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BOARD # 174: How Much Math is Too Much? Exploring the Effects of Extensive Math Coursework on Collegiate Engineering Students who Enter Engineering Programs without being Calculus-Ready

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How Much Math is Too Much:
Exploring the Self-Efficacy Effects of Extensive Math Coursework on College Engineering Students who Enter Engineering Programs without being Calculus-Ready

Abstract

In light of the recent ASEE Mindset Report and related research and scholarly discussion about the necessity of the difficult series of math courses required for an engineering degree and the negative impact it has on underserved populations of students, this work-in-progress research begins to explore the effects of math courses on students who do not enter collegiate engineering programs with the traditionally expected math readiness. This case study narrative inquiry highlights trends for this type of student during year one – when retention is the lowest - as part of a larger study that will follow students through their entire collegiate career. While "traditional" engineering students come into most engineering programs ready to start math coursework at the calculus level, some students who elect to pursue an engineering degree do not have the test scores, math course experience, or general math confidence to enter at that level. In universities that offer test-optional admission or have minimal admissions criteria for engineering students related to math, these strict math requirements take an early toll on many students who enter programs at a lower math level, often resulting in their departure from the program. This study, framed in self-efficacy theory, aims to help better understand these students' experiences, what causes them to leave, and what struggles they face in an effort to generate solutions that address these issues and improve retention. Through analysis of participant interviews and interaction data, personal narratives are derived to help explain and explore the participant's lived experiences. This study aims to shed light on how challenging math coursework can impact self-efficacy and retention for students who enter engineering programs below a calculus level and provide research-backed suggestions for improving the experience these students have during their college journey, thus increasing retention in engineering programs. Early findings suggest that positive faculty-student interactions, a sense of belonging, and the ability to feel success (instead of defeat) in early mathematics coursework are key contributors to what improves self-efficacy for students who struggle in math-specific courses.

Keywords:

self-efficacy, mathematics, engineering education, underserved populations

Introduction

The Mindset Report published by ASEE in 2024 suggests that the way collegiate engineering education programs currently employ mathematics coursework is inherently problematic and recommends that educators no longer allow the sequential calculus courses required by most engineering programs to serve as a weed-out series for students interested in engineering [1]. Instead, it recommends that "every motivated student [should] have a path to success, increasing the number and diversity of students earning engineering degrees by removing math as an artificial barrier to the engineering career [1]." This ideology is supported by its notion that much of the content of upper-level math courses required for an engineering degree is not needed by people who practice engineering after completing a four-year degree and that the math in these courses is often not taught such a way that the students can find any connection between the math concepts and the engineering field they have chosen to pursue [1]. While this paper focuses largely on the struggle mathematics courses sometimes pose to engineering students on their path to completing their degree, it is important to acknowledge the clear value mathematics courses also bring to students. Advanced mathematics courses offer students valuable experience employing logical problem-solving strategies and using creativity to develop solutions for complex problems - which the Mindest report also suggests are some of the key attributes an engineering student should leave college with [1].

The Mindset Report's publication was timely in that many colleges reduced or removed the entrance test requirements and/or math placement minimums they previously had as a result of the COVID outbreak [2]. While some institutions have reinstated these entrance test requirements or standardized test score minimums [3], some - like the university observed for this study - still remain test *optional* [2]. One positive outcome of allowing engineering programs not to have minimum math entrance scores is that it opens the door to students with a genuine interest in engineering who might not have the test scores in mathematics to test into an engineering program in the past. At the university in which this study is being performed, another benefit of this test-optional transition is that the diversity of students in the program has increased. The test-optional strategy does not come without concerns, however. Because engineering curricula have some of the highest credit hour requirements of any major and the courses tend to build sequentially on each other as students work through the curriculum, if students fall behind in one class they don't simply have to retake that class, but they also cannot advance to the next class in the sequence which ultimately holds them back from completing their degree on time. Students who enter an engineering program not calculus-ready face this problem from the very start [4-5] with their pre-calculus status keeping them from the calculus-based physics class most engineering students take during their first semester.

