How Calculus Eligibility and At-Risk Status Relate to Graduation Rate in Engineering Degree Programs

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Abstract

The problematic persistence rates that many colleges and schools of engineering encounter has resulted in ongoing conversations about academic readiness, retention, and degree completion within engineering programs. Although a large research base exists about student preparedness in engineering, many studies report a wide variety of factors that makes it difficult to address specific issues that prohibit students from completing a degree in engineering. Many studies anecdotally address mathematics achievement as a factor associated with success, but few contain empirical data specifically related to success or readiness to take calculus. 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, and the mediating effects of being at-risk for non-matriculation on this relationship. A 10-year span of engineering student data, including admission and completion data, was accessed and analyzed to investigate student preparedness (as defined by calculus eligibility) and student success (as defined by at-risk status for non-matriculation) as they related to graduation rate. This study documents a partial mediating effect of at-risk status on the relationship between calculus eligibility and graduation rate; however, calculus eligibility remains a significant predictor of graduation rate and together with at-risk status predicts a significant proportion of the variance in graduation rate.

Introduction

A strong mathematical background has become one of the implied criteria for success in completing a degree in engineering. Significant research has been conducted to determine which mathematical factors associated with secondary education are most associated with a student's success in completing an engineering degree in a university setting. These factors have included high school GPA, SAT mathematics score, and ACT mathematics score (French, Immekus, & Oakes, 2005; Veenstra, Dey, & Herrin, 2009). At the university level, Levin and Wyckoff (1988) determined that GPA at the end of the freshman year is a strong predictor of success in engineering. In a study involving over 1,000 freshman students, two of the most significant factors in a regression model predicting continued enrollment in an engineering major at the beginning of the junior year were SAT mathematics score and a mathematics achievement score from an algebra placement test. At the post-secondary level, factors such as university GPA and grades in particular mathematics courses have been found to predict engineering degree completion (Besterfield-Sacre, Atman, & Shuman, 1997; Budny, LeBold, & Bjedov, 1998; Honken & Ralston, 2013; Levin & Wyckoff, 1988, 1995; Moller-Wong & Eide, 1997; Whalen & Shelley, 2010; Zhang, Anderson, Ohland, & Thorndyke, 2004). Budny, LeBold, and Bjedov (1998) reported a correlation between first semester mathematics grades and the likelihood of success in engineering, although the specific mathematics course did not seem to be a significant factor. However, research at the university level offers mainly anecdotal observations and little empirical evidence that demonstrates that mathematical success as a freshman engineering student directly correlates to completion of an engineering degree (Levin & Wyckoff, 1988; Gainen, 1995; Lee & Lee, 2009; Robinson, 2003; Seidman, 2012; Sorby & Hamlin, 2001).

Calculus is typically required as the first course for students admitted to an engineering degree program in the freshman year (Bressoud, 2015). Although there is no consensus about the specific factors that contribute to success in engineering, the literature supports the assumption that students not eligible to take calculus during their first semester or are not successful in calculus are less likely to graduate in engineering. Gardner, Pyke, Belcheir, and Schrader (2007) concluded that the grade a freshman engineering student received in their first mathematics course, regardless whether it was calculus or not, was significantly correlated to their retention in engineering. This study, however, defined retention as still being enrolled in engineering after the first year and did not consider degree completion. Although mathematics is commonly used in statistical models for predicting engineering success, few studies specifically consider eligibility for, enrollment in, or success in calculus as a predictive factor. In one of the few studies that uses calculus as a single variable, Bowen, Hall, and Ernst (2017) researched 10 years of freshman engineering admission data. They concluded that engineering students who were eligible to register for calculus as their first mathematics course were significantly more likely to graduate with a degree in engineering than students who were not calculus eligible. Overall, the literature offers a wide variety of results and therefore more research is needed to determine the specific factors related to success in mathematics that in turn lead to success in engineering (Budny et al., 1998; Gardner et al., 2007; Moses et al., 2011; Pyzdrowski et al., 2013; Robinson, 2003; Zhang et al., 2004).

