention at around 50 percent [1] - [6]. This low retention number is placing a growing demand on the higher education system to keep and produce more engineers [7] - [9]. There are numerous reasons students leave engineering that range from student issues to institutional issues, but one of the leading causes has been attributed to the coursework that engineering students are required to take early on in their program [3], [10] - [12]. These early courses include a series of math courses typically made up of 2 or 3 calculus courses depending on engineering degree type, a linear algebra course, a differential equations course, and a series of science courses.

Calculus I is required for all engineering degrees. Engineering students typically have to take the course their first or second semester upon entrance to college in order to graduate with an engineering degree in four years. The literature has classified this course as a barrier course for many engineering students implying that it is one of the major stopping points where students leave the major [3], [13], [14]. Calculus I is often taken prior to any theoretical engineering curriculum, so there is no context for the students to apply the concepts they are learning [3], [9], [11], [15] - [17]. Additionally, at many institutions Calculus I is offered through the math department resulting in an even further separation early on for engineering students from their chosen program of study [18]. All of these issues have helped create the retention crisis in engineering [19]. However, in contrast, if an engineering student can successfully complete their prerequisite math courses, then they have a much higher likelihood that they will graduate in engineering [11], [16], [19].

This growing concern for engineering retention has led to a focus on finding ways to predict performance in these prerequisite math courses to identify the students that are at-risk of failing and dropping out. These models use pre-college variables like SAT/ACT score, high school GPA, and math placement score [20] - [22]. Another focus on this topic has been the use of student performance in these math courses to determine how they affect engineering retention longterm [4], [11], [16]. The purpose of this study is to combine both the predicting variables and Calculus I performance variables to model engineering persistence for different student groups.

The university that the data was collected from is an R2: Doctoral University that offers seven ABET accredited engineering bachelor degree programs. Each engineering program has a pre-professional component that students must complete during their first two years at the university. In order to stay on track and be accepted to the professional engineering program their 5th semester, the students must take Calculus I during their first semester. A student must meet one of the following requirements to take Calculus I upon entrance to the university: Math ACT score of 27 or higher, Math SAT score of 620 or higher, completed college level algebra and trigonometry with a grade of C- or better, AP Calculus AB score of 3 or higher, or a high enough score on the Math Placement Exam administered by the math department. Calculus I is offered through the math department and taught by a constant rotation of instructors. For any one semester there may be up to 6 different instructors assigned to the different sections, but the students do not know who their instructor will be until the course begins. Within the last 4 years the math department has created some Calculus I sections that have 2 lectures a week and 2 recitations a week, but prior to that the sections were all offered as 4-day a week lecture courses with 100-300 students registered in each section. Students also have the option to take a broadcast section of the course or an online section, but there is only one offering of these sections a semester. Due to the vast number of instructors and wide variety of teaching methods that have been used for Calculus I over the 13-year period of this study, the authors did not factor in these differences because the populations were very small for some sections.

Methods

A quantitative analysis involving both descriptive and inferential statistics was used to determine how academic performance in Calculus I is correlated with persistence in an engineering degree program. The student data used was extracted from the Banner system at the university through partnership with the Registrar's Office. Banner is a large software application created by Ellucian that contains a large database of student records including transcripts and all other relevant data. The analyses performed for this study were done using the SAS System®.

The population that was selected for this study consisted of all declared engineering students that took Calculus I at a major research university in the Rocky Mountain region between Fall 2005 and Spring 2018. There were 3,927 student records within this 13-year period that were enrolled in Calculus I at least one time at the university of interest as a declared engineering major. The data does not consider any engineering student that may have come to the university with their Calculus I requirement already fulfilled through Advanced Placement (AP) credit or transfer credit from another university.

This population was then classified by two descriptive categorizations. The first categorization indicates where the students ended up following their enrollment in Calculus I, and the second categorization provides the grade distribution received by the students from their first time taking Calculus I. These categorizations help represent the population of students that were used to create a logistic regression model to determine the significant factors that affect persistence in engineering. Once the population was described, two logistic regression models were created for two different populations of interest. The first population group contains all students in the data set and groups them into persisters and leavers. The persisters are the students that are still registered or have graduated as engineering majors. The leavers in this group include all other students in the 13-year data set. The second population group is the graduated student group which contains only students, initially declared as engineering majors, that graduated from the university in engineering or another discipline. This second population also included persisters, the students that graduated with an engineering degree, and leavers, the students that graduated from the university with a non-engineering degree. The distribution of the population used within this study is provided in Table 1. There is an additional row in the table to look at retakers, which are students that took Calculus I again at least one time. Due to the significant impact of retaking this course on a student's schedule, the authors recognized this group as an important sub-group of students to investigate in this study. It is also important to note that there was a large amount of missing data for certain independent variables used in the study. As a result, the number of participants used in each analysis may differ from the total numbers reported below and will be listed for each section.