Attrition out of engineering programs is a noted and consistent problem collegiate engineering programs face [4-6]. Students who enter engineering programs not calculus-ready have even higher attrition, and this is not only a function of the schedule-related challenges their situation poses [4-16]. Initial collegiate math coursework success has repeatedly been found to be an indicator of whether or not students will persist and be successful in engineering degrees [4-10, 12-17], and finding ways to improve outcomes for students who are not successful in their initial collegiate math coursework is a continued area of study [11, 14-15]. Related specifically to this study, Middleton et al. found that students who started their engineering program below a Calculus I level were *less than half* as likely to complete their engineering degrees than students who started at a Calculus I level. And, regardless of the course they started in, getting high marks (A or B) in that course made them *6.5 times* more likely to complete their degree than students with low marks (D, F, or W) [7].

While much of the work aimed at improving student success and persistence in math coursework considers the math course design itself [2, 5, 11], this study attempts to consider this phenomenon instead from the student's experience through the lens of self-efficacy. For example, the self-efficacy of students who, from the start, feel behind in their math coursework may be reduced due to how not being in the same courses as their peers makes them feel. Conversely, struggling through mathematics coursework and coming out successful at the end may build their confidence and show them that, with effort, anything is achievable. For many, however, that struggle will turn students away from the field entirely [1-2, 5-8, 11-12, 14-15]. Studying how students' self-efficacy changes as they advance through their coursework and identifying specific elements that are stimulating this change (whether positively or negatively) should highlight areas for improvement in how these students are approached to increase their retention and graduation rates. This leads to the specific research questions for this study: (1) How does the self-efficacy of students who enter an engineering program not calculus-ready evolve, and (2) What factors impact this evolution?

Perspectives from Literature and Theory

Studies have shown that small changes to the way educators approach math coursework can have meaningful impacts on retention [11-12, 18]. For example, increasing efforts to ensure students are initially enrolled in a math course that meets their entry preparedness helps ensure that more students will have positive experiences in their initial coursework [12]. Similarly, breaking calculus courses into smaller segments (so students have the opportunity to retake small chunks of a course instead of an entire semester of a course) has also been found to have significant merit - particularly for students of color [11]. Increasing a sense of belonging and building a STEM identity for students was also found to increase success - again, even more notably for underrepresented minorities and students of color [18]. Given that the percentage of non-white students continues to increase in the university investigated in this study and that the retention of these students has been found to be only half that of their peers [11], these findings are increasingly important for increasing success in the program. This study looks specifically at understanding how students develop their STEM identity by investigating how math skill self-doubt impacts students' *engineering* self-efficacy (and their related STEM identity) as they progress through their program of study.

Self-efficacy theory explains how people's beliefs about their ability to impact the outcomes they achieve are shaped [19-20]. It suggests that these beliefs are shaped by mastery experiences, social persuasion, vicarious experiences, and physiological experiences, and have been repeatedly found to be a strong indicator of persistence and retention in engineering programs [21-22]. Positive mastery experiences are generated by successfully completing endeavors that require perseverance. Vicarious experiences are gained by observing individuals similar to oneself successfully achieving a goal or completing a task, thereby gaining the belief that they too are capable of achieving that task. Social persuasion can be defined as the influence on an individual's belief in their abilities through positive verbal feedback and encouragement received from others. In other words, social persuasion is being convinced by others that they are capable of achieving a task, thereby boosting their self-efficacy. Lastly, physiological states impact self-efficacy as well. Positive moods often enhance self-efficacy, while negative feelings (e.g., stress, anxiety) typically reduce it [19-20]. Studies aimed at improving first-year engineering students' sense of belonging (and consequently increasing students' general positive physiological experiences in college) have shown this to have a significant positive impact on retention [23-24]. Related specifically to this study, self-efficacy can be explained as a measure of how confident students are in their ability to complete their engineering coursework and become an engineer, with implications ranging from how they feel when they are working on their engineering coursework to whether or not they ultimately continue to pursue the field.