An engineering student's drive to succeed will potentially lead to the development of particular behaviors, both academic and non-academic, that will result either in successful degree completion or not. Lent, Brown, and Hackett (1994) concluded that the level of persistence and related outcomes are due to a combination of environmental, personal, and behavioral factors outlined in Bandura's (1986) Social Cognitive Theory. In addition, academic circumstances must be considered to adequately identify and analyze the critical educational features influencing early successes of students in engineering (Clark & Ernst, 2012; Ernst & Clark, 2013; Guner et al., 2014; Meyer & Marx, 2014; Ohland et al., 2008). Early successes, such as a high GPA at the end of the first year, self-regulated learning, academic self-efficacy, career awareness, and motivation have been identified as critical to degree completion in an engineering program (Carroll, Gordon, Haynes, & Houghton, 2013; Clark & Ernst, 2012; Dekker, 2009; Ernst & Bowen, 2014; Ernst, Bowen, & Williams, 2016; Ernst & Clark, 2012, 2013; Fantz, Siller, & DeMiranda, 2011; Lent, 2005; Maxwell, 1997; Wood & Locke, 1987). A lack of these early successes puts a student at-risk of non-matriculation in a university setting. Understanding how a student's at-risk status interrelates with early successes and failures and potential degree completion can have important implications for early identification of at-risk status and the increased potential to provide necessary supports to enhance the likelihood of success.

Study Rationale

Research has demonstrated that mathematics placement and performance are elevated predictors of preparedness, attainment, retention and graduation in post-secondary education (Efird, 2005; Goonatilake & Chappa, 2010; Jacobs & Pretorius, 2016). Hilgoe, Brinkley, Hattingh, and Bernhardt (2016) identify that students who are prepared are ultimately successful in their initial mathematics placement within university settings and more likely to remain in their chosen major. Much effort has surrounded building a profile of entry-level university student characteristics of mathematics to assist in the formulation of preparation and advancement initiatives. Recent research has documented that students' readiness to take calculus is a significant predictor of their time to graduation (Bowen, Hall, and Ernst, 2017), however, there may be other unidentified performance factors that also predict success and graduation in engineering majors. This suggests that a more holistic method to evaluate overall academic performance is of higher importance than basic calculus readiness. This notion is further supported by the work of Hodara and Lewis (2017) that identifies general grade point average in required subjects and its use to predict graduation. A broader academic preparedness during progress toward matriculation is becoming more widely addressed in contemporary readiness and retention models (Scrivener & Logue, 2016). The need to account for wider academic sets and academic progress toward degree completion is evident as it pertains to students majoring in engineering.

Bowen et al. (2017) concluded that calculus eligibility in the first semester was a significant predictor of success in completing an engineering degree. However, the researchers acknowledged other factors that could contribute to overall engineering success. In addition to other factors that may additively contribute to the prediction of degree completion, it is also possible that there are interactive relationships between factors. In particular, given the amount of time between identified calculus eligibility, as a freshman, and degree completion there may be factors that could mediate this relationship. Therefore, this research study builds on the research of Bowen et al. (2017) by examining additional factors. In particular, this study considers a student's status in terms of at-risk for non-matriculation in a university setting as a potential mediating variable of the relationship between calculus eligibility and graduation rate. This investigation could explain why this relationship may occur and at the same time investigate the additional influence of at-risk status on graduation rate. In other words, given the relationship between calculus eligibility and graduation rate, are there other variables that mediate this relationship and/or add to the overall predictability of graduation rate? This is investigated specifically with the following research questions:

RQ 1: Is there a relationship between calculus eligibility and students' at-risk status?

RQ 2: Does a student's status as at-risk for non-matriculation in a university setting mediate the effect of calculus eligibility on engineering graduation?

Methodology

This research project involved a single-site data collection method from a large Midwestern university. The data, obtained from the office of Registration and Records, included all freshman admitted to the college of engineering from fall 2005 through fall 2011. The intent was to focus on the students that represented traditional admits into the college of engineering as first semester freshman.

Engineering Degree Descriptions

This university offers nine engineering degrees within six departments from which the students can choose and upon degree completion will be eligible for the Professional Engineers license. These degrees are Agricultural Engineering, Biosystems Engineering, Civil and Environmental Engineering, Computer Engineering, Construction Engineering, Electrical Engineering, Industrial Engineering & Management, Manufacturing Engineering, and Mechanical Engineering. Only the students initially enrolling in one of these nine programs were considered in the study.

