Calculus eligibility as an at-risk predictor for degree completion in undergraduate engineering

Abstract
Academic readiness and its association with retention and success in engineering has been an ongoing topic of discussion in higher education. These discussions largely stem from the problematic persistence rates that many colleges and schools of engineering encounter. The ability to retain students in engineering until degree completion has a large research base, although, studies over time report a variety of factors that contribute to a student's success in engineering. Many address the entry point or readiness for university mathematics courses as the critical variable, however, few rely on empirical evidences. This study specifically examines engineering degree completion of calculus eligible students compared to non-eligible calculus students upon acceptance into a College of Engineering as a first-semester freshman. A 10-year span of University student engineering admission and completion data was accessed and analyzed in efforts to provide distinguishing qualities in student preparedness as they pertain to calculus eligibility as a differentiator. The results of this study show a statistically significant difference in the rate of degree completion for these two groups of students. This paper discusses the methodology and results for how being calculus eligible as the first math course taken in an engineering program impacts a student's ability to complete the engineering degree.

Keywords: first-year engineering, at-risk students, calculus readiness, academic success, academic retention, degree completion

Introduction

Retention and success factors are at the foreground of PK-20 educational research. Specifically, experiences [1], opportunities [2], and proficiencies [3], [4] that enhance the prospect of educational and ultimately career success for learners is of high attention [5]. According to Levin and Wyckoff [6], [7], "Students are more likely to perform well academically and make sound educational decisions when they understand how their interests and abilities mesh with the characteristics of their chosen fields of study." Many factors, both academic and non-academic, contribute to the successful completion of a college degree. There is a broad research base that has tried to determine the factors and indicators that lead to post-secondary academic success. Many studies have been conducted to try and determine the factors that may lead to more success in graduating from a university [6-10]. Whether or not a student completes a university degree, particularly on-time degree completion, has significant impact on student and university resources, such as but not limited to money, time, faculty investment, and impacts of student advising. Research tries to determine these factors so that universities can make better use of these resources and determine better means for graduating students. From the student perspective, a study conducted by Meyer and Marx [11] identified that "common themes of non-persisting engineering undergraduates included individual factors (such as poor performance, feeling unprepared for demands of the engineering program, difficulty fitting into engineering) and institutional factors (such as disappointment with engineering advising)".

There is broad teacher and learner research for developing models in determining student retention factors. This research indicates that both academic and non-academic factors determine

a student's success in engineering. One study by Levin and Wyckoff [6] reported a model that contained both intellective and non-intellective factors as a means of predicting a student's overall grade point average and ability to persist in an engineering program. It was determined that student success is not dependent on academics only, but included a variety of academic and affective factors. Some of the non-academic factors that have been studied include gender, perception of content area, attitudes, confidence, pre-college experiences, self-efficacy, and career awareness in the field [6-9], [12], [13]. In regard to academic factors that determine a student's success in degree completion, some of the more common factors considered in the research on student retention include, but are not limited to, high school GPA, SAT and ACT scores, college GPA, as well as specific grades in individual courses [9], [10].

Engineering

There are a relatively low number of students who declare an engineering major as a freshman who successfully graduate with an engineering degree [5], [10], [14]. In an attempt to address the issue of student retention, research on factors that determine general academic success has also been conducted [15]. Research on undergraduate engineering retention focuses mainly on high school and mathematical achievement, primarily high school GPA, SAT math, and ACT math [16], [17].

Mathematical computation ability has become one of the implied criteria for a student's success in degree completion for an engineering program. An anecdotal observation has been that lack of student success in first-year mathematics courses is the primary reason for the attrition in university engineering programs [6], [18-22]. Levin and Wyckoff [6] determined that computational ability is a strong predictor of engineering success, although this research included computational ability within a larger predictive model and did not single out mathematics as a single predictor. By observing the end of course grades in first semester math courses, Budny, LeBold, & Bjedov [23] imply the higher the grade the more likelihood of retention in engineering. However, there is very little empirical evidence to show that mathematical success as a freshman engineering student directly correlates to completion of an engineering degree; and very few studies single out first-year mathematics course success as a predictive factor.

