The Influence of Mathematical Preparedness on Student Performance in an Engineering Statics Course

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Abstract

Student proficiency in algebra and trigonometry (Pre-calculus) and elements of differentiation (Calculus I), integration (Calculus II), and vector operations (Calculus III) are beneficial for success in Engineering Statics, the entry-level course for most engineering disciplines. However, many colleges and universities only require a co-requisite of Calculus I to enroll in Engineering Statics. Poor student mathematics preparation, speed of content delivery in college, magnitude of work outside of class (especially at The Citadel), and differences in content delivery between engineering and mathematics departments contribute to students meeting only the co-requisite rather than exceeding it. This research hypothesizes a correlation between a student's mathematical preparedness and their overall performance in Engineering Statics. Quantitative data collected suggests a positive correlation between the two that could indicate a need to revisit the pre-requisite/co-requisite discussion for Engineering Statics.

Keywords

Mathematical Preparedness; Engineering Statics

Introduction

Engineering Statics is the first intensive engineering course for many engineering disciplines at colleges and universities throughout the United States. This course sets the foundational knowledge needed by students to be able to perform well in subsequent engineering courses within their respective disciplines and as a result, is often seen as a "gatekeeper" course. Due to its importance, it is critical that students begin Statics with a firm foundation in several areas of mathematics, including trigonometry, geometry, differentiation, and integration. Therefore, a co-requisite of Calculus I is typically set by engineering departments in order to ensure that students have the appropriate mathematical preparation before they begin statics. This allows students to focus on learning new content within engineering rather than struggling to learn mathematical concepts that should be pre-requisite knowledge. At The Citadel, all engineering academic course maps require students to take Calculus I as their entry-level mathematics course. However, for many students coming directly from high school, their math placement exam scores indicate they lack the basic skills required to succeed in Calculus I and are subsequently placed in Pre-calculus.

At The Citadel, Engineering Statics serves civil, mechanical, and electrical engineering students. The course is led by the civil engineering department but faculty from any engineering department may teach the course. Over the past several semesters, faculty invest a significant portion of class time teaching basic mathematics skills, such as trigonometry and geometry, rather than focusing on Engineering Statics content. Inadequate mathematics skills create a language barrier between mathematics and engineering, severely limiting student investigation and learning of Engineering Statics course material.[1] Pilot efforts at the high school level may overcome the aforementioned language barrier eventually, [2] but this research primarily correlates the relationship between mathematics skill strength and Engineering Statics performance.

Due in part to the perennially abysmal results on international assessments of mathematics knowledge and ability,[3] many states in the US have adopted the Common Core State Standards for Mathematics (CCSSM). The Common Core outlines what a student should know and be able to do at each grade level, from kindergarten through high school.[4] Even those states that have not adopted the original CCSSM have adopted their own similar version of the standards, (eg. South Carolina College and Career Ready Standards). The *Content Standards* for High School cover the areas of Number and Quantity, Algebra, Functions, Modeling, Geometry, and Statistics and Probability. For example, one standard included in the functions category reads: "BF.A.1: Write a function that describes a relationship between two quantities."[4] In addition to Content Standards, the CCSSM includes *Standards for Mathematical Practice*, such as MP1: "Make sense of problems and persevere in solving them."[4] Overall the CCSSM provide a more focused view of mathematics than seen in previous standards documents, while at the same time attending to research-based notions of how students' mathematical understandings and abilities develop over time.[5,6]

While the CCSSM represent what a student *should* learn by the end of high school, higher education faculty are concerned with what students *actually learn* before they reach college and their corresponding level of college preparedness. Several factors relate to a student's college mathematics preparedness, including persistence within the math curriculum and rigor of courses taken during secondary school.

A student's willingness to persist within the high school mathematics curriculum is one of the largest indicators of collegiate mathematical success. For example, students who exit the math curriculum at Pre-calculus or Calculus I are 8 to 16 percent more likely to persist in college compared with their peers who finished high school with Algebra 2, and 16 to 27 percent more likely than those who only took Algebra I.[7] The South Carolina (SC) Department of Education requires that high school students have four mathematics credits to graduate, of which, eighth grade Algebra I can count as one of those credits[8]. Furthermore, SC does not require that students take a mathematics course every year, so it is feasible that a SC high school student that finishes with four mathematics credits, but only completing up through Algebra II, could successfully graduate high school and enter college without having actively practiced mathematics in over two years.

