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Quantitative Investigation of Preparatory Math Coursework as a Barrier for Degree Attainment in Engineering*

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Preparatory, or "remedial" math and writing courses have long been studied as barriers to success in postsecondary education, particularly for disadvantaged students. The negative effects seem to be particularly pronounced at four-year institutions, like the one studied here. Prior work in this area has not had the granularity to determine at what point students who are not math ready leave engineering pathways. We set out to determine how performance in trigonometry courses affects further math and science course enrollment, as well as college graduation rates. We used logistic and linear regression to investigate outcomes for 3,615 engineering students at a public research university. We find that the probability of graduating with an engineering degree within 6 years or leaving the university with no degree depends on the grade received in trigonometry. We find that students who get an A in trigonometry are no more likely than calculus-ready students to leave the university but are still less likely to stay in engineering. We find that math-ready students are more likely to enroll in physics and calculus 2 than trigonometry students who get As. This work shows that preparatory math courses may serve as a barrier to persistence in engineering, even if students are successful in the courses, and that the primary point of attrition for these students appears to be after calculus 1.

Keywords: remedial math; persistence; equity; introductory STEM courses

1. Introduction:

There is a noted gap between what qualifies as satisfactory completion of secondary education and what constitutes being ready for post-secondary education in the United States [1]. This is indicated by the growing use of developmental education (sometimes called remedial education, here called "preparatory" education), which is now undergone by 40% of undergraduate students nationally [2] These are high-school level courses taken at a postsecondary institution to make up for gaps in students' preparation for postsecondary coursework.

There is a unique challenge to examining preparatory math coursework in engineering disciplines because the threshold for math-readiness is different from most college students: engineering students are expected to be ready for calculus 1 when they enter college, rather than trigonometry or algebra. Designing good preparatory coursework is thus a substantial challenge because students can be two or more semesters behind in their mathematics preparation. The existing studies that look at this find that students who place into lower levels of "remediation" see some positive outcomes [3–5]. For example, Ref. 3 found that enrolling in pre-algebra at two-year institutions had some positive effect on eventually passing college level-math (while being enrolled in algebra did not). We should note, however, that any positive effects are often small, even if statistically significant.

The current study aims to investigate the impacts of preparatory math coursework on outcomes for engineering students at a research-intensive university. The results as to the impacts of preparatory coursework are mixed, though generally it is thought to pose a barrier to students' long-term success. However, almost all this prior research was conducted at two-year institutions or primarily undergraduate four-year institutions. Relatively little is known about the impact of preparatory coursework at more selective institutions. Furthermore, studies of preparatory coursework rarely consider the degree of success within the preparatory course and how that contributes to differences in student outcomes. For example, how do the outcomes of students receiving As in preparatory courses compare to the average outcomes for students placed into standard course sequences?

Another contribution made by the present study is a more thorough understanding of the course trajectories of students who enroll in preparatory coursework. For example, if someone enrolls in preparatory math, to what degree are they successful in calculus 1? Do they eventually enroll in courses that have calculus 1 as a prerequisite like calculus 2 and physics 1? Do they enroll in other required science and math courses instead of physics and calculus because they do not meet the

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prerequisites? Most studies examine only holistic outcomes like graduation rates, GPA, and credits earned. Here, we zoom in on the core course sequence that is critical for all engineering majors to complete: chemistry, calculus, and physics.

Furthermore, as Scott-Clayton and Rodriguez (2015) note, few studies examine larger variations in student preparation and the impact that has on student outcomes – most studies are limited to students near the cutoff for preparatory coursework placement [6]. In this study, based on prior research demonstrating that past performance in STEM is a strong predictor of future performance [7], we examine how outcomes vary for students of varying levels of performance in the preparatory math courses. The research suggests this will be strongly related to the level of mathematics preparation.

Preparatory coursework is also important from an equity perspective. In the United States, historically marginalized groups are more likely to attend under-resourced high schools [8, 9], and thus enter the university with lower levels of preparation for college coursework; they are thus more likely to enroll in preparatory coursework. If preparatory courses are indeed posing a barrier to success for students, they may be systematically excluding marginalized groups from pursuing engineering degrees. We thus examine whether preparatory courses are serving as more of a barrier to low-income students in engineering, who are more likely to be first-generation students or students of color. Though there has been much attention paid to gender disparities in engineering education, there is very little research on income disparities [10, 11].

Due to the complex nature of student pathways, in the present study we choose to focus solely on outcomes for engineering students whose first math course in college is trigonometry (one semester behind schedule). We investigate a variety of outcomes for these students including leaving college with no degree, 6-year engineering graduation rates, enrollment in future courses, and grades in calculus courses. We investigate outcomes for a wide range of students by controlling for students' high school preparation, and by investigating outcomes across the range of the grade distribution in the preparatory course, rather than focusing simply on a binary measure of enrollment. The results will show that being even one semester behind in the math sequence can pose a significant barrier to success in undergraduate engineering programs.