Calculus Eligibility

All nine of the above-mentioned engineering degrees list Calculus I as the first required mathematics course on the plan of study for the first semester. So, for this study, a student is designated as calculus eligible if they register for Calculus I, or a more advanced mathematics course, as their first mathematics course. If a student did not register for a mathematics course their first semester, but then registered for Calculus I or higher the second semester, this student was designated as calculus eligible. The data set also included several situations that needed to be cleaned before the data analysis phase. For example, several students took multiple mathematics courses during their first semester. This resulted in these students having multiple lines on the spreadsheet causing them to be counted more than once within the sample. In this situation, additional mathematics courses were removed and only the highest mathematics courses was used for each student. Since the purpose was to determine calculus eligibility, once a student was determined to be calculus eligible, other mathematics courses were removed to prevent the student from being counted multiple times. To be eligible to register for Calculus I, students must meet several requirements set forth by university requirements. These include having a minimum ACT score and achieving a certain score on a university placement test. The specific requirements for a student to register for Calculus I are described by Bowen et al. (2017). 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 mathematics course.

At-Risk Status

For the purposes of this study, the definitions of at-risk and not at-risk are placed in the context of the likelihood of a student to matriculate through an engineering program to degree completion. The matriculation parameter used is a GPA of 3.0, as defined by Ernst and Clark (2012, 2013). Students with a GPA lower than 3.0 at the end of their freshman year are classified as at-risk of matriculation in a university setting. Students with a GPA of 3.0 or higher are classified as not at-risk of matriculation in a university setting. Although students with less than a 3.0 can still be in good academic standing with the university, research shows that students with less than a 3.0 have significantly less chance to matriculate to degree completion within an engineering program (Ernst & Clark, 2012, 2013).

Degree Completion

In this study, successful degree completion refers to students who were admitted as first-semester freshman directly to the college of engineering and completed a degree in one of the nine engineering programs. The data set includes the engineering program in which the students were admitted and, if a degree was earned, the department in which that degree was earned. The data does not include students that transferred in from another university; as the researchers were only interested in students that represented a traditional freshman admit. Degree completion is measured within a 6-year graduation rate since this is a common metric of graduation rate in engineering programs nationwide. The final data set resulted in five cohorts of students that could be considered for a 6-year graduation rate.

Statistical Analysis

In a previous study, Bowen et al. (2017) documented a relationship between calculus eligibility and engineering graduation: The odds of students who are calculus eligible to graduate in engineering within 6 years are 3.39 times the odds of students who are not calculus eligible. In the present study, the researchers build on this finding by examining the potential mediating effect of a student's at-risk status on the relationship between calculus eligibility and graduation in engineering within 6 years (see Figure 1). In addition, the effect of at-risk status on graduation rate is examined as well as the total effect of calculus eligibility and at-risk on graduation rate.

Because part of the study focused on the mediating effect of students' at-risk status on the relationship between calculus eligibility and graduation rate, a series of three binary logistic regression models was used to an-

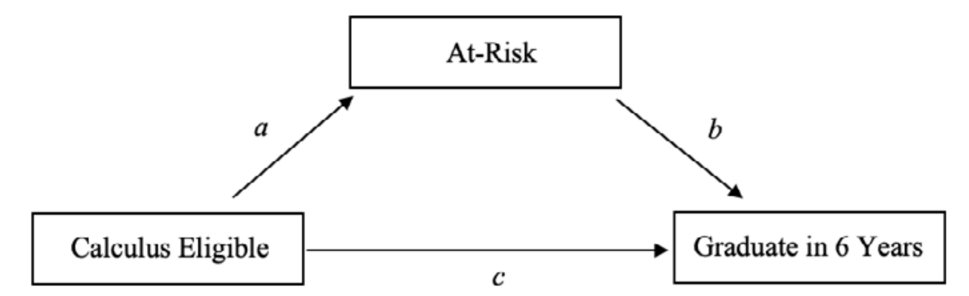

Figure 1. At-Risk to matriculate as a mediator of the effect of calculus eligibility on graduating in 6 years.

swer the research questions. The creation of these models aligned with the steps outlined by Baron and Kenny (1986) to establish the mediating effect of a variable on a relationship. Referencing Figure 1, the researchers (a) regressed graduation rate on calculus eligibility, (b) regressed at-risk on calculus eligibility, and (c) regressed graduation rate on calculus eligibility while controlling for at-risk status.

The first step was to estimate a model for the bivariate relationship between graduation rate and calculus eligibility (see path *c* in Figure 1, also established in Bowen et al., 2017) without other variables in the model (Model 1). Next, a model for the bivariate relationship between at-risk and calculus eligibility (see path a in Figure 1) was estimated to establish a relationship between calculus eligibility and at-risk (Model 2, see Research Question 1), without which there is no mediating effect. Finally, the researchers estimated a model that regressed graduation rate on calculus eligibility while controlling for at-risk status (Model 3, see Research Question 2). A reduction in the effect of calculus eligibility on graduation rate as a result of controlling for at-risk would provide evidence of the mediating effect of at-risk on the relationship between calculus eligibility and graduation rate. This reduction in the effect is also referred to as an indirect effect. A Sobel test (Sobel, 1982) is used to determine the significance of the indirect effect associated with at-risk. As another measure of mediation, the proportion of the effect that is mediated by at-risk is calculated; operationally this is the indirect effect, *ab*, divided by the total effect, *c*, or *ab/c*.