Because of the noteworthy impact self-efficacy has been shown to have on retention [21-22], many investigations with similar motives to this work-in-progress study have been conducted. Notably, a study that attempted to address this phenomenon by investigating students' *mathematics* self-efficacy was conducted in 2012 [25]. In that study, efforts were taken to improve the way mathematics courses were taught and, while students did show improvement in their confidence in solving problems, those improvements did not result in improvements in their math course self-efficacy as a whole. The study did find, however, that mastery experiences (both positive and negative) were the most powerful indicators of self-efficacy for the participants. Another notable study by Van Dyken and Benson [13] took a qualitative look at the journey toward an engineering degree for one particular student who started the program not ready for Calculus I. That study, conducted with the perspective of a self-regulated learning framework, found that having a mentor to help the student develop self-regulation strategies was key to his success in passing the math courses required to complete his engineering degree successfully [13]. While the Van Dyken and Benson study offers a success story, this work-in-progress shares an initial story of struggle as part of a larger study that aims to identify trends related to retention with a larger sample size. Understanding positive and negative student outcomes and what factors push students toward those outcomes is precisely what this study aims to explore.

Methods

Positionality

The researcher for this study is an engineering professor who formerly worked as an engineering instructor for a career technical high school (for eight years) and as a practicing engineer (for nine years). She has experience working with high school students as they decide to enter the engineering field, with college students as they prepare to be engineers, and with practicing engineers and faculty as colleagues. Over her professional career as an educator, she has seen many students who are skilled problem-solvers and critical thinkers with an excellent understanding of technical concepts related to engineering *not* continue their path into the engineering field because of the stringent math requirements in the coursework required for an engineering degree and their lack of confidence and struggle in that area. This has led her down a research path that attempts to examine the role collegiate math courses play in a professional engineer's life and the impact these courses have on students in their training to become engineers.

Context

This work-in-progress study (and the larger, ongoing study it is part of) was conducted at a small liberal arts university in the Midwest. The engineering program has two accredited disciplines and has approximately 25 students per year, most of whom come to the school from within the state. While more than a quarter of the university's students identify as students of color and/or non-Caucasian, the engineering program struggles to retain this diversity in its student population. Like so many collegiate engineering programs, this school struggles with the retention of engineering students in general [6]. While for some this is a clear result of being accepted into a test-optional school without understanding the coursework implications of an engineering degree, oftentimes, this is the result of a lack of preparedness of these students to start engineering coursework at a calculus level and the lack of structured support being offered to students in this situation.

Participants

Students who start the engineering program without being calculus-ready are invited to participate in this study. In the first year of the full study that is currently in progress (2024-2025), 10 of 33 first-year engineering students started the program at a pre-calculus level. This work-in-progress paper reflects the pilot trial for this study and follows one student who entered the engineering program during the 2023-2024 school year not at the calculus level. This student entered the program enrolled in pre-calculus and had both a strong interest in engineering and self-reported struggles with math coursework, making him an ideal candidate for the pilot study. For the purposes of this study, we will refer to this pilot study participant as Eli.

Data Collection and Analysis
Students identified as candidates for the study are personally invited to participate in the study by the researcher via email. Upon receiving their consent to participate in the study, a semi-structured interview is scheduled at the end of the spring semester to gather data surrounding students' experiences throughout the year and what impact, if any, their concerns related to math had on their engineering self-efficacy. In addition, jottings are taken to record interactions, meetings, observations, and correspondence with the students throughout the year as it pertains to the study.

To ensure the quality of the findings in this pilot study, significant time was spent with the participant (through informal meetings, as his instructor, and in an advising capacity) to build a relationship with him and understand his perspective both before and after the semi-structured interview was conducted [26] to ensure his story was captured accurately. It should be noted that this time would have been spent with him regardless of the study because of the researcher's investment in Eli as a student (except for the interview itself), but that the documentation of these activities was included for the study. Findings were triangulated from this data (jottings, interview transcript, course outcomes, discussions with professors, etc.) to develop a rich personal narrative and ensure its consistency [26-28]. Narrative analysis was selected to ensure the emotion [29-30] and complexity [29] surrounding evolving self-efficacy trends could be captured meaningfully from various sources [31-32].