Our research questions for this study were:

1. How is performance in trigonometry correlated with important milestones in an engineering degree such as enrolling in calculus and graduating?
2. How is performance in trigonometry correlated with performance and enrollment in follow-on required courses in engineering programs?
3. Are the effects of preparatory coursework different for students from lower socio-economic strata?

The ultimate goal of this study is to provide a more detailed understanding of the impacts of preparatory coursework: to what degree success in these courses impacts student outcomes, how preparatory coursework affects enrollment in required engineering courses, and who preparatory coursework most affects. With this, we hope to identify places for potential intervention on the part of both teachers of preparatory math courses and administrators concerned with the success of first-year engineering students.

In the following sections we review the literature on preparatory math courses and describe the conceptual framework for this paper. We then describe the sample population and analytic methods used and follow with the results of that analysis. We then discuss those results and the implications for policy makers and future research directions, and then conclude with some final thoughts.

2. Literature Review

Most of the quantitative research on preparatory coursework consists of regression discontinuity analyses. This is a technique that allows one to compare students who are just above and just below a cutoff for placing into a preparatory course. Studies of this kind have found mixed results as to the effectiveness of preparatory courses [3–5, 12–15]. Furthermore, Ref. [6] point out that policy makers need to interpret these results carefully because the effects are not well understood for students far below the cutoffs for preparatory coursework. Some studies have attempted to address this by controlling for other student characteristics and preparation measures [15].

The specific outcomes investigated in the literature on preparatory coursework vary. Some studies examine degree attainment, some measure the decision to enroll in preparatory coursework, some measure credit hours completed, and a small, but growing, subset investigates grades in follow on non-preparatory courses. A recent meta-analysis [1] found substantial negative effects on performance in the follow-on course, credit hours completed, and degree attainment. This study covered both mathematics and reading/writing courses.

Most studies of preparatory coursework are found in educational policy and community college literature. A more limited set has expanded these analyses to include more four-year institutions, but so far, we found few studies that address the role of preparatory coursework in science, technology, engineering, and mathematics (STEM) disciplines specifically, and none that focused on engineering students in particular. A study of an online preparatory course at UC Davis showed that students in the online preparatory course had similar course grades to chemistry-ready students after controlling for academic preparation like SAT score [16]. The UC Davis study, however, is subject to strong selection bias as students could either choose to enroll in the online summer course or take a traditional in-person preparatory course. Similar findings have been seen in physics [17], though there are also studies showing how online remediation does not always work for those who need it most [18].

There are a few studies in the engineering education literature that address the issue of preparatory math coursework. Most recently, Main & Griffith (2022) conducted a study of preparatory coursework at a selective research university [19]. They found negative impacts of taking preparatory coursework on declaring an engineering major, time to degree, and overall graduation rates. Interestingly, they find that women and students of color fare better in remedial courses than do white men. Another study conducted a study of math placement at another highly selective public university [20]. They found that students enrolling in calculus 1 (as opposed to calculus 2 or higher-level math courses) were less likely to receive engineering degrees and had lower GPAs overall. They also found that approximately 18% of students enrolled in a lower-level course than they were prepared for. Finally, one study found some potential positive effects of preparatory coursework [21]. Indeed, they found that students who placed into preparatory coursework and received higher grades were more likely to graduate than equivalently prepared students who placed into calculus and received lower grades.

3. Conceptual Framework

Scott-Clayton and Rodriguez (2015) delineate three broad hypotheses for the role of preparatory coursework in postsecondary education [6].

1. *The Developmental Hypothesis* posits that preparatory courses primarily serve to develop students' skills that prepare them for future college-level courses and do not pose a barrier to their success, rather an opportunity to be successful [22]. This is embodied in the terminology of "preparatory" coursework or "developmental education." Thus, these courses might serve as an investment to assure that these students do not have negative experiences in their first math or reading courses. Ref. 13 provides some promising evidence for this hypothesis: they found that students across two- and four-year colleges in Ohio were more likely to complete a bachelor's degree in four years if they participated in preparatory coursework (compared with similarly prepared counterparts). However, they also found that students remediated within math were more likely to drop out within the first year. Refs. 14 and 15 found no effect of remediation on degree attainment or eventually completing the equivalent college-level course, suggesting students in preparatory coursework fared the same as the college-ready students. In our data set, if this hypothesis were supported, we would expect non-calculus-ready students to complete engineering degrees and enroll in higher level math courses at rates similar to calculus-ready students.
2. *The Discouragement Hypothesis* posits that these courses stigmatize students and send a negative signal about their probability of success [23]. This follows [24] which describes a "cooling out" process in which obstacles gradually diminish students' career aspirations. Students who place into preparatory coursework may never enroll in the course or may drop out sooner even if they do enroll. Ref. 6 emphasizes the need to thus track students from the point at which they are sorted into preparatory coursework onward, as well as the effects of placement on actually enrolling in the preparatory course [25]. Ref. 6 also emphasizes that this hypothesis highlights the importance of considering the heterogeneity of effects in student populations. For example, one study finds that negative effects are less pronounced for the least prepared students, suggesting they may interpret this placement differently than students closer to the cutoff [15]. In our data, the discouragement hypothesis would manifest as students enrolling in preparatory math courses not enrolling in higher level courses like calculus, and not receiving engineering degrees at the same rate as calculus ready students.
3. *The Diversion Hypothesis* posits that these courses reduce the heterogeneity in preparation in college classrooms and may or may not pose a barrier to success. This posits preparatory coursework as learning experiences for poorly prepared students rather than preparation for future coursework. That is, a student may take

