Approaching Math as a Tool for Engineering: A Bridge into College Engineering

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Abstract

There is long-standing data which indicates that many incoming engineering students struggle with math upon entry into college. A very successful approach has been the Wright State model, which teaches math in a highly applied engineering context. This paper describes a course derived from the Wright State model, which has evolved significantly over time. The course includes moderate-intensity active learning, with 1 hour of lecture, a 2-hour studio, and 2-hour lab each week. Data on student perceptions and performance from the most recent offering of the course in Fall 2022 are presented. A large number of students were batch enrolled into the course in summer 2022, but then subsequently withdrew early. The students who dropped had lower math confidence, lower self perceptions of science and math ability compared to their peers, and lower STEM identity, compared to students who remained in the course. Among students who earned overall course grades of D or F, the majority were taking pre-calculus in Fall 2022 (so failed to place into Calculus 1 or higher) and did not have strong participation in the course or completion of basic reflections, homework, or lab assignments. At the end of the semester, the students who earned a D or F in the course had a lower engineering identity, feelings of belonging at the university, and feelings of belonging in the course in comparison to students who earned an A, B, or C in the course. The results indicate that in the local context there is still further work needed to best support the needs of students with respect to their math skills as they transition into college.

INTRODUCTION

Much has been written about the challenges that many college students encounter with math, and that math is sometimes a barrier to student progression and persistence in engineering and natural science majors [1]. A variety of models have been tried to help with student math success in college including: summer math preparation [2], [3], placing students into appropriate math courses (sometime pre-calculus, for example [4]), enrolling students in extra math help tutorials (may be pass/fail, 1 credit courses taken with calculus 1 [5]), and learning assistants to serve as peer mentors [6]. One model that has proven very effective was developed at Wright State University and focuses on application-driven, hands-on, and just-in-time learning [7], [8]. Other institutions have also adopted and/or adapted some of the Wright State model (e.g., [9]). It may also be relevant to consider that the COVID pandemic and abrupt transition to online / hybrid learning may have further eroded students' math skills and/or left unusual gaps in their knowledge.

A number of studies have explored factors the impact students' math performance. For example, Hieb et al. [3] found that the performance of engineering students on the exams in a calculus-based *Engineering Analysis 1* course in the first semester was correlated with students' algebra readiness, time and study environment management, internal goal orientation, and test anxiety. Less related to the higher education context but also relevant may be the findings of Gjcali and Lipnevich [10] who found that among 15 year olds their attitudes, subjective norms, and perceived behavioral control were related to behavioral engagement in math learning and performance on a standardized math assessment test.

In addition to the specific issues related to mathematics, other studies have explored the academic performance or college success of first-semester students more generally. Stewart [11] found that for male students, self-control was a predictor of academic performance; high school GPA and SAT scores were predictive of the first-semester academic performance of both male and female students; and grit was not related to the academic performance of male or female first-semester students. For students with a first-semester GPA of 2.67 or less, self-control was the best and only predictor of academic performance. Honken and Ralston [12] found that a lack of self-control in high school was related to a lower first-semester GPA among engineering students who were generally high achievers in high school; homework behavior in high school was one of the indicators of self-control in high school that was correlated with first semester college GPA.

At the University of Colorado Boulder there have traditionally been high DFW rates in the math courses typically taken by first semester engineering students (Table 1); DFW represents students who were awarded a grade below C- in the course or withdrew late in the semester (past the point of tuition reimbursement). In an effort to help engineering students struggling to be successful in math, the College of Engineering began to implement a course modeled on Wright State Math starting in 2017 [13], [14], [15], [16]. The course was variously (un)popular with students, some of whom perceived it as ‘remedial’. Despite this, early data was promising that taking the course provided a ‘lift’ in students’ persistence, determined by using prediction-based propensity score matching [17]. Changes in the course title and format over time have been responsive to the feedback from students, instructors of the course, and colleagues in mathematics (summarized in Table 2).

Table 1: Local institutional data for math course enrollment and DFW rates.

