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First-Year Math and Physics Courses and their Role in Predicting Academic Success in Subsequent Courses

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First-Year Math and Physics Courses and their Role in Predicting Academic Success in Subsequent Courses

This paper builds on the previous literature, primarily studies at large public institutions, by exploring the role that first-year math and physics courses play in the persistence and success of undergraduate engineering students in the context of a small private business, science, technology, engineering, and mathematics (BSTEM) only university. Literature has identified math and physics aptitude as predictors of academic success in college. Additional literature has indicated that there is the potential for overload through students taking too many courses in their first year; however the presence of a corequisite calculus and physics requirement provides an opportunity for the transfer of math knowledge to a different context. Findings from logistic regressions and group comparisons on institutional data from engineering students enrolled between 2001 and 2010 indicate that there are no significant differences in course grades between students that took calculus as a prerequisite versus as a corequisite, however students that had lower course loads during the semester they took Calculus I were more likely to graduate with a degree from the university, though not necessarily in engineering. Additionally, Physics I course grades appear to be a predictor of persistence in engineering and subsequent Physics II course and corequisite Calculus I grades. The findings provide information that can be used by other institutions of similar size and scope to examine the structure of their first year courses in engineering, initiate university policies, and develop interventions to support math, physics, and overall graduation success.

Introduction

The first year coursework, similar in most engineering curriculums, involves a series of introductory engineering design, graphical communication, and programming courses. In addition students are required to complete Calculus I and Physics I as a prerequisite to Calculus II and Physics II which are themselves prerequisites to advanced engineering science courses (i.e., statics, dynamics, fluid mechanics, and solid mechanics).

At a small private institution in the Southern region of the United States there is currently a corequisite requirement of Calculus I for students taking Physics I, but a perceived lack of mathematical ability has indicated that the Calculus I course should be a prerequisite for Physics I and subsequently Calculus II as a prerequisite for Physics II. The physics courses primarily utilize differentiation and integration of algebraic and elementary trigonometric functions taught in the calculus courses. Descriptions of these courses can be seen in Table 1.

Literature has identified math and physics aptitude as a predictor of academic success in college[1, 2]. Within these studies math and physics aptitude was represented by ACT and SAT math scores along with math and physics enrollment. Additional literature[3-5] has indicated that there is the potential for overload through students taking too many courses in their first year; however a corequisite requirement provides an opportunity for the transfer of calculus knowledge to a different context, specifically physics[6, 7].

Calculus courses have been recognized as one of the reasons students leave engineering within their first year and have served as a filter of under-prepared students in many engineering schools[8, 9]. The traditional model of engineering curriculum begins with one year of freshman calculus as a prerequisite to subsequent core engineering courses[10]. In their work, Klingbeil et al.[10] acknowledge that the correlation between retention rates and the inability to progress through the required calculus sequence is a problem.

Table 1. Descriptions of Calculus and Physics course topics

Course	Description
Calculus I	Graphs and functions; limits and continuity; differentiation and integration of algebraic and elementary trigonometric functions; applications of first and second derivatives.
Calculus II	Differentiation and integration of transcendental functions; special integration techniques; polar coordinates; applications of the definite integral; numerical methods.
Physics I	Vectors and scalar quantities, geometrical optics, kinematics, Newton's Laws of Motion, work, work-energy, conservation of energy, conservation of momentum, center of mass and its motion.
Physics II	Rotational motion, simple harmonic motion, waves, fluid, heat, kinetic energy, and thermodynamics.

This paper builds on the previous literature, primarily studied at large public institutions, by exploring the role that introductory calculus and physics courses play in the persistence and success of undergraduate engineering students in the context of a small private business, science, technology, engineering, and mathematics (BSTEM) only university in the southern region of the United States. The study addresses two primary research questions:

1) *How are corequisite & prerequisite requirements related to grades in first-year physics and math courses?*
2) *How are prerequisite math and physics courses related to success in the following sequence of math and physics courses?*

Literature Review

Calculus is an essential component of nearly every engineering discipline, making success in calculus critical to retaining students in engineering. One approach to ensuring success is by accurately predicting which math course a student should be taking, allowing them to be adequately prepared to take calculus. Jin, Groll, Imbrie, and Reed-Rhoads [11]were able to accurately predict end-of-semester grades 67.3%-85% of the time based primarily on pre-semester placement exam scores and entrance qualifications. Recommendations by Budny, Bjedov, and LeBold [1] and Ohland et al.[12], indicate that students should be placed in courses at their appropriate skill level, particularly in math, and the ability to accurately predict course grades is a key component of that placement.