Calculus is typically required for students choosing to enter an engineering field [24]. This course is usually indicated on the suggested plan of study as being required for first semester freshman. Therefore, due to the implications of not being successful in calculus, research exists that tries to identify factors for success in mathematical courses. However, current research demonstrates there is a wide variability in the conclusions on the significance of mathematical success to retention in engineering. Zhang et al. [10] and Budny et al. [23] both determined that high school GPA and math SAT scores were positively correlated with graduation rates in engineering. Pyzdrowski et al. [25] researched factors that determine a student's' successful completion of an entry-level college calculus course. As part of a five-year study, the researchers determined that high school grade point average and higher scores on a calculus readiness assessment were the academic factors that had a significant positive correlation to course performance. Gardner, Pyke, Belcheir, & Schrader [26] concluded the grade a freshman engineering student received in their first mathematics course was significantly correlated to

their persistence in engineering, but that the actual course they took was not significant, and could not be found to be directly related to calculus. However, in this study, the researchers defined persistence as being enrolled in engineering one year later, and not by degree completion. In addition, Budny et al. [23] found that the grade an engineering student received in their mathematics course the first semester was an important predictor of retention, even if the math course was not calculus. Moses et al. [5] concluded that the math portion of the SAT was a significant factor in a student retention for engineering, but Robinson [20] reported that it was not.

There is an extensive amount of research, with no general consensus, on the specific predictive factors that determine success in engineering. The research demonstrates that a wide variety of factors, both cognitive and affective, influences a student's graduation potential in an engineering program. However, the literature supports a causal assumption that students who are not eligible to take calculus during their first semester are less likely to graduate in engineering. There is very little research that provides empirical data to support this idea, and very few studies look at calculus as a single independent variable as a predicting factor. The purpose of the current research paper is to focus on whether or not being eligible to register for calculus as the first math course in a higher education 4-year institution is significant in determining a student's likelihood of continuing on to degree completion once enrolling in an engineering program as a freshman. Using empirical evidence to determine calculus eligibility as the single predictor of degree completion will contribute a research-proven component to a developing knowledge base. This study is designed to answer the following research question:

Research Question: Do students have a greater likelihood of graduating with an engineering degree if they are calculus eligible in their first semester.

To examine the research question, the following hypothesis was developed and tested:

H_0: There is no significant difference in degree completion in the college of engineering for engineering students that are eligible to register for calculus as their first math course compared to the engineering students that are not eligible to register for calculus as their first math course.

H_1: There is a significant difference in degree completion in the college of engineering for engineering students that are eligible to register for calculus as their first math course compared to the engineering students that are not eligible to register for calculus as their first math course.

Methodology

The research team conducted this study from data collected at a single site from a large Midwestern university. Data was collected from registration and records for all students initially accepted into the college of engineering from fall 2005 through fall of 2011. The intent of the study was to focus as much attention as possible on the student population that represents traditional admits into the college of engineering as first semester freshman.

Degree Descriptions

The students at this university have the option of enrolling in nine engineering degrees within six departments. The degrees are: Agricultural Engineering, Biosystems Engineering, Civil and Environmental Engineering, Computer Engineering, Construction Engineering, Electrical Engineering, Industrial Engineering & Management, Manufacturing Engineering, and Mechanical Engineering. There is one Construction Management degree offered in the Department of Construction Management and Engineering. The students in the construction management department were removed because the research team's intent was to only include degrees which prepared the individual for a professional engineering license (PE). Architecture, Landscape Architecture, and Environmental Design were initially part of the College of Engineering at the University, but they are no longer designations within engineering. Therefore, the students initially entering the College of Engineering declaring one of these degrees were also removed from the data set.

Calculus Eligibility

The single independent variable in the study is calculus eligibility. All nine of the included engineering degrees have a plan of study listing MATH 165, Calculus I, as the recommended mathematics course during the first semester of freshman year. Therefore, the researchers are defining calculus eligible as the student registering for MATH 165, or into a higher level course, as their first mathematics course. The one exception is MATH 194, which is designated as an independent study. Since the level of mathematics required to complete these credits cannot be determined, students registering for MATH 194 as their first mathematics course were removed from the data set. In some cases, a student may not have a math class the first semester but registered for MATH 165 or higher the second semester. These students were counted as calculus eligible because the first math class they registered for was at least MATH 165.