In addition to math courses taken, the level of rigor within those courses is also a strong indicator of future success, with Advanced Placement (AP) and International Baccalaureate (IB) courses relating to higher collegiate achievement and less likelihood of remediation.[7, 9] Not only do these courses offer a deeper level of content exposure, they often increase students' *mathematical proficiency* in ways that less rigorous courses do not. The National Research Council defines mathematical proficiency in terms of five interrelated strands:

- *conceptual understanding:* comprehension of mathematical concepts, operations, and relations

- *procedural fluency:* skill in carrying out procedures flexibly, accurately, efficiently, and appropriately
- *strategic competence:* ability to formulate, represent, and solve mathematical problems
- *adaptive reasoning:* capacity for logical thought, reflection, explanation, and justification
- *productive disposition:* habitual inclination to see mathematics as sensible, useful, and worthwhile, coupled with a belief in diligence and one's own efficacy.[9]

The traditional mathematics classrooms often focus on procedural fluency at the expense of the other strands[3], whereas IB approaches education as holistic,[11] and CollegeBoard advertises its AP courses as more rigorous and offering a deeper dive into the material.[12]

This research hypothesizes a correlation between a student's mathematical preparedness and their overall performance in Engineering Statics. Quantitative data indicating enrolled mathematics course versus Engineering Statics performance during the spring 2017 semester test this hypothesis. Results from this research provide the foundational knowledge for assessment of appropriate pre-requisite/co-requisite Mathematics course for Engineering Statics students.

Methods

Plickers, a real-time formative direct assessment tool,[13] was utilized near the end of the spring 2017 semester to record students' level of mathematics that they were currently enrolled in during the semester. Figure 1 illustrates the question asked to students using Plickers to collect the pertinent information (N = 54 students). This information was coupled with the students' overall performance (i.e., final grade) calculated at the end of the semester using a weighted-average scheme.

The Citadel requires that students in all engineering disciplines take at least four mathematics courses: Calculus I (MATH 131), Calculus II (MATH 132), Calculus III (MATH 231), and an Applied Engineering Mathematics I (MATH 234) course that is an integrated course covering linear algebra and differential equations. Students must take Calculus I and Calculus II in succession, but they have the option to take Calculus III and Applied Engineering Mathematics I in any order once they complete Calculus II. Additionally, Civil and Mechanical Engineering students are required to take Engineering Statics, but it is only a potential elective course for Electrical Engineering students. Students should have at least completed Calculus II if they are on track with their respective department's curriculum plan.

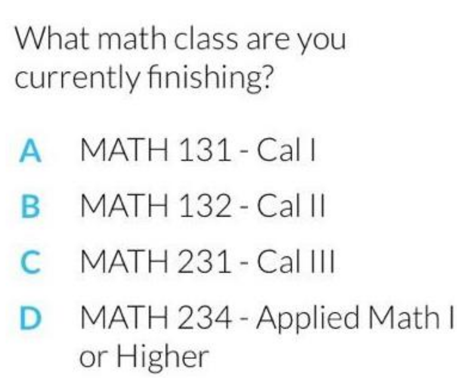

Figure 1: Plickers question used to capture 54 students' current level of mathematics during spring 2017.

Results and Discussion

Figure 2 show Engineering Statics performance as reflected in final letter grade versus the students' enrolled mathematics class during the Statics course. The trends are stark. Evaluation of the minimums and maximums are particularly revealing. No students enrolled in Calculus I or Calculus II concurrently with Engineering Statics earned an *A* in Statics and had a 30% chance of earning a *D* or *F*. By comparison, 92% of those students currently taking Calculus III or Applied Mathematics I were able to earn a *C* or better.

The averages are also illustrative. Calculus I students taking Statics received an average final grade of a *D*. Fortunately for the study population, very few students attempted to take Engineering Statics and Calculus I at the same time. Calculus II students performed better, earning a *C* average with half earning a *B*. Calculus III students improved to a *B* on average. Applied Mathematics I students, the largest population of students, averaged between an *A* and a *B* with 84% earning *A* or *B*.