Hensel, Sigler, and Lowery [8, 10] identified several other approaches to dealing with preparing students to succeed in calculus courses. These include the incorporation of cooperative learning and hands on application oriented problem solving activities, creating learning communities, early identification of students who will have difficulties in math courses and the removing of prerequisites so that students can proceed with other engineering course work without first completing the calculus course.

One such instance of the removal of prerequisites was described by Ohland, Yuhasz, and Sill at Clemson University[12]. In this instance, the university recognized a bottleneck due to the prerequisite of a Calculus I course for enrollment into Clemson's ENGR 120, Introduction to Engineering Problem Solving and Design. By removing this prerequisite, Clemson was able to allow students to progress through a general engineering curriculum, thus releasing the bottleneck and allowing students to persist through their first and second year that would otherwise have been held back by the bottleneck. They also implemented requirements for enrollment policies and the prerequisite of earlier pre-calculus courses for low performing students. These actions led to higher retention rates among students that took and passed pre-calculus courses in comparison to those who failed the calculus course on the first attempt.

Transfer and application of knowledge from other courses is a great concern as engineering and science students seek to perceive the relevance of the introductory topics they study, especially in their math courses. A major goal of any curriculum is to integrate the knowledge from one course and apply it to other settings and professional work. This transfer becomes increasingly important when looking at the first year curriculum that introduces calculus and physics courses, often taught by non-engineering faculty, but that are fundamental to the core of engineering. As a result, there have been several attempts at integrating math into other courses in an effort to encourage that transfer [2, 13-16]. Instead of a separate "math" course, calculus is taught throughout multiple courses, as topics are needed, allowing for a clear relationship between the how and the why. This model provides increased motivation for, and transfer of, calculus to other related areas, in part because terminology differences are quickly resolved. The increased learning and motivation associated with such models often improves student retention[16]. In their work, Hundhausen and Yeatts [13]examined the effect of an integrated physics and calculus course in comparison to the traditionally isolated courses. They saw that the integrated students had significantly higher grades than the traditional students. McKenna, McMartin, and Agogino[2] also explore the differences between students that took the integrated version of the math and physics courses in comparison to the traditional. These studies allude to a strong relationship between math and physics success in engineering programs.

Methods

A quantitative analysis of institutional data from engineering students enrolled at a small private BSTEM only institution in the southern region of the United States from 2001 to 2010 was used to address the research questions.

Context

This study utilized institutional data from the college of engineering at a small private BSTEM only school in the Southern region of the United States. The institution has approximately 37% of its students enrolled in the College of Engineering, which offers degrees in aerospace, civil, computer, electrical, mechanical, and software engineering, as well as computer science. The campus as a whole has 92% full-time students, 84% male, and 86% domestic with approximately 35% of all students residing in-state. In addition to the specific disciplines mentioned, the college also has a Freshmen Engineering Department, responsible for teaching three first-year engineering courses introducing engineering design, graphical communication, and programming.

Data

The data for this study has been collected and provided to the Freshman Engineering Department by the university’s Department of Institutional Research. The full data set includes 5974 students that enrolled in the college of engineering between the 2001 and 2010 Fall semesters. The data included graduate/attrite status, demographics (sex, citizenship, individual financial status (IFS)), high school success (GPA, SAT math, ACT math), and college grades in the math and physics courses (Table 2). Course grades, reported on a standard A-F scale with no +/- weightings, were converted into a 4.0-0.0 scale to allow for numerical analysis.

While the focus of this study is on the implication of the first year math and physics courses, prior studies that examine student success and attrition in engineering[17-21] have indicated that high school GPA, college entrance math tests (like the ACT and SAT), sex, and socioeconomic status have significant roles in the retention and success of students. Therefore they have been included in this study. Other retention factors associated with student motivation, identity, and belonging have not been included due to the institutions limited access to this data. The institutional data allowed for the strongest statistical sample possible, whereas these other factors would have been representative at best.

