Intended and Unintended Consequences of Rapidly Expanding an Engineering Mathematics Intervention for Incoming First-Year Students

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The Wright State Model (WSM) for Engineering Mathematics Education is a meaningful disruption to the traditional required engineering calculus sequence as it offers a one-semester laboratory-based immersion into the ways mathematical concepts—including trigonometry, vectors, derivatives, integrals, and differential equations—are actually used by engineers. Research from Wright State, as well as other implementation sites, has robustly demonstrated that completing the WSM course during the first semester of college leads to boosts in retention rates and engineering persistence, important factors for all institutions seeking to keep engineering students on track for a future in engineering. However, the challenges of starting up a new implementation of the WSM at any institution are numerous and indicative of the obstacles inherent to making any significant curricular change within the rigidly sequenced course flows of traditional engineering degree programs. At the University of Colorado Boulder, the local implementation of the WSM has just completed its second full iteration. In year one, the pilot course featured less than twenty-five students, one instructor, and two teaching assistants, with all course activities housed in a single room dedicated to the class. Based on positive outcomes from the first year, administrators decided to scale-up the WSM course dramatically: the second year of the course featured over one hundred students, one instructor, and five teaching assistants, with course activities spread across multiple lecture, lab, and recitation sections meeting at different places in time and space.

This research paper explores the consequences of this scaling for the students enrolled in the course, as well as for the instructors, teaching assistants, and facilities involved in course implementation. A mixed-methods approach featuring quantitative data including student academic performance metrics, demographic characteristics, and pre- and post-survey results related to attitudes and motivations to persist in engineering are combined with qualitative data from individual student interviews and textual responses to biweekly reflection questions to understand how the course changed from year one to year two. Overall, we find that while scaling-up presents unavoidable challenges to the instructional team with regards to resource constraints, logistics, and engagement of a larger audience with a wider distribution of incoming preparation levels, the larger size of the course also presents some unexpected benefits to students. Mainly, the research team was surprised to find that even students who dropped the course derived substantial benefits from the informal social relationships forged during the first few weeks of classes. We share our findings with the first-year engineering education audience to continue the conversation about how to meaningfully create learning environments – at-scale – which can support the needs of all incoming first-year students in engineering.

Introduction and Motivation

The Wright State Model for Engineering Mathematics Education (Wright State Model or WSM) is being modified during a three-year pilot implementation to fit within the context of a large, public, research-oriented engineering college with an incoming first-year cohort of approximately 900 students [1]. During year two of the pilot (Y2), the WSM course, known locally as Engineering Math, became compulsory for all first semester engineering students assessed not to be ready for enrollment in a one-semester Calculus I course - about 14% of the first-year engineering cohort.[1]

Inspirations for adapting the WSM model into Engineering Math harken back to the original motivation for Wright State's engineering college: to develop a first semester course experience that addresses the inability of first year engineering students to successfully advance quickly enough through the traditional calculus sequence, resulting in unacceptably high attrition [3]. Like at Wright State, the Engineering Math course is centered on hands-on lab experiences, emphasizing an application-oriented, active approach to studying math topics subsequently applied in core engineering courses. Taught by engineering faculty, course topics include examples from physics, engineering mechanics, electric circuits, and programming. A goal of the course is for students to demonstrate their prowess in applying mathematics knowledge, so that they can begin to advance through the engineering curriculum while they simultaneously complete the four-course Calculus I through Differential Equations required mathematics course sequence - thus shifting the traditional emphasis on math prerequisite requirements to an emphasis on engineering *motivation* for the study and application of math. Along the way, the goal is for students to begin to identify as engineers themselves, seeing themselves as doing engineering, not just mired in decontextualized mathematics equations. Finally, the Engineering Math course offers not just the possibility of improved retention, but also a pathway towards engineering identity and motivation that does not add a semester or a year onto the completion of a B.S. in engineering.

Background

Based on other implementations of the WSM model, Engineering Math was intended for first-time, first-year engineering students with the goal of improving engineering persistence [4], [5]. In fall 2017 (Y1), one section of Engineering Math was piloted in the College of Engineering with a target course enrollment of 32; 22 students earned a grade in the course and one withdrew at the end of the term.

Students were chosen to participate in the Y1 pilot based on their incoming math placement level into Pre-Calculus. Priority was given to students underrepresented in engineering, most of whom were already strongly cohorted through a two-week summer bridge experience [6].