algebra instead of a college-level math class and still receive a degree that does not require further math coursework; the algebra course thus becomes a pure learning experience. This is akin to "tracking" in the K-12 literature, which largely finds negative effects of tracking [26, 27]. There is some concern that having poorly prepared students in introductory coursework may hinder the learning of better prepared students, but this seems to be largely untrue [28]. This hypothesis cannot be supported with the data in this paper because we are specifically interested in engineering degree attainment, not other pathways that students might take.

In Ref. 6, the authors find little evidence for the developmental hypothesis. They also find little evidence for the discouragement hypotheses, except in cases where students place into one preparatory course and one college-level course in similar disciplines. The effects are for reading and writing and are large and noisy. They find their results to be most consistent with the diversion hypothesis. In principle, diversion of students to different post-secondary pathways may not be a negative outcome. However, from the perspective of producing a skilled and diverse engineering workforce, it would be concerning if preparatory math courses were diverting students away from engineering careers. There is some literature to suggest this may be the case.

We posit an additional hypothesis based on our own conversations with undergraduate students.

4. *The Structural Hypothesis* posits that these courses pose logistical and financial barriers to student success by increasing the time to degree. This is particularly salient for students from lower socioeconomic strata, who are more likely to be first-generation students and/or from underrepresented demographics in STEM. This is not the same as stigmatizing students, rather it represents practical barriers to degree attainment. In our data, the discouragement hypothesis would manifest as students enrolling in preparatory math courses not enrolling in higher level courses like calculus or physics. In this study, we explicitly test this hypothesis. Namely, we quantitatively test whether socioeconomic gaps in achievement can be explained by math readiness, and whether the relationship between math readiness and achievement is different for low and high socioeconomic status students (as measured by Pell grant status). If the pathways are different, this would support the hypothesis that preparatory math courses pose more of a barrier to marginalized students compared with majority students, which would be evidence in support of the structural hypothesis.

To us, these hypotheses are not mutually exclusive. Indeed, it seems likely that multiple factors may influence students' perceptions and experiences of preparatory coursework. We also note that any type of quantitative analysis cannot prove any of the stated hypotheses. Quantitative research can provide critical insight into how prevalent certain trends are – it cannot tell us about the reasoning behind student decision-making. As we describe in the discussion, this highlights the strong need for qualitative research in this area.

4. Methods

Data were collected from institutional records from a public research-intensive university in the southern United States. The institution is predominantly white (80%) and the interquartile range of composite ACT scores is 25–31 (the ACT is one of two prevalent college entrance exams in the United States and the maximum score is 36). We had access to student records for over 100,000 students enrolled at the university between 2011 and 2022. As we were investigating six-year graduation rates, we included only students who enrolled between the Fall of 2011 and the Fall of 2015 to ensure we had a six-year graduation window in the data. We chose a six-year graduation window rather than a four-year graduation window as many calculus-ready engineering students take five years to graduate due to internship requirements. Additionally, it is much less likely for non-calculus-ready students to graduate in four years due to the extra time required to take preparatory math courses. We wanted to allow these students the time that would be required to receive an engineering degree. We restricted our analysis to first-time freshmen and U. S. citizens because transfer student and international student populations face different sets of challenges. Additionally, international students and transfer students represent <1% of engineering students at the university, so we did not have statistical power to examine separate outcomes for these groups. We included only students initially studying engineering. The final pool of students was 3,615 students. 13.5% of these students were Pell grant recipients, 9.5% were first-generation college students, 10.8% were underrepresented minority students (Black, Latinx, or Native American students), and 19% were female (only binary measures of gender are kept in this institutional dataset).

For each student in the sample, we had a list of any degrees they received in the 6-year window, their major during each term they were enrolled, their grades from all mathematics, physics, and chemistry courses, and data from their admissions records. 21% of students were first enrolled in trigonometry prior to taking calculus. In the results presented below, we note that the grades are for the first time a student takes their first preparatory math course. We do not account for taking a course multiple times. The outcomes we investigated were graduating with an engineering degree, leaving the university with no degree, enrollment and performance in calculus 1, enrollment in calculus 2, enrollment in physics 1, and enrollment in chemistry 1.

The instructional style in these preparatory math courses can be quite variable. The courses are taught in sections of roughly 20 students by multiple instructors. For example, in the last semester 10 sections of one preparatory math course were taught by 5 different instructors. The predominant style in the math department at this university is to use typical lecture-based instruction, with weekly assignments and high stakes exams. There is a small, but growing, number of mathematics faculty who have been trained in student-centered pedagogy, but that is not the norm in these courses.