Table 2. List of variables

Math & Physics Knowledge	*High School Success*	*Other Characteristics*
Calculus I Grade	ACT math	Sex
Calculus II Grade	SAT math	*(Male-0, Female-1)*
Physics I Grade	HS rank	US Citizenship
Physics II Grade	HS GPA	*(Citizen-0, Non-Citizen-1)*
Remedial Math Courses		Individual Financial Status (IFS)
(No - 0, Yes -1)		*(Budget – Family Contribution)*
		Course Load
		(Credit Hours)

** Note: Math and Physics course data includes the first grade achieved, the number of times repeated, and high grade achieved

Data Analysis

The data was analyzed using descriptive statistics, comparison of means, multiple and logistic regressions. In order to explore the implications of requiring a calculus prerequisite physics courses a t-test was used examining the difference in calculus and physics course grades between students that took Calculus I as a prerequisite to Physics I (group 1) to those students that took Calculus I as a corequisite to Physics I (group 2). The same analysis was conducted comparing the prerequisite and corequisite requirement for Calculus II and Physics II.

Multiple regressions were used to determine the predictors of success for the calculus and physics courses. These studies utilized the end of course grades for Calculus I, Calculus II, Physics I, and Physics II as dependent variables. The independent variables included the student demographics, high school success characteristics, prerequisite end of course grades for the dependent variable, and the course load during the semester that the dependent variable was taken. An additional multiple logistic regression was used to determine predictors of graduation success using the all of the independent variables identified in Table 5. The purpose of multiple regressions is to predict a single variable from one or more independent variables. Multiple regression with many predictor variables is an extension of linear regression that accounts for interrelationships among all the variables. The result of the analysis identifies statistically significant ($\alpha \leq .05$) independent variables and assigns weightings, β, for each of the variables used to model the dependent variable[22, 23].

Findings

In order to prevent the progress bottleneck observed at Clemson[12], it was necessary to understand whether a calculus prerequisite to the corresponding physics course would benefit the students. The comparison between the corequisite and prerequisite students indicated that the presence of a prerequisite did not provide the students with any added benefit. In fact, the data shows that students who took Calculus I and Physics I during the same semester (corequisite) had statistically significantly higher grades in Physics I than those who took Calculus I as a prerequisite. However, the difference was not practical as it has a low effect size and there was no statistical significance between the groups for grades in Calculus I (Table 3).

Table 3. Comparison of course grades for Calculus I and Physics I for corequisite and prerequisite requirements

	Corequisite *(N=2544)*	**Prerequisite** *(N=234)*	
Calculus I	2.34	2.37	
Physics I	2.08	1.89	*

* $p < .05$

Similar results were seen for Calculus II and Physics II as there were no statistically significant difference in course grades between students who took Calculus II and Physics II during the same semester (corequisite) than those that took the respective math course as a prerequisite (Table 4).

Table 4. Comparison of course grades for Calculus II and Physics II for corequisite and prerequisite requirements

	Corequisite *(N=1479)*	**Prerequisite** *(N=790)*
Calculus II	2.49	2.57
Physics II	2.31	2.36

* p < .05

Findings indicate that the requirement of a calculus prerequisite to the corresponding physics course is not warranted. Success in these courses is most likely related to factors other than the sequence in which the courses were taken. As an additional note, a comparison of math aptitude, as measured by average ACT math score, shows that there are no practical differences in the prerequisite (25.7) and corequisite (25.3) students at the Calculus I level. Similar results were seen at the Calculus II level (prerequisite=27.9, corequisite=27.5).

Math and Physics Predictors

The results of using multiple regression to predict course grades returned a modest R-square values for each of the four courses of interest as a dependent variable, ranging from .430 to .528 (Table 5). The results indicated significant predictors related to prior course work, high school success, and course loads.

Physics II grades were significantly predicted by the first grade achieved in Calculus II ($\beta = .461$, $p<.01$) and the high grade achieved in Physics I ($\beta = .142$, $p<.05$). Calculus II grades were significantly predicted by the students' first Calculus I grad ($\beta = .266$, $p<.01$) and their high school GPA ($\beta = .122$, $p<.05$). Similarly, the Physics I grade was significantly predicted by the first Calculus I grade ($\beta = .555$, $p<.01$) as well as ACT math grade ($\beta = .100$, $p<.05$) and the sex of the student tending towards females ($\beta = -.111$, $p<.05$). These findings allude to the importance that success in Calculus I has in the first year programs as well as their future courses.