Y1 students were enrolled in the course by an advisor over the summer, a common practice for core courses in the College of Engineering at CU Boulder. After they were enrolled, students were sent a message from the course instructor explaining why they were enrolled in the pilot Engineering Math course and the expected benefits of completing the course. The tone of the messaging was especially important for several reasons: the course was not included in any engineering degree planning flowcharts, was not a required course for any engineering major, and required that students take Engineering Math in addition to Pre-Calculus their first semester.

[1] Of note, 10 years ago, CU Boulder's engineering college did not offer a Pre-Calculus course. Students who were not deemed ready for Calc 1 were simply denied entrance into the college. Yet today, about 14% of the first year engineering cohort is enrolled in Pre-Calculus or year-long Calculus I their first semester [2].

Eight credit hours of math is a lot to ask of first semester students, especially those among the least mathematically prepared in the college.

During the course approval process, it was decided to make Engineering Math a 3000-level course (a designation usually reserved for third year courses) so that it could *count* as a technical elective in several engineering degree programs. If it had been approved as a 1000-level course, most students would not have had free space in their degree plan to count the four-credit course towards graduation. For all these reasons, it was important to explain the course to students and make sure they understood that they were enrolled *on purpose*. However, many students chose to drop Engineering Math from their fall schedule before the first day of classes or after attending the first day or week (see [7] for more details on Y1 implementation and enrollments).

The Y1 pilot lecture, lab, recitations, and TA office hours were held in a dedicated, small, equipment-rich, newly constructed classroom called the Engineering Math Lab with all students in the same sections. The immediate results for the 22 students who completed the course were encouraging; they had higher grades in their concurrent Pre-Calculus course than comparable students who did not take Engineering Math and they provided positive qualitative feedback on the content, structure, and value of the course.

As a result of the early course outcomes, the pilot went forward to a second year, with college leadership seeking cooperation from all engineering departments to honor the Engineering Math course and "count" it as something valid toward a student's completion of their engineering degree. The Y2 pilot was scaled to enroll up to 120 students, split in two lecture sections of 60 students, then shuffled among four lab sections and five recitation sections. Recitations were led by undergraduate Teaching Assistants (TAs) while the lab and lecture sections were all taught by the same highly regarded engineering faculty member from Y1.

To address the issue of students dropping themselves from the course, the college-wide Undergraduate Education Committee agreed to make Engineering Math mandatory for all engineering students who had a math placement below semester-long Calculus I (i.e. they would be taking either Pre-Calculus or year-long Calculus 1). A petition process administered by academic advisors was agreed upon for students who had schedule conflicts or other strong reasons for not taking Engineering Math. As the course was automatically added to students' schedules, they received a welcome message similar to the one sent in Y1, but with the additional note stating that the class was mandatory if they were concurrently enrolled in Pre-Calculus or year-long Calculus I. The same message was conveyed to the academic advisors in each degree program. However, the mandatory designation was not entirely accurate since the completion of Engineering Math was not actually required for graduation in any engineering major, an ethical and implementation issue discussed at length in another paper presented at this conference [8].

Proposing the change in status of the course from optional to mandatory was difficult because prescribing more rigid degree program requirements is not ideal considering curricular flexibility is important for engineering students [9]. And, with only ~14% of first year engineering students required to take Engineering Math, it was challenging to avoid deficit or remedial mindset and messaging. This is a significant deviation from the WSM model implemented at many institutions, where all engineering students are required to take the course their first semester before embarking on the Calculus sequence [7].

This paper analyzes the differences and challenges of moving from a single offering to multiple offerings of the course, and the overall consequences of changing the course structure between Y1 and Y2 of pilot implementation. Demographic changes in who took the class, how the classroom space was utilized, the resulting shifts to larger distributions and class sizes, and changes in the ways social grouping and relationship building occurred are discussed to illustrate consequences, both intended and unintended, of scaling up the course. Overall we see that while increasing the size of the course moved the class away from a personalized process where each student had immediate access to many resources (peers, TAs, instructors, spaces) to one where students still had the opportunity to share in the same course resources, but did so to a lesser and different extent than in Y1. In other words, as the larger Y2 course moves more toward an institutionalized, standard, more factory-like model, we note the tradeoff in losing some of the benefits that existed in the smaller implementation of the course as well as some surprising gains. As the size of the Y2 pilot is more realistic for any first-year course at a large public university, we share our lessons learned in the hopes of helping other designers of first-year programs ponder the consequences of scaling up any course to fit the standard scale of larger institutions and engineering colleges.