Table 1: Student demographic breakdown

	Total	All Persisters (% of total)	All Leavers (% of total)	Graduated Persisters (% of total)	Graduated Leavers (% of total)
Male	3432 (87%)	1777 (89%)	1655 (86%)	803 (90%)	395 (81%)
Female	495 (13%)	229 (11%)	266 (14%)	85 (10%)	90 (19%)
Total Students (Male + Female)	3927	2006	1921	888	485
Retaker*	605 (15%)	267 (13%)	338 (18%)	121 (14%)	88 (18%)

*Retaker is not part of the summation for total students

The independent variables that were considered in this study are described in Table 2. The Pearson Correlation Coefficients were determined for the variables Calculus I grade and ACT Score compared to the other independent variables used in the logistic regression models. This comparison determined that there was no auto-correlation or confounding of these variables, allowing all variables to be available for the model.

Table 2: List of Independent Variables

Independent Variable	Variable Type	Variable Range
Calculus I Grade	Continuous variable	Values range from 0.0-4.0, including +/- grades
Retaker	Categorical variable	Coded as 1 or 0 (1=student has taken Calculus I more than one time)
Gender	Categorical variable	Coded as 1 or 0 (1=female)
Admission Index	Continuous variable	71-142 (computed using ACT Score, HS GPA, and other admission factors)
HS GPA	Continuous variable	1.4-4.0
ACT Score	Continuous variable	11-35
ACT Math Score	Continuous variable	14-36

The use of a logistic regression analysis was chosen based on the nature of the dependent variable, i.e. persisted in engineering, or not. The independent variables were chosen based on the purpose of this study or the common use of the variable in the literature. All independent variables were available for selection in the regression analysis, but the final variables in the model were selected in a stepwise procedure with α set at 0.05. The stepwise selection process continued until there was no significant change in the model due to adding additional variables. The statistically significant change in the χ^2 for each additional variable was measured to determine the fit of the model. The results included parameter estimates for each variable to build the predictive model. The Odds Ratio for each variable is also reported which represents the multiplicative change in the odds of persistence for each 1 unit change in that variable while holding all other independent variables constant.

Results

For each analysis procedure, the population used was a subset of the complete data set. Further reduction of the data may have occurred due to missing data for certain variables, or the classification of student type that was of interest for a specific test. The population used for each procedure is described with each test. The total number of students included in that analysis is also listed.

Figure 1 graphically represents the breakdown for student majors following Calculus I. Table 3 contains the numbers that are represented in Figure 1. The three populations represented include the entire population from the data set of 3,927 students, the graduated group of students, and students that retook the course. There are three major sub-groups of student outcomes: 1) Engineering students, those that are still registered or have graduated in engineering (considered persisters), 2) non-registered Engineering students, students that have since left the institution with their last reported major being in engineering (considered leavers), and 3) other majors, students that have switched their major from engineering as categorized by the different colleges at the institution that students have switched to (considered leavers).

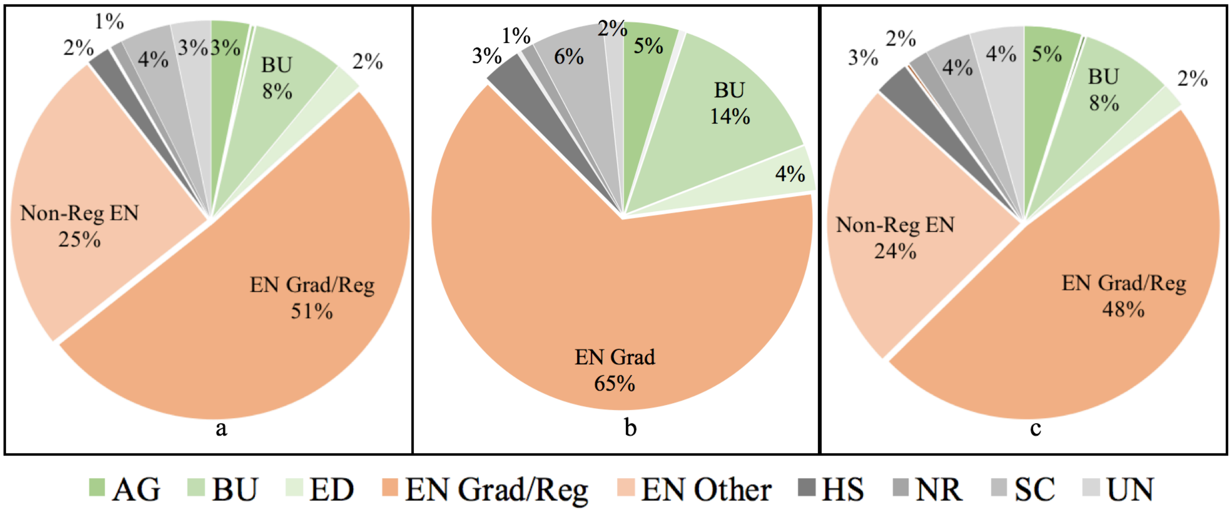

Figure 1: Student majors after enrollment in Calculus I for (a) all students N=3927, (b) graduated students N=1373, and (c) retakers N=605