To investigate graduation, leaving, and follow-on course enrollment rates, we used logistic regression. The outcome variables were binary (e.g., receiving an engineering degree or not). The primary input variable was categorical: grade received in the preparatory mathematics course. This was factor with levels A, B, C, DFW, and None, where None indicated that a student was calculus ready. In addition, we controlled for the equivalence of students' high school academic preparation using composite ACT scores and high school GPA as covariates, though this did not qualitatively change any of the findings. This allows us to measure the probability of certain outcomes for students who may have different math pathways but have equivalent college preparation. The regression model was:

$$\log\left(\frac{P}{1-P}\right) = \beta_0 + \beta_1 Math\ Grade + \beta_2 ACT + \beta_3 HS\ GPA \quad (1)$$

In the results, we report probabilities (P) computed by the logistic regression models with associated standard errors instead of regression coefficients for ease of interpretation. We note that, because of the covariates, this probability cannot be interpreted as an exact proportion of students. For example, the probability of a trigonometry student graduating with an engineering degree turns out to be higher than the probability of enrolling in Calculus 2 when you control for other effects. This does not mean that there are students graduating from engineering without taking calculus 2, it means that the effects of ACT and HS GPA on enrollment in calculus 2 are slightly more pronounced than their effects on graduation rates. These models can roughly be thought of as predictions for how students will fare in their undergraduate engineering program based on their initial college preparation and math placement/grade.

To investigate grades in Calculus 1 we used linear regression with grade converted to a 4.0 scale as the outcome variable. The regression equation was:

$$Calc\ Grade = \beta_0 + \beta_1 Math\ Grade + \beta_2 ACT + \beta_3 HS\ GPA \quad (2)$$

To investigate whether enrollment in preparatory had different impacts on different socioeconomic groups we also used logistic regression. We primarily investigated whether the gap in graduation rates between majority students and minority students was different for students who were math ready versus students who placed into trigonometry. This was done by including an interaction term between enrollment in remedial math courses and Pell-grant status.

5. Results

The probability of a calculus-ready student graduating with an engineering degree is 0.78 (95% CI = [0.76, 0.79]). The effect of trigonometry grade on graduating with an engineering degree is shown in Fig. 1. The probability of a student who gets an A in trigonometry receiving an engineering degree is 0.66 (95% CI = [0.58, 0.72]), which is significantly different from the calculus-ready students at the $p = 0.05$ level. The probability of a student who gets a B

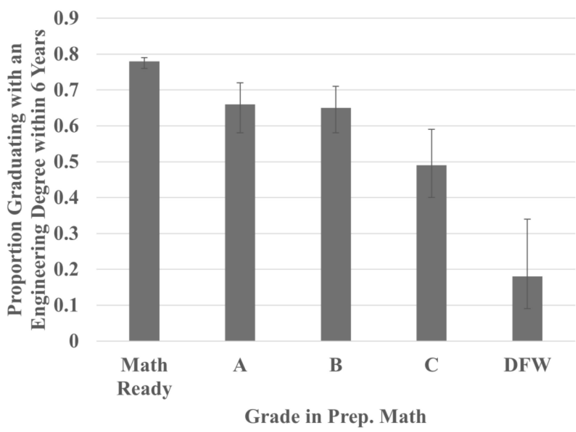

Fig. 1. Probability of graduating with an engineering degree within 6 years as a function of course grade in trigonometry (preparatory math). Partial letter grades are not assigned, and the error bars represent 95% confidence intervals.

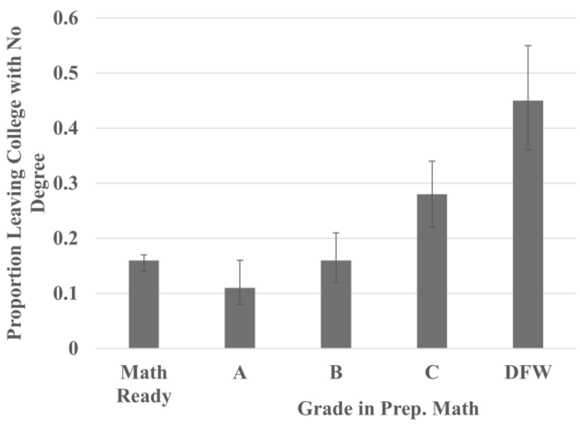

Fig. 2. Probability of leaving college with no degree as a function of course grade in trigonometry. Partial letter grades are not assigned, and the error bars represent 95% confidence intervals.

or C in trigonometry receiving an engineering degree is 0.65 (95% CI = [0.58, 0.71]) and 0.49 (95% CI = [0.40, 0.59]), respectively. The probability of a student who gets a D, F, or withdraws (DFW) from trigonometry receiving an engineering degree is 0.18 (95% CI = [0.09, 0.34]).