Methods

The data used in this research investigation include many different sources, including institutional data, pre/post survey results, and written responses to reflection questions posed to students as routine course assignments. Each student in the pilot course (Y1 and Y2) had the option of having their data included or excluded from the research project.

The types of institutional data collected include student demographics, course outcome, performance and persistence metrics. The institutional dataset is pulled from campus sources after each subsequent academic term so that longitudinal student performance and persistence can be tracked.

All students in the pilot course take a pre-survey administered the first week of class and a post-survey the last week of class, administered for course improvement purposes. However, only students that consented to participate in the research have their results presented in this paper. The surveys ask questions about the students' level of comfort in the classroom, sense of belonging within many contexts, engineering identity, skills and abilities, intent to continue engineering in college and as a career, and some math confidence questions.

Since reflection questions were assignments in the class, all students submitted them as part of their coursework. But, only the results from consenting research participants are included in this research dataset. Six students who dropped after attending the course for multiple weeks were invited to interview with a member of the research team to discuss their experience; three of these six students agreed and followed up, and their responses are also included in the research findings. The second offering of the pilot just concluded at the time of writing this paper; thus we are looking mostly at raw data to confirm what the authors saw as emerging themes from the post-assessments.

Research Limitations

Of the 99 students enrolled in the class at the end of the term, 92 took the post-survey, 63 of which consented to full participation in the research study. A research limitation is that the students who agreed to participate in the full study by releasing their pre/post survey responses and qualitative reflection question responses for research analysis had markedly different Engineering Math grade outcomes than their peers who chose not to participate. For example, the average Engineering Math course grade for research participants was 83.9% (85.1% median) versus 74.3% (77.8% median) for non-participants. Thus the results presented in this work, such as those gleaned from student reflections or open-ended survey responses, may be biased toward higher achieving students.

The research questions presented in this paper are:

1. What are the consequences, both intended and unintended, of the course expansion from Y1 to Y2 of implementation?
2. What can engineering administrators and decision-makers learn from this scaling-up process to ensure that the positive outcomes of the course are not lost when the course is expanded?

Findings

Demographic Changes and Use of Space from Y1 to Y2

When the course changed from enrollment being targeted in Y1 to mandatory in Y2 for all students with a specific math placement level, significant demographic shifts in the course participants were observed. For example, the course went from predominantly enrolling in-state residents (91%), many from low-income families (73%), first-generation to attend college (59%), underrepresented minority students (82%) to seeing each of those populations much less represented in the course the second year (63%, 33%, 34%, and 38% respectively). For context, students from most of those populations were still overrepresented as compared to the engineering college population at large (see **Table 1)**, but the demographic differences of the students enrolled in Engineering Math between the Y1 and Y2 pilots were marked.

Students in the two iterations of the pilot did have comparable high school grade point averages and ACT Math test scores; however, both were markedly lower than their cohort peers in the larger engineering population.

Table 1: Demographic comparison for Engineering Math and College Cohort, Y1 and Y2

	Students in Engineering Math		**Comparable First-Year Engineering Cohort**
	Y1	**Y2**	
Enrollment	N=22	N=99*	N=818
In-state residents	91%	63%	61%
International	5%	11%	5%
Women	36%	56%	37%
Underrepresented minority	82%	38%	16%
Low income	73%	33%	15%
First-Generation college	59%	34%	12%
GoldShirt Program participant	59%	34%	1%
ACT Math Min	20	20	23
ACT Math Max	28	33	36
ACT Math Avg/Median	25/25	25/25	31/32
High School GPA Avg	3.77	3.79	3.93

** N =99 in Y2 reflects only students who completed the course and received a grade (students who withdrew or dropped the class are not included in this analysis)*

With these shifts in demographics, the culture of the course changed as well. In the Y2 pilot women were highly represented at 56%, with one lab and one recitation section each enrolling over 80% women. And, the Y2 course enrolled international students at twice the rate of their representation among the first-year engineering cohort. An additional change from Y1 to Y2 was the percentage of students in the course who were also part of the GoldShirt Program; a foundation of the program is a 2-week on-campus summer bridge experience focused on community building and immersion in engineering practices [6]. With the majority of the Y1 students also a part of the GoldShirt Program, the Y1 pilot began with many of the students already knowing each other well and residing together in the same dormitory. In Y2, the percentage of students in the GoldShirt Program decreased and the students were split between multiple lecture, lab, and recitation sections, so that they were not as strongly cohorted together as in Y1.