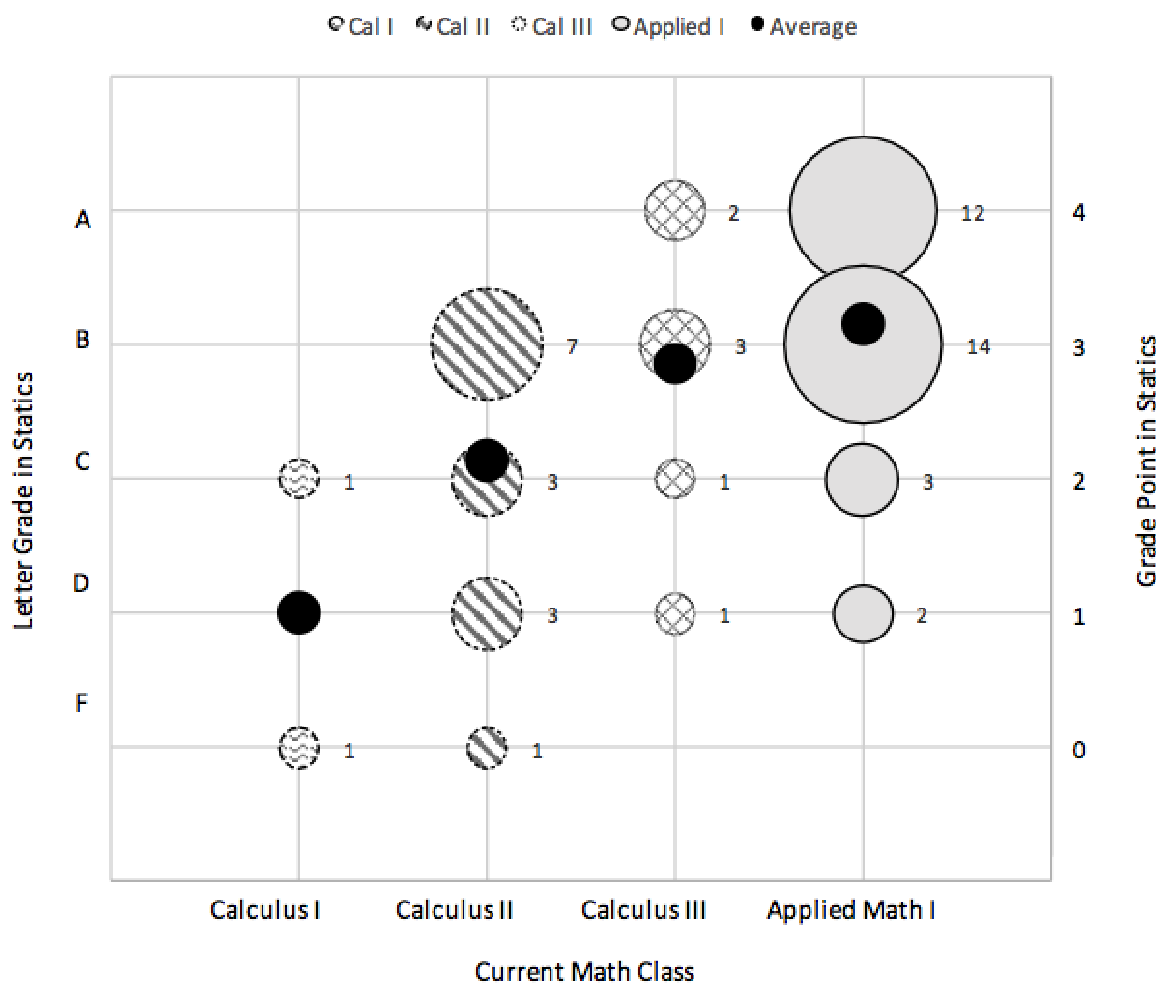

Figure 2: Statics performance by currently enrolled math class for 54 students during spring 2017

To understand whether Statics grade (or performance), measured on a continuous scale from 0-100, differed based on class, a Kruskal-Wallis test was performed. This test is sometimes also called the "one-way ANOVA on ranks" and is a rank-based nonparametric test used to determine statistically significant differences between two or more groups (e.g**.,** Calculus I, Calculus II, Calculus III, Applied Math I). The assumptions in order to use this test include a continuous dependent variable, an independent variable from independent groups, and independent observations (*i.e.* no one student is in more than one class). The Kruskal-Wallis test showed that there was a statistically significant difference in Statics grade between the different math classes providing a Chi-squared statistic of 12.855 and a p-value of 0.00496.

Conclusions

Results from the direct assessment show a positive correlation between students taking a higher level of mathematics beyond the co-requisite of Calculus I; however, correlation does not necessarily imply causation. A variety of lurking variables could contribute to the correlation; perhaps other student attributes developed while taking higher-level courses including perseverance, improved study habits, and improved ability to visualize multidimensional problems. Additionally, because a student only meets the co-requisite of Calculus I does not necessarily mean that they are unable to perform well in Engineering Statics. This research does not identify all causes that will influence student performance in Engineering Statics, but rather it serves as an exploratory first step. Future research must uncover particular factors underlying this correlation, particularly those significant to the trend. For example, certain strands of mathematical proficiency are likely critical to a course like Engineering Statics in which students engage with non-routine, open-ended problems on a daily basis (e.g. strategic competence). Despite the novelty of this research, these results support further research into determining the appropriate pre-requisite/co-requisite mathematics requirements for Engineering Statics. Students may be disadvantaged if allowed to take Engineering Statics while still developing core mathematics skills. Based on these preliminary findings, students would be best served if a co-requisite of Calculus III was established. Coincidentally, Calculus III or Applied Mathematics I are the mathematics courses that students would be taking if strictly adhering to The Citadel engineering academic course curriculums.

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