Fall 2021 Course	N	DFW	Engr Math / Tools & Analysis DFW	N	Term
Pre-calculus for Engineers	29	52%	18%	105	Fall 2019
Calculus 1 with algebra (full year)	30	23%	10%	40	Fall 2020
Calculus 1 for Engineers (9 sections, 23 to 125 students/section)	818	26% (9-40%)	7%	15	Fall 2021
Calculus 1 (23 sections, 17-31 students/section)	619	32% (14-52%)	16%	127	Fall 2022

Table 2: Engineering math course changes over time at the University of Colorado Boulder.

Year	Course Identifier	Weekly	Student enrollment and support	Instructional Team
2022	GEEN 2010 Engineering Tools and Analysis (3 cr)	1 hr lecture, 2 hr studio, 2 hr lab	~140 students, 1 lecture, 6 studio/labs ~30 students max	3 co-instructors 12 undergraduate course assistants
2021	GEEN 3830 Special Topics: Engineering Analysis and Problem Solving (3 cr)	1 hr lecture, 2 hr studio, 2 hr lab	15 students (Fall) 12 students (Spring)	1 instructor 2 undergraduate course assistants
2020	GEEN 3830 Special Topics: Engineering Analysis and Problem Solving (3 cr)	1 hr lecture, 2 hr studio, 2 hr lab	40 students; 1 lecture, 1 lab with 24 students and 2nd lab with 16 students	1 instructor 4 undergraduate course assistants
2019	GEEN 3830 Special Topics: Engineering Math (4 cr)	3 hrs lecture, 1 hr recitation, 2 hr lab	120 students; 2 sections lecture, 5 recitations and 4 labs (14 students dropped early in semester)	2 co-instructors 9 undergraduate course assistants
2018	GEEN 3830 Special Topics: Engineering Math (4 cr)	3 hrs lecture, 1 hr recitation, 2 hr lab; 6 office hrs	120 students; 2 sections lecture; 5 recitations and 4 labs (16 students dropped early in semester)	1 instructor 5 undergraduate course assistants
2017	GEEN 3830 Special Topics: Engineering Math (4 cr)	3 hrs lecture, 1 hr recitation, 2 hr lab; 6 office hrs	28 students at start of semester and 22 at end of semester	1 instructor 2 undergraduate course assistants

The learning objectives for the course as articulated to students on the course syllabus have been generally consistent over time, shown in Figure 1. The topics covered in the engineering math / engineering tools and analysis course overlap with material also taught in precalculus, calculus 1, and MATLAB courses, while also integrating material taught in calculus 2, calculus 3, linear algebra and differential equations, circuits and electronics, dynamics, and data / measurements courses. The engineering tools and analysis course also had additional goals to build students' sense of engineering identity, belonging in engineering, and excitement and interest in future engineering courses.

Upon completing this course, students will be able to:

- Identify, formulate, and solve [real-world engineering questions / problems] involving applications of algebra and trigonometry, vectors [and complex numbers], systems of equations and matrices, derivatives, integrals, and differential equations in engineering.
- Use MATLAB and Excel to analyze and solve a variety of introduction engineering mathematics problems.
- Conduct and evaluate a variety of physical experiments using engineering laboratory equipment.
- Create cogent, well-written [laboratory reports including executive summaries / executive summaries for engineering laboratory assignments].
- [Acquire knowledge, as needed, to answer engineering questions]

Figure 1: Learning objectives for the engineering math / tools and analysis course, where consistent text is in black and changes over time are shown in brackets [2022 text is in red, 2019 text is in blue].

The goal of this study was to explore the most recent offering of the course in Fall 2022, looking specifically at various student attitudes and the ultimate success (or not) of the students in the course in terms of grade they earned.

METHODS

The research was conducted under a protocol approved by the Institutional Review Board for Human Subjects Research. The course included a pre and post survey which embedded items on self-efficacy (confidence), engineering identity, and belonging in the course and at the institution [17]. Students also consented to have their grades and assignments (such as reflective essays) explored.