The probability of a calculus-ready student leaving college with no degree is 0.16 (95% CI = [0.14, 0.17]). The probability of a student leaving college with no degree as a function of trigonometry grade is shown in Fig. 2. The probability of a student who earns an A in trigonometry leaving college with no degree is 0.11 (95% CI = [0.08, 0.16]), which is statistically indistinguishable from the probability of a calculus-ready student leaving college with no degree. The probability of a student who gets a B or C in trigonometry leaving college with no degree is 0.16 (95% CI = [0.12, 0.21]) and 0.28 (95% CI = [0.22, 0.34), respectively. The probability of a student who gets a D, F, or withdraws from trigonometry leaving college is 0.45 (95% CI = [0.36, 0.55]).

The probability of a calculus-ready student enrolling in Calculus 1 is 0.84 (95% CI = [0.82, 0.85]). The probability of a student who gets an A in trigonometry enrolling in Calculus 1 is 0.87 (95% CI = [0.81, 0.91]); see Fig. 3. This is statistically higher than calculus-ready students at the 0.10 level For a student who gets a B in trigonometry the probability is similar: 0.81 (95% CI = [0.74, 0.86]). For a student who gets a C it drops to 0.68 (95% CI = [0.59, 0.76]), which is lower than calculus-ready students. For students earning a DFW in trigonometry, the probability of eventually enrolling in Calculus 1 is 0.36 (95% CI = [0.27, 0.45]).

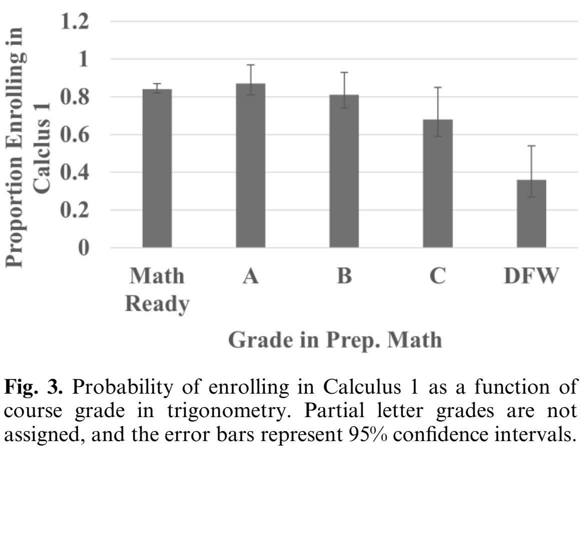

Fig. 3. Probability of enrolling in Calculus 1 as a function of course grade in trigonometry. Partial letter grades are not assigned, and the error bars represent 95% confidence intervals.

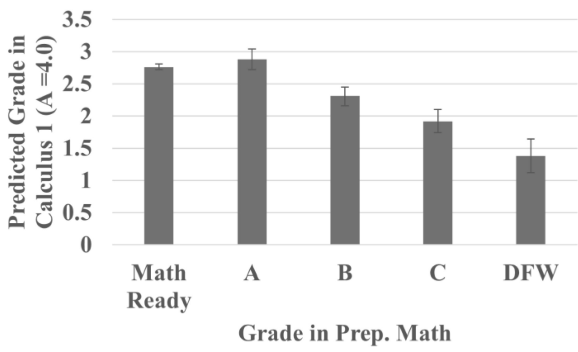

Fig. 4. Predicted grade in Calculus 1 as a function of course grade in trigonometry. Partial letter grades are not assigned, and the error bars represent 95% confidence intervals. Note that the grade in each bar represents the average grade for that group of students.

The average grade for a calculus-ready student in Calculus 1 is 2.76 (95% CI = [2.72, 2.81]; see Fig. 4). The average grade in Calculus 1 for a student who gets an A in trigonometry is 2.88 (95% CI = [2.72, 3.04]), which is statistically identical to math ready students (see Fig. 4). For students who get a B the average grade drops to 2.31 (95% CI = [2.16, 2.45]), which is still above the threshold for enrolling in Calculus 2. For students who get a C the average grade is 1.92 (95% CI = [1.74, 2.10]), and for DFW students it is 1.38 (95% CI = [1.12, 1.64]); the latter CI does not overlap with the 2.0 threshold required to move on to calculus 2.

The probability of a calculus-ready student enrolling in Calculus 2 is 0.81 (95% CI = [79, 0.82], Fig. 5). For trigonometry students who get an A or a B, the probability of enrolling in Calculus 2 is 0.56 (95% CI = [0.49, 0.63]) or 0.43 (95% CI = [0.38, 0.50]), respectively, which is substantially lower than calculus-ready students. For students who get a C, the rate of enrollment drops to 0.26 (95% CI = [0.20, 0.32]) and for DFW the rate drops substantially to 0.14 (95% CI = [0.10, 0.21]).