Table 3: Student majors following Calculus I course

College	All students	Graduated students	Students who retook Calculus I
Engineering (EN Grad/Reg)	2006	888	290
Non-registered Engineering (Non-Reg EN)	988	-	146
Agriculture (AG)	125	64	29
Arts (AR)	16	7	2
Business (BU)	291	191	46
Education (ED)	90	52	12
Human Services (HS)	77	45	18
Humanities (HU)	7	5	2
Natural Resources (NR)	37	15	10
Science (SC)	162	83	23
Undeclared (UN)	128	23	27
Total Number of Students	**3927**	**1373**	**605**

The inferential statistical analyses included a *t*-test and two logistic regression models created for both groups of students: the graduates and all students. The mean grade received for each group in Calculus I was used in a *t*-test to determine if there was a significant difference between the persisters and leavers of each group. The grade for the course was reported on a 4.0 scale, where a grade of F=0.0. For the group of graduated students this test included 871 students that graduated in engineering and 464 students that graduated in another major. For the all students group these respective counts were 1,903 students that are registered or graduated engineering majors and 720 students that are registered or graduated in another major. The students that are reported as absent or not currently registered at the university were not included in this *t*-test comparison. There was found to be a significant difference (α set at 0.05) for the mean grade received in both groups, where the mean grade is higher for the persisters than the leavers.

Table 4: Effect of Calculus I Grade on Persisting in Engineering

Population	N	Mean grade received	Significant
Graduated Persisters	871	3.00	Yes <0.0001
Graduated Leavers	464	2.31	
All Persisters	1903	2.88	Yes <0.0001
All Leavers	720	2.32	

The actual grade breakdown received by the students during their first time taking Calculus I are categorized in the following figure.

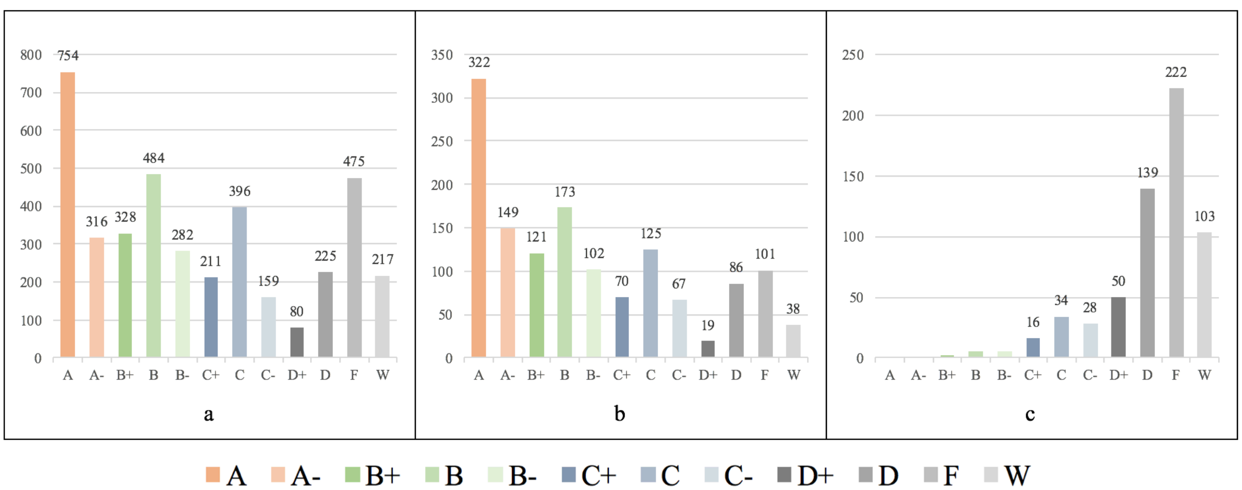

Figure 2: Grade breakdown for (a) all students N=3927, (b) graduated students N=1373, and (c) retakers N=605

A logistic regression was run for both populations of students. All independent variables listed in Table 2 were entered into both models, but only the significant variables were retained by the stepwise selection process. The population group that included all students had a total of 2,805 observations that had complete data for all variables included in the model. This includes 1,447 graduated or currently registered engineering students and 1,358 other students (including graduated and registered students in all other majors and students who were last reported in engineering but are not currently registered at the university). The model selected after the stepwise process for all students included only four of the independent variables and accounts for 67% of the variation in the data.