In Y1, students felt comfortable inhabiting the dedicated Engineering Math Lab classroom at all hours of the day, as evidenced by end-of-semester feedback and reflection question data. Several students recalled the room as the site of the most memorable moments of the course, particularly when students fell asleep while pulling late night / early morning study sessions (see [10] for more details regarding room use in Y1). There were no other scheduled courses in the Engineering Math Lab during the entirety of the Y1 pilot, as it was a brand-new room completed in time for the start of the semester. During Y1, the students took full advantage of the speakers in the room and would request music to be played during lab sections, or would take the initiative to put on their own playlists before or after formal class activities, while simply studying or working in the room. Often during Y1, students from minority populations chose to share aspects of their culture including their music and customs with the other students, instructors, and TAs of the course. Prior to the Fall Break holiday, students discussed their favorite foods - including menudo - and explained what they were looking forward to about going home.

During the Y2 pilot, these instances of sharing personal background and culture were much fewer and farther between. In general, students did not feel as much ownership over the classroom space, as class activities were divided between labs and recitations occurring in the Engineering Math Lab and lectures happening in a different classroom in an adjacent building. In contrast to Y1, other classes were scheduled in the Engineering Math Lab, meaning that the room was unavailable for blocks of time during the week and the Y2 students were not the only students with legitimate access to the room. While the students in Y2 were told that they had priority access to the room after-hours, they simply did not use the room as often as the students in Y1. Data from reflection questions in Y2 reflects this change in classroom usage, as few students mentioned the room as a meaningful or memorable site of activity for learning or identity development.

In both Y1 and Y2, all TA office hours took place in the Engineering Math Lab. In Y1 there was a total of 6 office hours offered each week: 2 hrs/wk from each of the two TAs, and 2 hrs/wk from the course instructor. In Y2 this increased to a total of 14 office hours offered each week: 2+ hrs/wk from each of the five TAs, and 2 hrs/wk from the course instructor. Notice that this scaling-up of office hours was not proportional to the scaling-up of the number of students in the course, as in Y1 there were 0.27 office hours per week per student (6/22), while in Y2 the number dwindled to 0.14 office hours per week per student (14/99). Put another way, in Y1 there were no student complaints about not having enough help or access to TAs for homework or lab assistance, while in Y2 as early as the first week of classes many students were already voicing concerns about not having enough access to TAs or the instructor to have their questions answered in a timely manner.

Y2 students were vocal in expressing their desires to have urgent and immediate access to resources, in sharp contrast to the year prior. In the early weeks of the semester, when students were still getting to know one another and building networks of peers to collaborate on homework problems or study with, it was a common occurrence to see individual students sitting in the Engineering Math Lab during office hours, recitation, or lab with their hands raised, simply waiting for a TA or instructor to walk over to them to hear their question. This led to frustration and impatience for students, TAs, and the instructor, as many students felt they had to wait ‘forever’ to ask clarifying questions or get help while the TAs and instructor felt that they were running around nonstop to answer the same questions over and over again. While the severity of the frustrations decreased as students became more self-sufficient and better at utilizing their peers for help, the initial tone of the class in Y2 was rife with impatience and urgency.

We wonder whether this increased sense of urgency and impatience could be attributed in part to the demographic shifts from Y1 to Y2 of the pilot, as the Y2 students were largely from higher SES families, were much more likely to have relatives who had obtained college degrees, were less likely to be underrepresented minority students, and were students who hailed much more from other states or countries (an expensive proposition at a public institution that does not meet financial need). Y2 students were also less familiar with one another at the start of the semester, as the GoldShirt Program participants were a smaller overall fraction of the course and were spread out across multiple lecture, lab, and recitation sections. In general, Y2 students were accustomed to having more resources at their fingertips and seemed unfamiliar with waiting.