Table 5. Results (standardized β) of multiple regression for Calculus and Physics courses

Predictor	**Calculus I** (R^2 =.504)	**Calculus II** (R^2 = .528)	**Physics I** (R^2 = .434)	**Physics II** (R^2 =.430)
Sex	**.075***	-.011	**-.111***	-.043
Citizenship	.049	.023	-.004	.014
SAT math	-.007	-.093	.058	.050
ACT math	**.150****	-.006	**.100***	.089
High School rank	-.074	-.020	.036	-.050
High School GPA	**.177****	**.122***	.057	-.025
IFS	-.040	-.024	-.040	.036
Remedial math (N/Y)	-.040	-.069	-.012	.004
Calculus I $_{\text{first}}$		**.266****	**.555****	-.047
Calculus I $_{\text{high}}$		.175*		.014
Physics I $_{\text{first}}$	**.486****	-.024		.173
Physics I $_{\text{high}}$		.020		**.142***
Calculus II $_{\text{first}}$				**.461****
Calculus II $_{\text{high}}$				
Physics II $_{\text{first}}$		**.371****		
Physics II $_{\text{high}}$				
Same term course load	**-.120***	.030	-.046	-.040
Calculus I/Physics I same term	.010	.000	.009	.096
Calculus II/Physics II same term		.076		-.113

Statistically significant predictors: * $p<.05$, ** $p<.01$

Note: grey cells are not included in regression analysis

An examination of the predictors of Calculus I grades indicates several statistically significant predictors which include the corequisite Physics I first grade ($\beta = .486$, $p<.01$), high school GPA ($\beta = .177$, $p<.01$), semester course load Calculus I was taken ($\beta = -.120$, $p<.05$), ACT math ($\beta = .150$, $p<.01$), and the sex of the student tending to favor males ($\beta = 0.075$, $p<.05$). A multiple logistical regression of the same data indicates that High School GPA ($\beta = 1.999$, $p<.05$), IFS ($\beta = -3.9E-05$, $p<.01$), average course load ($\beta = -0.130$, $p<.05$), and Physics II high grade ($\beta = 2.816$, $p<.05$) are significant predictors of graduation. Figure 1 illustrates the connection between these critical courses, their predictors and academic success.

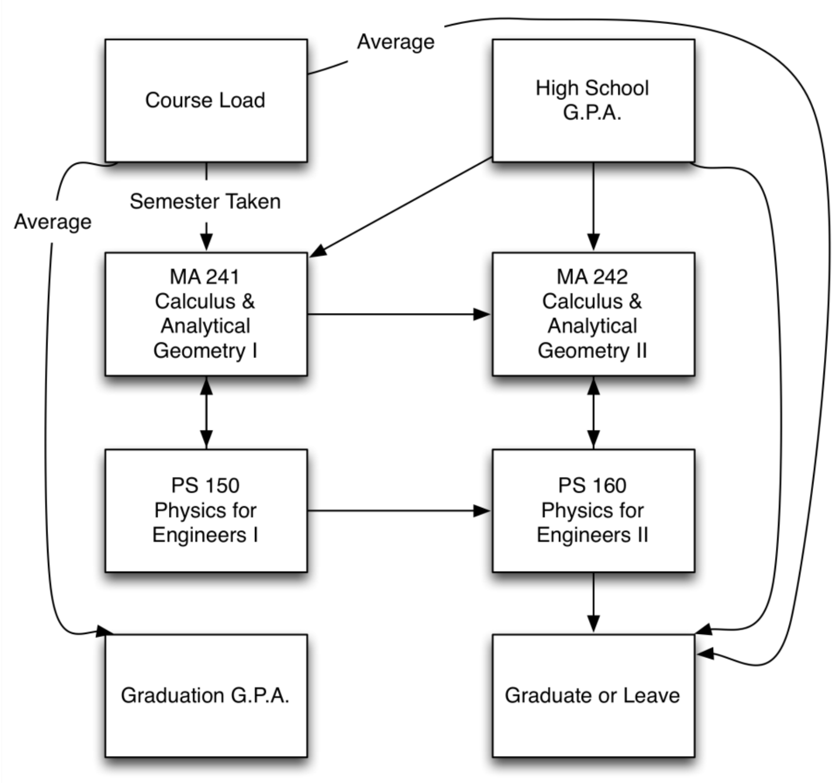

Figure 1. Flow diagram of academic success (arrows indicate predicts success in)

While the high school GPA and ACT math scores are fixed college entrance criteria specified by the institution and cannot be easily altered, the semester credit hours, because they are typically defined at a department level and are more easily controlled, can be recommend for varying performing students. Since the analysis leads to Calculus I as a potential bottleneck, the limiting of credit hours for this course could be beneficial.