The probability of a calculus-ready student enrolling in Physics 1 is 0.88 (95% CI = [0.86, 0.89]). This is statistically higher than any of the students who started in trigonometry (Fig. 6). Students who received an A in trigonometry had a 79% chance of enrolling in Physics 1 (95% CI =

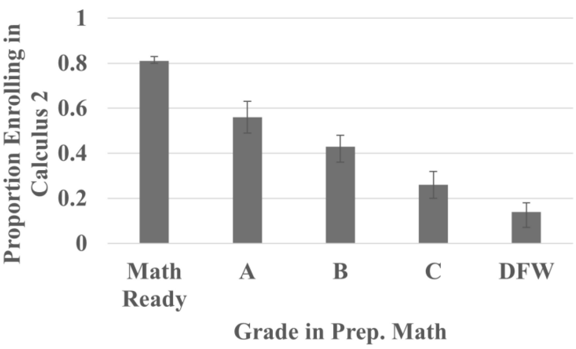

Fig. 5. Probability of enrolling in Calculus 2 as a function of course grade in trigonometry. Partial letter grades are not assigned, and the error bars represent 95% confidence intervals.

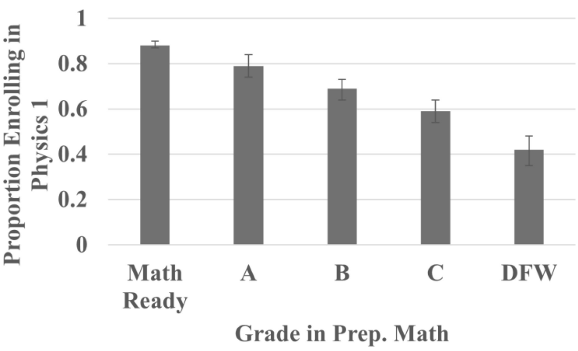

Fig. 6. Probability of enrolling in Physics 1 as a function of course grade in trigonometry. Partial letter grades are not assigned, and the error bars represent 95% confidence intervals.

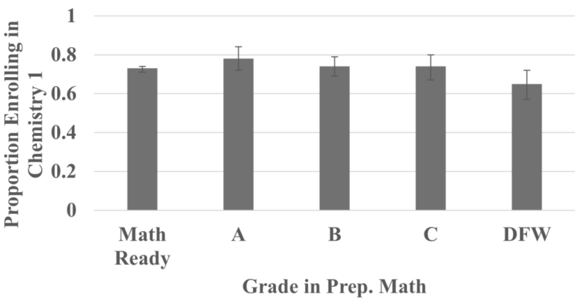

Fig. 7. Probability of enrolling in Chemistry 1 as a function of course grade in trigonometry. Partial letter grades are not assigned, and the error bars represent 95% confidence intervals.

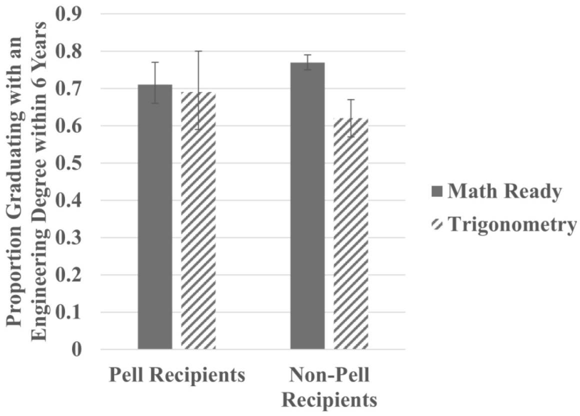

Fig. 8. Probability of receiving an engineering degree for Pell Recipients (left) and non-Pell recipients (right) who were math-ready (solid) or enrolled in trigonometry (shaded). Error bars represent 95% confidence intervals.

[0.74, 0.84]), students who received a B or a C had a 69% chance (95% CI = [0.65, 0.74]) or 59% chance (95% CI = [0.54, 0.64]) of enrolling in Physics 1, respectively. Students with a DFW in trigonometry had only a 42% chance of eventually enrolling in Physics 1 (95% CI = [0.36, 0.49]).

The probability of a calculus-ready student enrolling in Chemistry 1 is 0.73 (95% CI = [0.72, 0.75]). This is statistically identical to the students who started in trigonometry (Fig. 7). Students who received an A in trigonometry had a 78% chance of enrolling in Physics 1 (95% CI = [0.72, 0.84]), students who received a B or a C had a 74% chance (95% CI = [0.69, 0.79]) or 74% chance (95% CI = [0.68, 0.81]) of enrolling in Physics 1, respectively. Students with a DFW in trigonometry had a 65% chance of eventually enrolling in Chemistry 1 (95% CI = [0.58, 0.73]).

Finally, we examined the differential probabilities of receiving an engineering degree for Pell-Recipients and non-Pell Recipients who were math ready or enrolled in trigonometry. Among students who were math ready, Pell Recipients had a 71% chance of receiving an engineering degree (95% CI = [0.65, 0.76]), whereas non-Pell Recipients had a 77% chance (95% CI = [0.75, 0.79). This difference is not statistically significant. Similarly, among students who enrolled in trigonometry, Pell Recipients had a 69% chance of receiving an engineering degree (95% CI = [0.58, 0.79]), whereas non-Pell Recipients had a 62% chance (95% CI = [0.57, 0.67]). Again, this difference is not statistically significant. When comparing within groups (Pell or non-Pell), we see that enrolling in preparatory math courses does not seem to pose an additional barrier for Pell recipients, while it does for non-Pell recipients. This is the opposite of what was hypothesized. As shown in the Appendix, preparatory coursework does not appear to have a disproportionate impact on any demographic minority (women, students of color, or first-generation students).