In 2022, engineering students in a specially supported cohort who did not place into Calculus 1 or higher were enrolled in the course. Advisors of other engineering students also were given information on the course and encouraged to recommend the course to students they believed would most benefit, which historically were students who did not place into Calculus 1 or higher. Students who initially applied to engineering and were not admitted, but rather placed into an 'Exploratory Studies' major were batch enrolled in the course over the summer and comprised the majority of the students in Fall 2022. At the end of the semester there were 127 students enrolled in the course, 15 in the College of Engineering (ENG students) and 112 from Exploratory Studies and the College of Arts & Sciences (non-ENG students).

An instructional team of three faculty taught the course in a manner similar to the course structure in Fall 2021. All ~140 students had a 50-minute lecture together on Monday. This was followed by two smaller group sessions with 30 students or less per week. On Tuesdays or Wednesdays students attended a 2-hour Studio and on Thursdays or Fridays students attended a 2-hour Lab. Both Studios and Labs were taught in class environments of 30 students or less. Studios consisted of intermittent problem-solving demonstrations and practice sessions to assist students in problem solving. Labs consisted of a mix of hands-on, MATLAB, and Excel based applications of the course content. The labs were done in groups of two to four students, and the hands-on activities included work with circuits, robots, sensors, and/or physical measurements. The active learning approaches are congruent with literature showing that active learning benefits all students and reduces achievement gaps of underrepresented students in STEM courses [18]. The course instructors believe that the course represents medium-intensity active learning, based on the percentage of class time students spend engaged in active-learning activities. The course also required students to complete short metacognitive reflections almost every week; these averaged 5 free-response questions in length. They focused on celebrating accomplished mastery, identifying areas of struggle and resources for support, and strengthening study skills and test-preparation strategies.

RESULTS AND DISCUSSION

First it is worth noting that a number of students who were initially enrolled dropped the course (n=48); a number of students enrolled in the course in Fall 2018 and Fall 2019 also dropped, either before the start of the term or within the first few weeks. Student withdrawal was before the standard university deadline, so a W would not show up on the student transcript (and they would not be noted in the DFW rate for the course). Some differences were noted in the pre-survey responses of the students who withdrew from the course versus those who remained in the course, as summarized in Table 3. Based on these results, the group who dropped the course early had somewhat lower math confidence, lower STEM identity, and lower self-perception of ability compared to the students who persisted to the end of the term.

Table 3: Pre-survey responses among students who dropped the course and remained enrolled.

Item	Stay (n=115)	Drop (n=36)	Explanation of Scale
Math confidence (12 item avg)	2.9	2.6	1-5 high confidence
I see myself as a STEM person (STEM identity)	5.7	5.3	1 to 7 strongly agree
Self perception on each of the following traits as compared to your classmates:			1 lowest 10% to 7 highest 10%
- Science ability	5.1	4.3	
- Ability to apply math and science principles in solving real world problems	5.1	4.7	
Intent to complete major in engineering	4.2	4.2	1 definitely not, 5 definitely yes
CU / college belonging (avg 4 items)	5.6	5.5	1 to 7 highest

In Fall 2022 the students had an extremely wide range of preparation coming into the course in terms of math skills (based on their placement into other math courses). The disparity was perhaps exacerbated by COVID. The second author and lead instructor for the course noticed that a few students seemed to be very weak in basic algebra, for example. The course included students not concurrently enrolled in any math course or placing into an array of math courses (see Table 4; among students who persisted to the end of the term in GEEN 2010). Some of these students were additionally enrolled in associated 1-credit work groups with calculus or pre-calculus. Thus, in some cases, students were enrolled in 6-credits of math, in addition to the Engineering Tools and Analysis course. It was found that students could be successful in the engineering analysis course from any level of math placement. However, on average more of the students who placed into pre-calculus struggled (17 of the 20 students in the course who earned a DFW were enrolled in pre-calculus).

Table 4: Concurrently enrolled math course and final overall grade in Engineering Tools and Analysis course.