For the larger study, this data collection will be repeated each year the participant is enrolled until graduation. Narratives will be generated for each participant in the continued, larger study and the resulting set of narratives will be coded using the sources of self-efficacy presented in this paper to develop emergent themes related to how self-efficacy evolves and what causes that evolution.

Results: Eli's Narrative

Eli is a warm, easy-to-talk-to white male student who entered his first year in the engineering program with more "engineering" experience than many of his peers. He took part in an engineering program at a career technical high school before college, which he chose based on his clear interest in engineering and the fact that he did not excel in a traditional classroom. He thrived at the career center, gaining many industry credentials and confidence in his ability to be an engineer through his proficiency in technical skills related to the field (such as 3D modeling, coding, etc.). He entered the college engineering program with noteworthy confidence, proudly sharing stories of competing at a national level in robotics competitions and of the 3D modeling work he had performed for employers while still a high school student. In his first few weeks in the program, he met with faculty to try to understand how the skills and credentials he had earned at the career center would help him in his coursework, only to find that there was a bit of a disconnect between the engineering content he mastered at a career technical school and what would be required for an engineering degree. The hands-on credentials he had acquired while, for example, learning to operate robotic arms used in manufacturing facilities had given him valuable experiences related to the field, but this did not directly help him navigate the foundational math and science courses required in *the first two years of an engineering program (i.e. three calculus courses, two semesters of physics with related labs, chemistry courses, statics and dynamics, thermodynamics, and linear algebra).*

Outside of his coursework, Eli was on the university's baseball team, and playing baseball was a significant driver in his decision to attend college instead of trying to enter the workforce in an engineering capacity right out of high school. The team welcomed him and made him feel very much a part of a group, and even though he had to sit out much of the first year because he was recovering from an injury, the team camaraderie was something he notably relished and enjoyed.

Outside of baseball, his favorite parts of his first year of school were "the hands-on projects [he] got to do for engineering because that's how [he] learns the best and gets the most out of it." When it came to his math courses, however, Eli admittedly struggled. Despite acknowledging that the pace of the pre-calculus course he took during his first semester of college was faster than that of his high school, his struggle came as a surprise to him. In his words, "I did fine in pre-calc in high school. I took it my senior year and had straight A's. Just, I don't know why, but for whatever reason I just didn't seem to be able to get it [here]. I wasn't able to get on track for calculus." By the end of the year, his confident demeanor was visibly dwindling, despite performing well in both of the foundational engineering courses he took. When asked how he was feeling about his coursework and moving into the next year, his response confirmed this. "I definitely [am] questioning it …a lot…because of the math aspect of it. Because of how in-depth and how far I have to go through math classes and stuff. Cause like, I obviously didn't take calc or physics yet, but I guess I didn't necessarily feel like I was behind. I mean, I didn't feel like I needed the calc and the physics in the engineering class necessarily to do well. I still did well in both engineering classes, but I was definitely questioning whether I was going to come back or not, just simply because of the math." A key contributor to this lack of confidence was one particular interaction he had with his math professor. "She sent me an email that I should look to change to a degree that doesn't involve math because I wasn't getting pre-calc. She just said that engineering is math-heavy and it's just going to keep getting harder so maybe you should look at a degree that doesn't involve math. I responded with several emails to her, with my parents' help, trying to get [recovery plans] laid out and she didn't respond to one of them - like, no response at all. I mean, even my parents were like, how do you tell that to somebody? You know? Yeah, that was like, you're joking right?"

Despite this interaction, his confidence in being able to succeed as a practicing engineer did not waiver. He continued to express confidence that, based on the work experiences he had through the career center, he would be able to find a career in engineering that highlighted the elements of engineering he was proficient in and enjoyed that did not rely on heavy computational math work. He still hoped, however, that he would be able to complete his engineering degree in order to open up a wider range of job opportunities and ensure that his upward growth within a company was not limited by not having the required degree.