6. Discussion

We found that students who enroll in preparatory math courses are less likely to receive an engineering degree in 6 years, regardless of what grade they got in that course. We also found that most students in preparatory math courses were no more likely to leave the university with no degree than calculus ready students. These data thus support the diversion hypothesis: students who enroll in preparatory courses receive degrees at similar rates to calculus-ready students, they are just in non-engineering fields.

We see a strong correlation between grade in preparatory math coursework and either receiving an engineering degree or leaving college with no degree. This aligns with expectations and prior literature showing that students with higher GPAs are more likely to graduate and less likely to leave college [29]. While we do not report the correlation with high school math preparation directly, the established strong link between early college performance and high school preparation strongly suggests that this implies the least math-prepared students are the least likely to graduate with engineering degrees, and the most likely to leave college. Ref. 6 reported more negative outcomes for preparatory math students with higher high school preparation. We see some evidence for this in Appendix A. Once controlling for grades in preparatory math, those with better high school preparation are less likely to persist to calculus 1. This means that two students who get an A in trigonometry, the one with a higher ACT score is less likely to persist.

Interestingly, we find that students who get As and Bs in trigonometry are slightly more likely than calculus-ready students to enroll in calculus. We believe this is because students at this university must declare a major when they apply to the university. Thus, there is likely a significant fraction of students who apply as engineering majors but change their minds when they arrive at the university. This is less likely among students who take trigonometry because they have already made the decision to start the math sequence their first term. Indeed, we find that 27 percent of calculus-ready students switch out of STEM within the first year, compared with 22 percentage of trigonometry students.

Another finding was that students who get As and Bs in trigonometry get similar grades in Calculus 1 to students who are math ready. However, we find that even the A-earning trigonometry students are less likely to enroll in Calculus 2 and less likely to enroll in Physics 1 indicating that there is a barrier in the transition to Calculus 2 from Calculus 1. This indicates that there is some barrier between calculus 1 and follow-on courses that is diverting students from their engineering pathways.

We hypothesize that the reason for this diversion after calculus 1 is primarily discouragement. It is well-documented in the literature on preparatory coursework that placing into these courses negatively affects students' motivation. It places students on a different track from what is "typical" (or rather, expected) of an engineering major. Students with fixed mindsets may perceive this as a signal that they are not "smart enough" to be a scientist or that they are not "good at science." These negative effects on self-efficacy may be driving students to change majors. The motivation hypothesis could be supported for some of the data presented here. For example, the students who get As and Bs in trigonometry suddenly become B and C students in Calculus 1, which could be discouraging and why they choose not to enroll in Calculus 2. However, this could also be a structural problem as we detail next.

Another hypothesis is that the barriers to persistence are structural. Placement into trigonometry places students one semester behind in the typical course sequence. For most students, this will likely increase the time it takes to receive a degree. Indeed, for all the majors studied, the calculus-ready students are expected to enroll in calculus 1 in their first semester. Many scholarships and financial aid packages are only valid for eight semesters, so being behind in math poses a financial barrier to pursuing an engineering degree for students from lower socioeconomic strata. We did not find a moderation effect in our data to support this claim: math-readiness did not pose a larger barrier for Pell-grant recipients than it did for non-recipients. This does not refute the structural hypothesis, rather it fails to provide evidence to support it. We believe that one explanation could be the limited measurement of Pell-grants. This is a binary variable, which thus has relatively little explanatory power in any model. Furthermore, Pell grant recipients are not all the students who may be on other loans and scholarships that only last for four years. Future quantitative investigations should attempt to collect more detailed socioeconomic data on students to test for this possibility. We note, however, that there should still be continued efforts to support low-income students in engineering, as there are other challenges that they face [30].

These numbers are for a single four-year institution in the United States and may not be reflective of national trends. However, the institution is representative of an institutional type in the United States which educates a significant number of engineering majors. We encourage other researchers to investigate these trends at their own institutions to determine to what extent the results hold true in different contexts.

Quantitative studies are limited in their ability to explain trends like these. In a future study, we will conduct interviews with students who place into preparatory math coursework to determine why they may choose to persist in engineering or switch majors. Seymour and Hunter (2019) conducted the most thorough qualitative study of STEM persistence to date, but they do not focus on particular subgroups such as those who enroll in preparatory coursework [31]. Our understanding of what influences particular groups of students to persist in STEM or not remains incomplete.

The data presented here, unfortunately, do not present a solution to the problem, nor do they fully illustrate the underlying causes. Regardless, it shows that the current structure of preparatory math coursework is not functioning optimally. Prior studies in chemistry have suggested two different paths for addressing preparation gaps: summer preparatory programs and intensive co-curricular courses (either online or in-person). Other studies, such as the STEM-Dawgs program at the University of Washington, have shown positive effects of intensive supplemental instruction on course grades in general chemistry [32]. That study controlled for selection bias by randomly selecting students for supplemental instruction from a waitlist and comparing the students in the intervention to other volunteer students.