MacKinnon and Dwyer (1993) identified a problem when conducting a mediation study using logistic regression. When outcome measures are dichotomous, the scale of the coefficients is not constant across the different models used in the mediation analysis. In our study, both at-risk and graduation rate are dichotomous outcome variables in the mediation models. This problem is resolved by standardizing the regression coefficients from the different models prior to estimating the mediating effect of at-risk (MacKinnon & Dwyer, 1993), that is, in our study, the proportion of the effect that is mediated. This was accomplished in our study following the recommendations of and using the tool designed by Herr (2017) to calculate the proportion of mediation. The Sobel test is not affected by the scale of the variables (MacKinnon & Dwyer, 1993).

Results

The descriptive statistics are shown in Table 1. Of the sample, 54% of the students graduated with an engineering degree within 6 years. Of the sample of students, 49% was calculus eligible upon entering their first year. Of the sample of students, 52% was considered at-risk for matriculating into an engineering program. Table 1 also shows the intercorrelations among the variables. A moderate and statistically significant association between graduation rate and at-risk ($\varphi = .38$) and calculus eligibility ($\varphi = .29$) was documented. In addition, a small but statistically significant association between calculus eligibility and at-risk was documented ($\varphi = .17$).

The results of the three logistic models are presented in Tables 2-4. The results from Model 1 indicate that students who are calculus eligible upon entering their first year are more likely to graduate within 6 years than students who are not calculus eligible (see Table 2; $\beta = 1.22$, SE = 0.11; Wald Statistic = 132.60, $p < .001$; cf. Bowen et al., 2017). Based on this result, the odds of students who are calculus eligible to graduate within 6 years are Exp(1.22) = 3.39 times the odds for students who are not eligible (95% confidence interval: 2.75, 4.17). Calculus eligibility was found to explain 11% of the variance in the model.

The results of Model 2 (Table 3) indicate that students who are calculus eligible upon entering their first year are more likely to matriculate into an engineering major (not be at-risk) than students who are not calculus eligible ($\beta = 0.70$, $SE = 0.10$; Wald Statistic = 46.98, $p < .001$). Calculus eligibility was found to explain 4% of the variance in the model. Based on this result, the odds of students who are calculus eligible to not be at-risk to matriculate into an engineering degree are Exp(0.70) = 2.01 times the odds of students who are not eligible (95% confidence interval: 1.65, 2.47).

Model 3 included both calculus eligibility and at-risk status as independent variables. Overall, this model was found to have a statistically significant Wald statistic ($\chi2 = 273.90$, $df = 1$, $p < .001$) and explained 26% of the variance in graduation rate (see Table 4). Specifically, after controlling for at-risk status, students who are eligible for

	Graduation in 6 Years	Calculus Eligible	At-Risk
Graduation in 6 Years (1 = Graduate in 6 Years)	-		
Calculus Eligible (1 = Calculus Eligible)	0.29^{***}	-	
At-Risk (1 = not at risk)	0.38^{***}	0.17^{***}	-
Mean	0.54	0.49	0.48
SD	0.50	0.50	0.50

Note: $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$.

Table 1. Intercorrelations and descriptive statistics (*N* = 1576).

	β	*SE*
Intercept	-0.45^{***}	0.07
Calculus Eligible	1.22^{***}	0.11
Model Chi-Square (Wald)	132.60 ($df = 1$)	
R-Squared	.11	

Note: $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$.

Table 2. Results of Regressing Graduation Rate on Calculus Eligibility (Model 1)

calculus are more likely to graduate in 6 years than students who are not eligible (β = 1.11, *SE* = 0.11; Wald Statistic = 95.78, $p < .001$); the odds of these students graduating in 6 years is approximately 3 times the odds of students who are not calculus eligible (95% confidence interval: 2.42, 3.78). At this point, the researchers compared the direct effect of calculus eligibility on graduation rate in Model 1 (β = 1.22) with that in Model 3 (β = 1.11). The reduction in the effect in Model 3 suggests a mediating effect associated with at-risk. A Sobel test found this reduction to be statistically significant (z = 6.26, $p < .0001$). This change represents a 22% reduction in the effect of calculus eligibility on graduation rate due to the mediating effect of student's at-risk status at the end of first year. Thus, it can be concluded that at-risk is a partial mediator of the effect of calculus eligibility, but overall, calculus eligibility still remains as an important indicator of graduation rate.