In order to be eligible to register for MATH 165, students must meet certain requirements. These include having a minimum ACT math sub-set score as well as taking the COMPASS Mathematics Test in college algebra and trigonometry or the university's math placement test. If the student has an ACT math subset score of 21 or higher or a composite SAT (math + critical reading) of 990 or higher, the students may take the COMPASS mathematics test to determine whether or not they are calculus eligible. On the COMPASS Mathematics Test, students are eligible to register for MATH 165 by receiving a score of 60 or higher on both college algebra and trigonometry. If the student has an ACT math subset score of 21 or higher or a SAT math subset score of 530 or higher, the students may take the university mathematics placement test to determine whether or not they are calculus eligible. On the university's mathematics placement test, students that receive a score of 13 or higher on the algebra and 10 or higher on the pre-calculus are eligible to register for MATH 165. On the university mathematics placement test, students that receive a score of 13 or higher on the algebra and between 4-9 on the pre-calculus are eligible to register for MATH 165, and must also take MATH 105, trigonometry, as a co-requisite. These students are considered calculus eligible, even if they need to take MATH 105 as a co-requisite.

There are several situations that required the data to be manually cleaned in regard to calculus eligible status. Several students took multiple math courses in the same semester. The data sheet reports a different line item for each class. This resulted in those students having multiple line

items on the spreadsheet. Therefore, duplicate lines were removed and the only line item remaining was the one indicating the highest level math course. This prevented the students from being counted more than once in the data analysis. Some students did not take a math course the first semester, but registered for calculus the second semester. These students were coded as calculus eligible because the first course for which they registered was calculus. This study does not include measurements of the students' mathematical abilities, only whether or not they were eligible to register for calculus as their first math course.

Degree Completion

The data set includes the original major of each student when they enrolled in the college of engineering as a freshman student, and the major they were in at the point of degree completion. The available student data did not include those who may have transferred to a different university. All of the initially declared majors are in one of the engineering departments. However, the data set shows a variety of degree completion majors across campus since many students who begin as engineering majors transfer out of engineering. Some students transferred to a different department, but remained within the college of engineering.

For this study, degree completion is the dependent variable of interest. The research team examined both completion of an engineering degree – "engineering graduates," and completion of any degree at the university, whether inside or outside the college of engineering – "non-engineering graduates." The combination of both categories is "total graduates." The measure of degree completion is the 6-year graduation rate since this is a common metric of graduation rate in engineering programs nationwide. Students who changed majors within the college of engineering are in the category of engineering graduate. The researchers coded these students as engineering graduates.

Statistical Method

To answer the research question, the researchers used simple descriptive statistics and binary logistic regression. The binary dependent variable was engineering graduate. The research team also looked at a separate binary model for total graduates. There was a single independent variable – calculus eligibility. The single independent variable in the study was a binary indication of whether the freshmen were, or were not calculus eligible. Given the data set was coded using a binary method, and the desired model contains dichotomous variables, the Wald test is appropriate for the statistical analysis [27], [28].

Results

Summary Statistics

Once cleaning and coding was complete, there were 1,576 students in the study group. Table 1 shows the raw data for the number of students by their calculus eligibility and degree completion status. Slightly under half of all the students in the sample were eligible to take calculus their

first term (779/1576 = 49.4%).

Table 1. Numbers of individuals for 6-year graduation rate.

6-year Result	Ineligible	Eligible	Total
Did Not Graduate	363	159	522
Non-Engineering Graduate	123	87	210
Engineering Graduate	311	533	844
Total	797	779	1,576

In Table 2, the raw numbers from Table 1 were converted to percentages within each category using the total number of students who are calculus eligible and students who are calculus ineligible as the denominator. As shown in Table 2, 53.6% of the students in the sample graduated with an engineering degree within 6 years. Of those who were calculus eligible, 68.4% graduated with an engineering degree, and for those who were calculus ineligible, 39.0% graduated with that degree. Of the calculus eligible students, 79.6% received some degree from the university, while only 54.5% of calculus ineligible students graduated from the university with a degree.

Table 2. Percentage of individuals for 6-year graduation rate.