Using the same institutional data, Figure 2 shows the distribution of Calculus I grade based on the credit hours taken that term and the students' ACT math score broken down into quartile distributions. As expected, students tend to follow a similar performance in Calculus I as they generally did on the ACT math exam. In addition, we also see that students taking between 12 and 14 credit hours, or just enough to be classified as full time students achieved higher grades than those students who took a higher course load regardless of which ACT quartile they scored in.

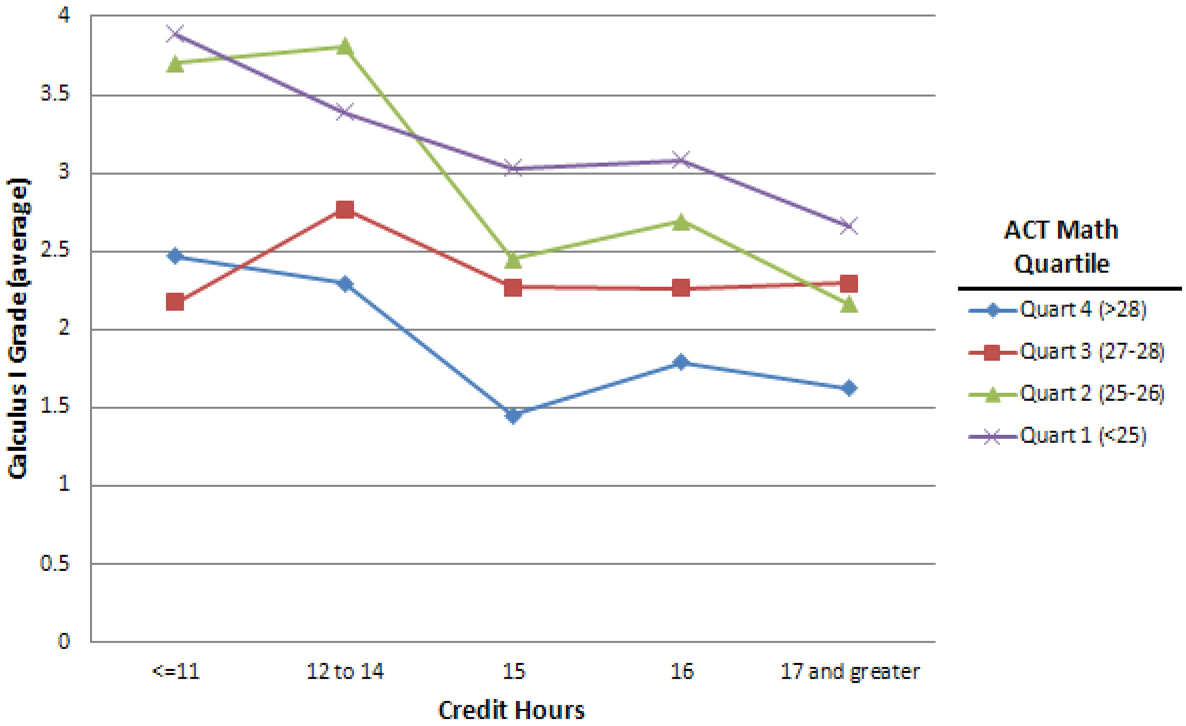

Figure 2. Average Calculus I course grade with respect to semester credit hours during term taken split by ACT math quartile *(Note: minimum N for students greater than 12 credit hours is 26)*

Conclusions and Recommendations

The enforcement of a prerequisite is not necessary and will only place further roadblocks to the graduation. The data, coupled with past studies, indicates that, while the Calculus I course is critical to student success in engineering, requiring it as a prerequisite to Physics I does not meaningfully impact Calculus I or Physics I grades. Based on the regression analysis and descriptive statistics one recommendation would be to limit the number of credit hours a student takes during the semester they are taking Calculus I based on the mathematical ability of the student. Students with limited prior success (based on ACT Math scores) are less likely to succeed in Calculus I if they are taking a high course load. Because Calculus I success is a major predictor of future engineering success (either directly in the case of Calculus II and Physics I or indirectly for Physics II) and graduation, it is critical that students build this solid mathematical foundation, and a reduced course load is one way to help do that.

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