Eli took the pre-calculus course unsuccessfully in the fall and again in the spring semester and - while he improved in the spring semester, he missed the 70% threshold needed to be admitted to Calculus I by one point at the end of the term. Though disappointed, he persisted and took the course for a third time during the summer (with success) to ensure he was on track to start his second year enrolled in the calculus and physics classes he missed out on during the previous year. The fall semester of his second year of college combined these challenging courses with other foundational classes that are prerequisites for many of the upper-level engineering courses (such as chemistry, etc.), and left him with a semester that was computationally heavy and had no engineering-specific coursework or the hands-on projects that excited him about the field. He worked hard through the first half of the semester while continuing to struggle through his classes, taking advantage of professors' office hours and university tutoring services as much as possible. In his words, "I live at home, I don't party - I don't do any of that. I literally go to school and I go home and I'm not out doing all this stuff, not studying and not doing this, and then still failing. I'm putting the effort in, doing this, wanting to get the credit for it and that kind of stuff and still coming up short." Ultimately, given the lack of success he was having in his classes and the lack of enjoyment he was getting from them, he made the difficult and emotional choice to withdraw from school mid-semester.

Discussion
This first look at a personal narrative developed around a student who came into the engineering program not calculus-ready already confirms how students can sometimes almost feel forced out of engineering programs due to challenges with math coursework. This result will be discussed through the research questions for this study, which were: (1) How does the self-efficacy of students who enter an engineering program not calculus-ready evolve, and (2) What factors impact this evolution?

Looking at the first research question for this work-in-progress study specifically, these results suggest that - for the initial pilot participant - the self-efficacy of a student who struggled with math coursework declined over time until it was so low that the student no longer felt they could successfully complete their coursework. This is consistent with research that confirms the large attrition rate for these students [5-8,12,15]. It should be noted, however, that his engineering self-efficacy did not degrade linearly over time. His *engineering* self-efficacy remained high - despite his struggles with pre-calculus - until he finally determined that because of the math requirements, he would not be able to complete the degree. While this will likely (and hopefully) not be the outcome for all students in the larger study, this initial data does confirm the uphill battle faced by students who start the program not calculus-ready.

Eli's narrative points to several preliminary answers to the second research question as well, which will be discussed in terms of each of the sources of self-efficacy below:

Mastery Experiences: Eli has had many positive mastery experiences during his schooling at a career center, his internships, and in engineering-specific coursework which made him feel confident in his ability to become an engineer. Unfortunately, the negative mastery experiences he received from his college-level precalculus and calculus courses outweighed those positive experiences, thus leading him to the choice to quit the program. While his engineering self-efficacy didn't devolve linearly, his math self-efficacy consistently diminished over time after having very little success and putting in a significant amount of effort. This result reinforces previous studies' suggestion that a student's success in early math courses is a strong predictor of retention [4-10, 12-17] and begs for continued work to discover new ways to make success in this coursework more attainable for those who do not enter the program with strong math skills. It also highlights, as did previous studies [2,11,14], the need to ensure students are starting engineering coursework in the level of math that they are correctly prepared for to help them achieve positive mastery experiences and grow at a pace appropriate for their mathematics mastery as they advance.