Math Course enrolled	n	n DFW	Average Eng course grade, %	Median, %	Range at end-of semester %	Median # total credits (range)
Pre-calculus	43	17	68	74	10-100	14 (9-18)
Calculus 1	66	3	86	88	8-100	15 (12-17)
Calculus 2	10	0	89	89	78-98	14 (12-18)
Calculus 3	3	0	88	85	83-95	14 (13-16)
(none)	5	0	92	94	86-97	15 (9-15)

Students were also taking a wide range of credits during their first semester (see Table 4), ranging from 9 to 18 credits (average 14 credits). This indicates a fairly wide range of other courses competing for students' time and attention. The credit load is also significant because some students could not drop the Engineering Tools and Analysis class and retain full-time status as required for some scholarships or fellowships. For example, of the 7 students who earned less than 50% in the course overall and were enrolled in pre-calculus, only 1 student was registered for more than 12 credits.

In the Fall 2022, several students fell behind in the coursework early. This was similar to years past, as this course has weekly homework and lab assignments that were more rigorous than many high school courses. Many of these students continued to come to class and attempt the work. However, in Fall 2022 there were six students who simply stopped coming to class, did not complete the assignments, and missed the exams yet remained enrolled in the class. In previous years, students who were not engaged often met with their advisor and dropped the course. The experience of Fall 2022 was most similar to the Fall of 2019, when students also were bulk enrolled in the course. In that semester there were also 6 students who simply stopped participating in the course.

The number of students who received a D or F in the course was higher during the two semesters when students were bulk enrolled in the course. In the Fall 2022, there were 20 students who received a final grade of D or F. In the other semester where students were bulk enrolled, Fall 2019, there were 14 students who fell into this category. This is in comparison to Fall 2020 (2 students DF), Spring 2021 (0 students DF), and Fall 2021 (1 student DF). It should be noted that the bulk enrollment process was different in 2022 (students not admitted to the College of Engineering) vs. 2019 (engineering students who placed into pre-calculus).

At the end of the semester, the DFW rates for non-engineering students was 16.8% (among n=120) compared to a DFW rate for the 15 ENG students of 46.7%. Students who were not admitted into engineering but came to the university and continued to strive for entry could be considered to be displaying grit. Grit is typically defined as being persistent and resilient to working toward their goals even in the face of setbacks [11]. The students striving to be admitted into engineering also may have appreciated the opportunity to have a hands-on engineering experience. For those students, the course was framed as an opportunity to be exposed to engineering. In contrast, the engineering students enrolled in the course may have perceived the course as remedial, given that only part of their 'cohort' was enrolled. Perceiving the course as remedial would have implications for the students' mindset [19]. Further, those students may have been taking other hands-on engineering courses their first semester and therefore were less dependent on the Engineering Tools and Analysis course for an exposure to hands-on engineering.

The DFW rate among the ENG students is concerning. Table 5 shows a breakdown of some of the graded activities in the course and the percentage of the students who earned a final grade of DF in the course or ABC who scored less than 70% on the particular activity. Table 6 shows the average percentage grade earned on these same assignment groups by the students in the different final grade outcome groups. It is particularly noteworthy that many of the students earning a DF did not appear to be engaging in basic course activities, such as participation in lectures and studios or completing the short weekly metacognitive reflections (typically about 80 words in length). All but one of the DFW students failed to complete 1 or more of the 10 laboratories (1 student completed none of the 10 labs). Thus, it appears that the majority of the

DFW students were not making an honest attempt to learn the course material by participating in the provided learning activities.

Table 5: Analysis of students' performance on different activities in the course.

Student college; Final course grade	Students earning <70% on portion of the course				
	Participation lecture / studio DF (10% grade)	Reflections DF (4.5% grade)	HW DF (15% grade)	Labs DF (18.5%)	Final exam DF (20%)
ENG DF (n=7)	29%	29%	57%	86%	100%
nonEng DF (n=13)	62%	54%	100%	92%	100%
ENG ABC (n=8)	0%	12.5%	12.5%	13%	63%
nonEng ABC (n=99)	3%	4%	26%	16%	13%

Table 6: Analysis of students' performance on different activities in the course.