Moreover, after controlling for calculus eligibility, students who are not at risk to matriculate are more likely to graduate in 6 years than students who are at risk (β = 1.54, *SE* = 0.11; Wald Statistic = 183.66, $p < .001$). Based on these results, the odds of students who are not at-risk are 4.7 times students who are at-risk to graduate within 6 years (95% confidence interval: 3.74, 5.84). Considered together, the odds for students who were eligible to register for calculus as their first mathematics course and not at-risk to matriculate at the end of their first year are Exp(1.11 + 1.54) = 14.15 times students who were not calculus eligible and at-risk after their first year.

	β	*SE*
Intercept	-0.43***	0.07
Calculus Eligible	0.70***	0.10
Model Chi-Square (Wald)	46.98 (df = 1)	
R-Squared	.04	

Note: * $p < .05$; ** $p < .01$; *** $p < .001$.

Table 3. Results of Regressing At-Risk Status on Calculus Eligibility (Model 2)

Variable	β	*SE*
Intercept	-1.10***	0.09
Calculus Eligible	1.11***	0.11
At-Risk	1.54***	0.11
Model Chi-Square (Wald)	273.90 (df = 1)	
R-Squared	0.26	

Note: * $p < .05$; ** $p < .01$; *** $p < .001$.

Table 4. Results of Regressing Graduation Rate on At-Risk Status and Calculus Eligibility (Model 3)

Discussion

Previous research has shown that mathematics achievement in general is an important predictor of success in engineering (Budny et al., 1998; French et al., 2005; Levin & Wyckoff, 1988, 1995; Moller-Wong & Eide, 1997; Seidman, 2012; Veenstra et al., 2009; Zhang et al., 2004). More recently, Bowen et al. (2017), focused specifically on the importance of calculus eligibility as a predictor of graduation in an engineering program, documenting a statistically significant relationship between calculus eligibility and graduation rate. In the current study, the researchers built on this finding by considering other factors that could possibly mediate the relationship between calculus eligibility and graduation rate, in particular, considering student at-risk for non-matriculation status as a possible mediator. It was documented that at-risk status did partially mediate this relationship, suggesting that some of the predictability associated with calculus eligibility may be a by-product of grades in calculus, indeed part of determining a student's at-risk status. However, although at-risk was found to be a partial mediator, overall, calculus eligibility remained a significant predictor of graduation rate, and when considered collectively with at-risk status, the two variables predicted 26% of the variance in graduation rate, significantly more than the 11% predicted by calculus alone (cf. Bowen et al., 2017). Furthermore, the odds of graduating with an engineering degree within six years for students who are not classified as at-risk for non-matriculation and are eligible to register for calculus as their first mathematics courses are 14 times the odds of students who are at-risk and were not calculus eligible.

Conclusion and Recommendations

In regards to successful completion of an engineering degree program, this study documents the importance of being able to register for calculus (or a more advanced mathematics course) as the first mathematics course and maintaining a not at-risk status in regards to academic success at the end of the first year. However, the researchers agree that calculus eligibility within engineering is not a stand-alone predictor of successful degree completion as shown in this study. Student retention and academic success is a multifaceted issue and the complexity of student success spans beyond mathematical placement and academic achievement. Student achievement is driven by a more holistic experience in which mathematics placement and academic success plays a role. This also includes stressing the importance of students being ready to take calculus as their first university mathematics course if they plan on pursuing a degree in engineering. By better understanding various factors of the overall approach to student success and retention, problematic and prohibitive features of the higher education system can be identified and therefore processes can be managed to increase the likelihood of student success specific to engineering programs.

Further research is needed to fully understand the factors that lead to the completion of an engineering degree. The source of data in this study is from a single site. Additional data could be used to determine if similar factors occur in other geographic regions. Although this study does address the importance of being calculus eligible, and maintaining good standing as not at-risk, the research design does not account for mathematical aptitude or other cognitive factors within a student's academic ability. This study also does not account for the variety of non-cognitive factors such as social acclimation, self-efficacy of learning, or prior experiences. However, this research does assist in further building a foundational base and impetus for working toward the establishment of verifiable factors and a protocol to initially identify at-risk students in undergraduate engineering curricula in subsequent efforts.

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