Social Persuasion: The most poignant element of Eli's narrative (and the story that he was the most emotional about when sharing) was the interaction he had with his pre-calculus professor. Being told that he should consider switching majors due to his math struggles harmed his belief in his abilities, and his morale seemed to decline quickly from that point forward. This serves as a reminder to faculty that the interactions had with students are incredibly important, and that the feedback given can have serious implications for their futures. While it is valuable to advise and aim students toward areas where they are having success, the way this advising is approached is critical. For example, if Eli's professor had scheduled a meeting with him (or reached out to his advisor directly) to discuss his grades, what could be done to improve, and what services were available to help the student, *and that she was available to help him and believed in him*, the outcome of Eli's college story may have been very different than the one achieved by sending an email saying he may want to stop pursuing an engineering degree with no follow-up. This ideology aligns with the work of Van Dyken and Benson, who observed that - even after having to take a calculus course four times - a student found success in a challenging math course with the support of an instructor who was willing to personalize instruction and take a vested interest in his success in the course [13]. There will undoubtedly be students who decide they do not have enough ambition for math to tough it out through an engineering degree, but the role of faculty is to uplift, support, and encourage students and not make them feel they are *unable* to achieve success in their courses. The workload impact on faculty of this idealistic approach should not be ignored, however, and many faculty may not feel they have the time or personal resources to commit to students in this way. Even for faculty in this position, pointing students toward other resources that may be helpful (such as student services, tutoring services, etc.) and continuing to discuss students' progress in an uplifting way would likely have a positive effect (or, at a minimum, not have this noted negative impact) on students.

Psychological Experiences: Eli was upfront about his struggles with test anxiety and the stress he felt during math testing in particular and discussed how this played a role in why he chose to pursue engineering at a career center in the first place. Even in his engineering class (which he performed well in), math-heavy concepts caused him to visibly freeze up and shut down slightly during tests. These experiences (which were even more significant in his pre-calculus, calculus I, and physics courses) likely had an additional negative impact on his engineering self-efficacy. On a more positive note, however, Eli mentioned that the camaraderie he felt with his baseball team and the sense of belonging he felt from his connection to the team and his teammates had a significant impact on his decision to continue pushing into the second year of schooling, despite his math struggles. This highlights the value that a sense of belonging has on students, particularly on those who may be struggling academically [23-24].

Vicarious Experiences: The only source of self-efficacy that was not identified negatively in Eli's experiences was related to vicarious experiences. As a white, cisgender, heterosexual male, it is not surprising that Eli did not struggle to feel that someone like himself would fit into the engineering world. It is important to note, however, that students who do not align with the traditional vision of what an engineer looks like would likely be more susceptible to additional negative outcomes related to their vicarious experiences.

Conclusions and Continued Work

It is important to reiterate that this is a work-in-progress study and that these results reflect the lived experiences of only one student, which is a clear limitation of the work as presented. The continued, larger-scale study will use the personal narratives derived from many students to find trends that impact students' engineering self-efficacy (whether positively or negatively) and work to develop interventions based on these findings.

The single narrative presented in this paper does, however, begin to answer these questions and shows promise for the larger study's merit. The presented narrative aligns with existing research in many areas, giving confidence that the trends observed from this one student will likely be seen in the larger study as well. It also reiterates the importance of students developing a sense of belonging and being placed in the appropriate starting math courses where they can build positive mastery experiences and advance confidently from those experiences. In addition, it serves as both a reminder of the important role faculty plays in supporting the students who struggle with math coursework and as a call to action to continue to develop ways to support students who struggle with math coursework. To stay true to the mission of the Mindset Report and the overarching goal of having more diverse representation in the engineering field, continued work needs to be done to address this issue, and this ongoing study aims to discover and highlight targeted interventions that can be implemented to help achieve these goals by increasing self-efficacy and ultimately retention.

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Appendix I

Semi-structured interview script

1. Do you agree to participate in this interview and study?
   First-year only:
2. How did you decide to major in engineering?
   All years:
3. Tell me a little about your experience in college last year.
4. What was the easiest part of college for you and why?
5. (What class is the easiest and why?)
6. What is your favorite part of school and why?
7. What was the hardest part of school for you and why?
8. What is your least favorite part of school and why?
9. How confident do you feel in your ability to be successful in your engineering degree?
10. How confident do you feel in your ability to be successful as a working engineer?
11. What would you say impacts your confidence in those areas?
12. Do you currently have any jobs related to engineering?
    If yes: Describe how what you are learning in your coursework helps you in your job.
13. Discuss how important you think math skills are to your success as an engineer.
14. Based on how you felt from when you started the year (college) to now, has anything changed?
15. Is there anything else you would like to share today?