Table 6: Logistic Regression Model Coefficients for Predicting Engineering Persistence for All Students

Variable	Estimate	Standard Error	Pr > ChiSq	Odds Ratio Point Estimate
Constant	0.547	0.306	0.074	-
Calculus I Grade	0.631	0.041	<0.0001	1.880
Retaker (N reference)	-0.931	0.142	<0.0001	0.394
Gender (F Reference)	-0.523	0.115	<0.0001	0.593
ACT Math	-0.045	0.012	0.0001	0.956

The logistic regression model for the graduated student population includes 914 observations that had complete data for all variables in the model, where 572 are engineering graduates and 342 are graduates in other majors. The model selected after the stepwise process for the students that graduated also included only four of the independent variables and is listed in the table below. This model accounts for 70% of the variation in the data.

Table 7: Logistic Regression Model Coefficients for Predicting Engineering Persistence for Graduates

Variable	Estimate	Standard Error	Pr > ChiSq	Odds Ratio Point Estimate
Constant	2.552	0.864	0.003	-
Calculus I Grade	0.744	0.084	<0.0001	2.104
Gender (F reference)	-0.929	0.200	<0.0001	0.395
Retaker (N reference)	-0.938	0.263	0.0004	0.392
HS GPA	-0.828	0.247	0.0008	0.437

Discussion

The authors have evaluated student performance in Calculus I, where students end up after the course, and the creation of a model to predict persistence in an engineering degree program. The first part of the analysis confirms the 50% retention rate that is often reported in literature. Of the 50% of students that leave the engineering program, about half switch their major and the other half leave the university altogether. It should be a major concern of the university and the College of Engineering that 25% of the students that start in engineering will not end up continuing on in their education. The mean grade comparison indicates that engineering students typically perform better in math. This is not a surprising result, but persisting engineering students average a grade of a B in Calculus I, while leavers average a grade of C+. It can be speculated that a poor grade in Calculus I does not properly prepare students for the following math courses or engineering courses, causing students to leave the major. The grade breakdown figures show that the majority of students who graduate from the university typically received a higher grade in Calculus I even if they did not continue on in engineering. This is contrasted with the large amount of poor grades that the retakers had; however, 48% of these students were successful at retaking the course to receive a higher grade and move on in engineering.

The two models that were selected for this study include the same explanatory variables with the exception of the fourth variable. Both models found that Calculus I grade was the most significant factor in predicting persistence in engineering. The model for all students resulted in finding that for every letter grade increase in a student's Calculus I grade, the likelihood of the student to persist in engineering increases 1.88 times as disclosed by the odds ratio. Similarly, in the second model for every letter grade increase in a student's Calculus I grade the likelihood of graduating in engineering increases 2.1 times. Neither model included the admission index or total ACT score. The admission index is correlated with a student's total ACT score based on the calculation of that metric, but this finding confirms that math readiness is more important for persistence in engineering over other types of standardized measures [8].

The major variable difference between the two models was the fourth variable of significance for each. The model for all students had ACT Math as a significant predictor for engineering retention, where the model for graduated students included HS GPA as the final significant predictor for engineering graduation. The inclusion of HS GPA for the model of graduated students represents that this variable, that represents a student's cumulative high school grade experience, provides better predictability for graduation than standardized math scores. However, for the model with all students, many of the students are still at the university or have left the university prior to graduation, showing that ACT Math score is a better predictor for persistence for students earlier on in their college career.

Implications

Evidence is presented of the over-arching retention problem in engineering colleges, along with demonstrating that the largest loss of students is not to other majors, but to drop outs. The understanding that a student is likely to leave a university altogether when deciding to leave engineering presents a major concern for both the university and the College of Engineering. The authors do not claim that Calculus I is the point when these students leave engineering, but there is a significant loss of students happening between this course and graduation. The results also indicate that using the math criteria to predict calculus readiness may be useful, but actually was not a significant predictor for graduation. A student's high school performance may better indicate college performance in the long term. The models created provide a way to predict student persistence in engineering after a student completes Calculus I. This can offer a College of Engineering the ability to predict better which students are likely to be at-risk based on their performance in Calculus I. By using this type of data analytics advisors and faculty will be able to determine at-risk students and offer an intervention before a student decides to leave engineering.

Future Research

A preliminary quantitative analysis of a larger mixed method study has been presented. It was important to fully understand the numerical significance of the impacts of Calculus I, but these results only capture the formal academic performance of each student. There is a significant amount to be learned about the actual student experience in this course that leads to persistence. The next part of the study includes interviewing students about their social and academic experiences in Calculus I and how those experiences influence their decision to remain in engineering or leave engineering. This qualitative part will provide the student perspective on Calculus I to help answer the question on whether that course really is a barrier course and offer insight to help inform curricular change to better help students persist through the early math series. The combination of the data analysis and student experience will provide recommendations to address the major engineering retention issue that happens during a student's first two years.

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