Student college; Final course grade	Average percentage earned on assignment group				
	Participation lecture / studio DF (10% grade)	Reflections DF (4.5% grade)	HW DF (15% grade)	Labs DF (18.5%)	Final exam DF (20%)
ENG DF (n=7)	75	84	51	47	24
nonEng DF (n=13)	63	60	24	31	24
ENG ABC (n=8)	90	92	83	80	76
nonEng ABC (n=99)	89	95	76	81	86

Among the students who earned a D or F in the course overall, only 3 of the 7 engineering students and 3 of the 13 nonENG students appeared to be making honest effort to pass the course (taking advantage of the opportunity to complete an extra credit lab); only 1 of the 20 DF students did not have a 0 on one or more of the labs. In addition, 6 of the 20 DF students had apparently given up completely and did not take the final exam. As another way to explore the data, among the 20 students earning a D or F in the course overall, none earned 70% or higher on participation, reflections, homework, and labs. Among the 3 engineering students who earned a D or F in the course overall and earned 70% or higher on participation, reflections, and homework, all had skipped one or more laboratories (earned 0).

The overall conclusion is that students who made a serious attempt, passed the course. This included students who may perform poorly on written exams (due to test anxiety or other reasons); an ENG student who scored 45% on the final exam earned an overall grade of C in the course and a nonENG student who score 44% on the final exam earned an overall grade of C+ in the course.

Why did some students fail to complete even the most basic requirements for the course in terms of attendance, simple reflections (graded for completion), and submitting homework or lab write-ups? Perhaps those students lacked self-control. Stewart [11, p. 24] quote [20, p. 214]: "individuals genuinely high in self-control have the ability to exert self-control when it is required (e.g., forgoing a party to study for an exam…)". Alternatively, perhaps some students were unfamiliar with the requirements to submit assignments – either due to policies at their high school during/post COVID or perhaps international contexts that rely almost completely on exams to determine course grades. In an attempt to help students in such circumstances to improve their grades, three grade recovery options were offered. These grade redemption opportunities included two extra credit labs and acceptance of past-due 'late' homework for 50%. (This was added onto the previous late homework allowance of up to one week late for 70% credit.) Results of these extra opportunities contributed to a decrease in the percentage of students in the D-F grade range from 24% in week 10 of the course to 13% at the conclusion of the semester.

On the pre-survey, there were not particular early indicators of students' eventual grades in the course. Across 12 items that presented various math problems and asked students to "indicate how much confidence you have that you could successfully solve each of these problems if exposed to the course materials" the average scores did not differ among students who earned different final grades in the course: 2.8 to 2.9 for A, B, C, and DF. There was a slightly lower self-perception of their math ability relative to their classmates (average 4.7 among DF students vs. 5.1 to 5.3 among ABC students). The students with different course grades did not differ in their engineering identity or university belonging at the beginning of the semester.

Sections of the post survey were reviewed to identify differences among the students who earned different overall final grades in the course; results are shown in Table 7. Note that statistical comparisons were not conducted, given the small number of students who responded to the survey. In common, students across the grade spectrum indicated that the top resource they used most often was 'other students taking the course' and the activity most useful for learning course content was 'studio group work'.

At the end of the semester, the math confidence, engineering identity, and feelings of belonging (and interest) in engineering seemed notably lower among the small number of DF students who completed the survey. It is unclear to what extent the low grade in this course contributed to those feelings ***or*** partially resulted from those feelings. The interaction is clear: a student feeling less belonging in the class may be less likely to attend and participate; or a student who is not attending and participating in class would build less feeling of belonging. Similarly, a student might lose interest or motivation for engineering, and then decide not to work hard in the Engineering Tools and Analysis course. The course is a single experience in the life of these students in their first semester of college; the entirety of their experience would be expected to impact both their engineering identity and feelings of belonging at the university.

Table 7: Post survey questions with differences in responses based on the grades earned by the students.