6-year Result	Ineligible (n=797)	Eligible (n=779)	Total (n=1576)
Did Not Graduate	45.5%	20.4%	33.1%
Graduated Non-Engineering	15.5%	11.2%	13.3%
Graduated Engineering	39.0%	68.4%	53.6%
Total	100.0%	100.0%	100.0%

Comparing the percent of those who graduated in engineering as calculus-eligible (68.4%) to those who were not calculus eligible (39.0%) provides valuable information.

To illustrate further the difference between the two groups of students by calculus eligibility, a graphical representation of the population is in Figure 1. The two groups have a much different composition in the number of students that have 4-, 5-, and 6-year graduation rates. This figure is an indication that degrees for those that are calculus ineligible generally cost more (for the student and the university) than those with first-semester eligibility.

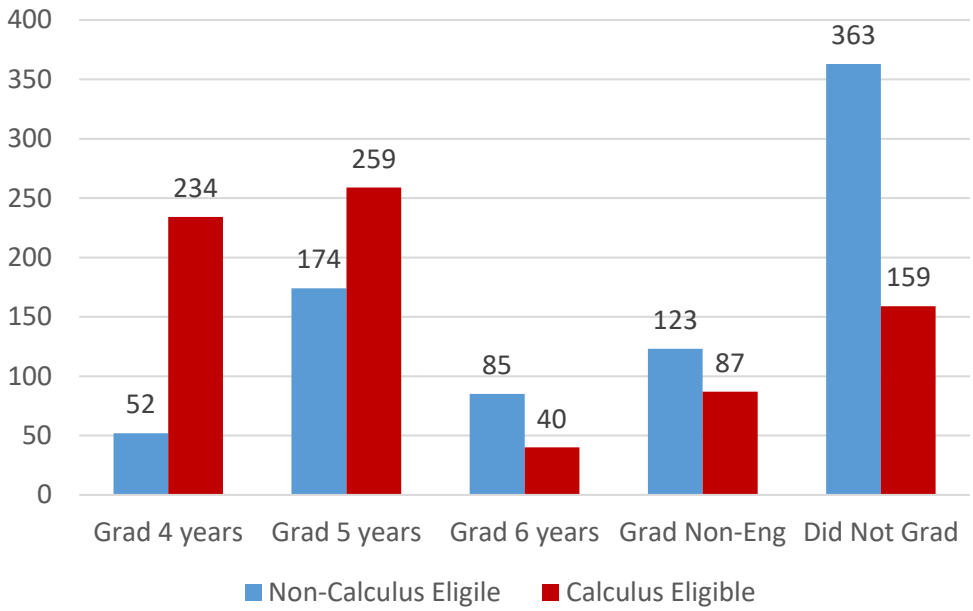

Figure 1. Distribution of possible outcomes for all students in study divided by calculus eligibility.

Research Question

The research question is whether a student who entered the university declaring engineering as a major with eligibility to take calculus in their first semester was more likely to complete an engineering degree than one who was not calculus-eligible. In Table 3, the results of this process show that a student who is calculus eligible as a new admit to the college of engineering is 3.386 times more likely to graduate in engineering within 6 years than a student that is calculus ineligible. The model has a Wald Chi Square of $p < 0.0001$ and a Generalized R-Square of 11.28%, indicating that the single variable, calculus eligibility, explains 11.28% of the variation in the model. Table 3 also shows the results of graduation rates for those who finished their engineering degree in 5 years or less and within 4 years.

It is 4.355 times more likely that an individual who is calculus eligible would graduate within 5 years than someone who is not calculus eligible. The statistical significance for the 5-year graduation rate has a Wald Chi Square $p < 0.0001$, and explains 15.78% of variation in the model. It is approximately 6.15 times more likely that a student who is calculus eligible would graduate within 4 years than a student who is calculus ineligible. The statistical significance for the 4-year graduation rate has a Wald Chi Square $p < 0.0001$, and explains 15.41% of the variation in the model.

Table 3. Binary logistic regression results for calculus eligible versus calculus ineligible students in regard to receipt of an engineering degree within 6 years of matriculation.