It remains to be seen whether similar interventions could work in mathematics. One of the challenges of making students calculus-ready is that they are often several semesters behind in math preparation, so co-curricular supports may not be sufficient [33]. At the institution studied here, an online preparatory course was recently implemented that allowed students to place into calculus after receiving a certain score in the course. In the future, we will repeat our study to see if this intervention has had the desired effects on student persistence. We will also extend our analysis to college algebra to investigate outcomes for students who are multiple semesters behind in math.

We strongly suspect that the diversion of preparatory math students away from engineering pathways occurs after calculus 1. They go from receiving As or Bs in trigonometry to Bs or Cs in calculus, and we hypothesize that this discourages them. An intervention to remedy this problem could thus be two-fold: (1) we should try to improve the performance of all students in calculus 1 and (2) we should conduct a sense of belonging intervention early in calculus 1 to send a signal to students that they belong in engineering [34]. Improving student performance in calculus 1 could be accomplished by reformed teaching methods. Indeed, our university recently changed the structure of calculus courses to include more recitation and practice time, which should result in improved outcomes for students. A transition to student-centered instruction in the lectures would also likely improve student outcomes. As for sense of belonging, Singh and colleagues have had great success using a sense of belonging intervention in introductory physics to reduce the gender gap in course grades. The intervention consists of students reading and discussing stories from senior engineering students about struggles they faced as first-year students. This discussion is carefully facilitated by a TA and sends the signal to students that struggling in these courses is normal, so they should not be discouraged.

7. Conclusion

This study investigated the correlation between grades in preparatory math courses and markers of achievement in engineering curricula. We found that even students who received As in preparatory math courses were less likely to graduate with an engineering degree than calculus-ready students, but they were no more likely to leave college with no degree. We find that students who get an A in trigonometry are approximately as likely as calculus-ready students to succeed in calculus 1. However, we saw significantly smaller enrollments of preparatory math students in courses that follow calculus 1, indicating an attrition after this first "on-sequence" math course. This study lays the groundwork for future qualitative work investigating to what degree these barriers to STEM persistence are structural or motivational and identifies potential points for intervention to improve retention of preparatory math students.

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Appendix A: Regression Tables

Table 1. Regression tables for various outcomes as a function of grade in preparatory math course while controlling for ACT score and high school GPA. Underlined entries are linear regressions, all other entries are logistic regressions. ACT and HS GPA are converted to z-scores and thus are in units of standard deviations. † $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

	Graduation	**Leaving**	**Calculus 1**	**Calc 1 Grade**	**Calculus 2**	**Physics 1**	**Chemistry 1**
Intercept (Math-Ready)	1.20*** (0.051)	–1.67*** (0.055)	1.66*** (0.058)	2.83*** (0.024)	1.43*** (0.05)	1.98*** (0.059)	1.04*** (0.046)

Grade = DFW	–2.73*** (0.45)	1.50*** (0.20)	–2.25*** (0.21)	–1.39*** (0.14)	–3.21*** (0.24)	–2.27*** (0.20)	–0.43* (0.21)
Grade = C	–1.27*** (0.21)	0.71*** (0.17)	–0.90*** (0.21)	–0.84*** (0.098)	–2.49*** (0.18)	–1.61*** (0.17)	0.087 (0.20)
Grade = B	–0.64*** (0.16)	0.022 (0.16)	–0.22 (0.20)	-0.46*** (0.079)	–1.69*** (0.14)	–1.17*** (0.15)	0.059 (0.16)
Grade = A	–0.60*** (0.16)	–0.39† (0.22)	0.25 (0.24)	0.11 (0.087)	–1.20*** (0.15)	–0.66*** (0.19)	0.30 (0.19)
ACT	0.22*** (0.053)	0.13* (0.055)	–0.63*** (0.057)	0.27*** (0.026)	-0.28*** (0.05)	–0.19*** (0.056)	–0.38*** (0.048)
HS GPA	0.25*** (0.055)	–0.70*** (0.05)	–0.28*** (0.053)	0.37*** (0.025)	0.0026 (0.048)	0.19*** (0.054)	0.0043 (0.046)

Table 2. Regressions predicting probability of receiving an engineering degree as a function of preparatory course enrollment and demographics. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

	Pell Grant	**First Generation**	**URM**	**Gender**
Intercept	1.25*** (0.051)	1.22*** (0.091)	1.15*** (0.087)	1.09*** (0.055)
Remedial = 1	–1.17*** (0.11)	–0.91*** (0.18)	–1.03*** (0.16)	–0.83*** (0.14)
Minority Group = 1	–0.44** (0.14)	0.022 (0.13)	–0.065 (0.12)	–0.28*** (0.078)
Interaction	0.73* (0.30)	0.25 (0.25)	0.078 (0.22)	0.57** (0.19)

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