Survey Question Grade Earned: / n survey responses^:	DF 5-7	C 9-10	B 15-21	A 19-23
Resources used most often (1 = most often, 6 = use but not in top 5)				
Khan Academy, YouTube, etc. videos	**4.0**	**3.4**	2.8	2.5
Online resources (Wolfram Alpha, etc.	**4.4**	3.3	3.3	3.4
Tutoring in residence halls	**4.2**	5.0	5.0	**5.9**
Activities most useful to learn course content (1 = most useful, 4 = not useful)				
Attending office hours	2.2	1.9	2.6	**3.0**
Studying with other students	1.8	1.9	2.1	**2.7**
Doing labs	**2.4**	1.7	1.9	1.7
Studying on your own	**2.4**	1.6	1.9	1.9
Attribute success in the course to… (1 = most important, 7 = least / not)				
Attending class	2.8	**1.4**	2.6	2.8
Attending lab	**4.0**	2.8	2.4	2.5
Seeking help when I needed it	**2.8**	4.3	4.3	3.9
Extent agree (1 = strongly disagree, 7 = strongly agree)				
I like figuring things out on my own	**4.2**	5.8	5.3	5.8
In hindsight, the frustration I experienced in this course helped me learn	3.4	**5.4**	4.3	4.5
Confidence in ability to successfully solve math problems if exposed to the course materials (average across 12 items; 1 = none to 5 = a great deal)	**2.2**	3.5	3.6	4.0
Engineering identity (average 4 items; 1 to 7 strongly agree)	**3.9**	**5.4**	4.7	5
Feelings of belonging at university (average 4 items; 1 to 7 = strongly agree)	**4.1**	5.0	5.6	5.3
Feelings of belonging in the class (average 4 items; 1 to 7 = strongly agree)	**4.6**	6.4	5.7	6.4
After taking GEEN2010 Engineering Tools and Analysis to what extent do you agree or disagree with the following statements? (1 to 5 = strongly agree)				
I belong in engineering	**2.3**	3.6	3.8	4.4
I like engineering	**2.5**	4.1	3.8	4.7

^ *different numbers of students completed different items on the survey; range shown*

Paired comparisons of the pre and post survey responses are shown in Table 8. When students rated their confidence in their ability to solve 12 different specific math problems if taught the concept in-class (which were the same problems on the pre and post survey), initially there were no differences among students earning different final grades in the course. Across the semester, there was an increase in confidence among the students who earned an A and B in the course, an increase that was not statistically significant among students who earned a C (perhaps due to the low number of students), and a decrease among the students who received a D or F. It is encouraging that students earning an ABC increased their self confidence in their ability to successfully learn math. Unfortunately, among the students who earned a D or F, the Engineering Tools and Analysis course (and/or potentially the precalculus class these 5 students were also taking) eroded their confidence in learning math. From initially similar intent to complete a major in engineering on the pre-survey, intent decreased among the DF students (although not a statistically significant amount). Again, it is unclear what amount of this change was due to the Engineering Tools and Analysis course versus other courses and/or the broader college experience of the students.

Table 8: Average pre and post responses of students earning different final grades in the course.

Survey Question Grade Earned:	DF	C	B	A
n paired survey responses:	5	8	12	21
Confidence in ability to successfully solve math problems if exposed to the course materials (average across 12 items; 1 = none to 5 = a great deal)				
Pre	2.9	3.0	3.2	2.9
Post	**2.2**	3.5	**3.6**	**4.0**
Paired t-test p	**0.08**	0.24	**0.02**	**0.00**
Intent to complete a major in engineering (1=definitely not to 5=definitely yes)				
Pre	4.3	4.4	4.1	4.2
Post	**3.3**	4.0	3.8	4.4
Paired t-test p	.27	.29	.45	.50

LIMITATIONS

This study was situated in a single institution with unique conditions that may not be relevant in other contexts. We have survey data from a limited group of students, which constrains our ability to fully understand the attitudes of students in the course. We have not analyzed the data through the lenses of the gender, race/ethnicity, socioeconomic status, first-generation status, or other conditions. This is an important area for further research, given that others have identified 'racialized and gendered mechanisms' in math instruction that may be particularly discouraging and marginalizing to some students [21]. In addition, future work might add items to look at self-control among the students (aligned with studies from [11]).

SUMMARY AND CONCLUSIONS

First-semester courses play an important role in developing students' feelings toward engineering and their own interests and capabilities. First-semester courses that are heavily reliant on math skills face challenges related to the uneven knowledge, skills, and attitudes of the students. Such courses should carefully work to build student knowledge as well as their growth mindset, engineering (and/or math) identity, and belonging, to serve as a foundation for future success and persistence. This paper provides an example of a course attempting to meet these goals. The paper also shows the value in surveys as an assessment method to provide insight into student experiences.

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