Odds Ratios	Eligible	Ineligible	Wald p-value	General R-Square (%)
6-year or less	3.386	0.295	< .0001	11.28
5-year or less	4.355	0.230	< .0001	15.78
4-year	6.151	0.163	< .0001	15.41

Note: Ineligible = 1/x of Eligible

Conclusions

As demonstrated by the results, there is a statistically significant difference in degree completion when comparing calculus-eligible and non-calculus eligible students in engineering. Students entering the college of engineering as freshman who are eligible to register for calculus as their first math course are 6.151 times more likely to graduate within 4-years, 4.355 times more likely to graduate within 5-years, and 3.386 times more likely to graduate within 6 years, all with a p-value less than 0.0001.

From Table 1, 363 students that were calculus ineligible when entering into the college of engineering did not complete a degree at all. This is 23.0% (363/1576) of the students included in the study.

When examining the students that completed a degree in more detail, the results of the data analysis demonstrates an interesting aspect concerning time to degree completion. These results are in Table 4.

Table 4. Mean years to degree completion for all degree recipients.

	Calculus Eligibility	
	Non-eligible	Eligible
Number of Students	434	620
Years to Completion	4.913	4.458

For students who were calculus ineligible and completed a degree, whether it was in engineering or not, they had a time to degree completion approximately only one semester, 0.455 years, more than those that were calculus eligible (4.913 years - 4.458 years = 0.455 years). This means that although it is 3.386 times more likely that a student who is calculus eligible graduates in engineering than those who are calculus ineligible, those calculus ineligible students who do persist to degree completion finish on average only one semester later than those that were calculus eligible. This means that calculus ineligible students need just one semester to make up not being able to take calculus as their first math course. Also, included in this number are the students that transferred out of engineering, but persisted to earn a degree in another major.

Discussion and Implications

This study provides much needed empirical evidence that identifies calculus eligibility as the first math course for a freshman engineer as an at-risk predictor for degree completion. Although the research includes upper level math preparedness as a factor, there is very little research, particularly empirical results, that singles out calculus' singular impact. Therefore, this study provides the results necessary to fill the gap in current research so that researchers and educators can further develop best practices for generating engineering graduates. Several of these practices are identified in previous research, some of the most critical elements being admission requirements, advising techniques, and resources dedicated to mathematical remediation.

Levin & Wyckoff [6] identify advising as one of the most critical factors is helping a student determine their future educational and career trajectory. The results of this study can have significant impacts on advising students that are calculus ineligible compared to those that are calculus eligible. Another critical implication is the remediation process for students that need additional courses to increase their mathematical ability [18], [19], [26], particularly for those that are engineering students and are not eligible to take calculus in their first semester. If a freshman engineering admit is not eligible to register for calculus as their first semester course, then the math credits they need to complete in order to register for calculus do not directly contribute to progression toward degree completion. This means that time and money for both the student and the university are spent in hopes of this student obtaining an engineering degree. However, the results of this research demonstrate that it is only 1/3 as likely for a student to ultimately graduate in engineering that is not calculus-eligible compared to a student that is calculus-eligible.

This study used a single predictor, calculus eligibility, as the only independent variable in the model. Therefore, even though the results demonstrate statistical significance, the Generalized R-Square is 15.41% for 4-year, 15.78% for 5-year, and 11.28% for 6-year graduation rates. There were three students that graduated in less than 4 years, which were removed from the data set. Occasionally in a university environment, first-semester freshmen may take a math course at a lower level than what they are eligible to take in order to increase mathematical confidence and foundational understanding of mathematical concepts. It could not be determined from the data set whether or not a student took the highest level math course for which they were eligible; therefore, a student was coded strictly on the first math course for which they registered. However, this is not to suggest that concentrated academic intervention prior to the onset of or

during a post-secondary engineering curriculum could not prove effective in enhancing degree program retention rates; this simply identifies that through traditional and intact programming that calculus readiness is a variable of substantial magnitude regarding engineering degree completion.

Although these results of this study show statistical significance, the researcher would like to continue to examine specific aspects of the longitudinal data and statistical approaches. Methods to increase the Generalized R-Square will result in a deeper understanding of how the variables in the model explain the results. Now that the overall significance of calculus has been identified, the researchers intend to study additional factors. This will include, but not be limited to differences in gender and calculus eligibility toward degree completion, incorporating additional mathematical aspects into the model such as academic success in various math courses, and determining which math courses for which students are initially eligible to register for have an impact of degree completion.

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