Reflecting on the shifts from Y1 to Y2, we wonder if by expanding the course to include a greater fraction of majority populations we inadvertently shuttered the productive use of the Engineering Math Lab as a *counterspace*. Counterspaces have been theorized as "'safe spaces' that, by definition, lie in the margins, outside of mainstream educational spaces, and are occupied by members of non-traditional groups" [11]. In Y1, the Engineering Math Lab was a physical counterspace, offering a haven for a largely minority population to exist as students, working and studying outside of the mainstream curriculum and the majority student body. Researchers have demonstrated the power of counterspaces in allowing underrepresented students to promote their own learning, vent frustrations about existing in predominantly white institutions, and challenge deficit notions of marginalized groups while establishing and maintaining a positive academic racial climate [11], [12]. The larger majority population in Y2 and shifts in course scheduling changed the climate of the Engineering Math Lab so that it no longer operated as a counterspace for minority students.

Larger Distributions and Large Class Size Effects

A natural consequence of expanding the class size from 22 to 99 was to move the lecture from the dedicated Engineering Math Lab, with a capacity 32 students, to a larger active learning classroom used by many courses and departments. The Y2 lecture classroom has a maximum capacity of 65 students, arranged around 15 circular tables. To accommodate the 99 students enrolled in Engineering Math in Y2, the class was split into two separate lecture sections, each meeting three times weekly for 50 minutes. Similarly, while in Y1 there was a single lab period for all 22 students, the class size in Y2 necessitated four lab sections with ~25 students in each section.

The scheduling of the course from Y1 to Y2 thus resulted in significant changes for in-class student-student interactions. All class events (with the exception of recitation) in Y1 occurred with the entire cohort of students, such that five hours of class each week were held with the same group of 22 students over the 16-week semester. In Y2, the 99 students were split between two lectures, four lab sections and five recitation sections - without the continuity of seeing all their peers across lecture and lab. And, by expanding the size of the lecture classroom and moving the lecture from the lab to a larger classroom, the tone of the lectures changed from intimate and conversational to the climate and atmosphere typical of a traditional college math lecture. Despite instructional efforts to make the lecture "active" in the form of group activities requiring students to work collaboratively on an example problem or stand up and work on whiteboards arranged around the perimeter of the room, students were frequently resistant to anything besides the default "chalk talk" lecture, with the instructor at the front of the room delivering content and reviewing notes on an electronic projection screen while students sat quietly and passively, "absorbing" content.

End-of-semester feedback revealed that some students found the round tables in the active learning classroom to be distracting and ineffective during lecture periods, as inevitably some students would need to sit with their backs to the front of the room or turn their chairs around so they were taking notes on their laps rather than on the tables. A few students described being easily distracted by their peers in the active learning classroom, as facing one another led to side conversations not related to the course. Some students suggested that future class lectures be scheduled in a traditional tiered lecture hall rather than an active learning classroom, so that all students could face the same direction, see the front screen, and have a hard surface to write on.

The suggestion to move from the active lecture classroom to a traditional lecture hall surprised course designers, as the intention to have an active learning class rather than a stand-and-deliver math lecture was built in to the foundations of Engineering Math implementation. However, this points to the durability of the traditional lecture model in engineering and mathematics education - first-year students acclimatized to learning math in a passive lecture style were unaccustomed to being asked to stand up and move around during a class period.

With the significantly larger Y2 student population, a wider distribution of students' incoming preparation levels and variation in prior exposure to math topics was encountered. And, more students were at the extremes or tail ends on both sides of every measurable variable of interest (see **Table 1**). For example, ACT math scores of students in Y1 ranged from 20 to 28, while in Y2 they ranged from 20 to 33. While a few points on the ACT scale may seem irrelevant to Engineering Math activity, the idea that with more students comes more variability was apparent from the first week of class. Some students were bored by the topics of quadratic equations and straight lines in engineering while others felt that the class was moving too fast for their comfort.

The question of pacing and the speed that new topics were introduced came up frequently during the course, as students voiced complaints that the content delivery was either too fast or too slow, with few experiencing the pace of the course as just right. This Goldilocks effect was exacerbated by differential institutional status markers of math placement scores and concurrent first semester mathematics class: in Y1, all students in Engineering Math were also enrolled in Pre-Calculus; in Y2, students in Engineering Math were also enrolled in either Pre-Calculus or the first semester of a yearlong Calculus 1 sequence (Calc 1A). While all students in Y2 were not deemed ready for Calc 1, the differentiation into two tiers of Pre-Calc vs. Calc 1A takers resulted in students self-identifying as "not in Pre-Calc" or "still in Pre-Calc," identities consequential for their feelings of being ahead, behind, or on track towards earning their engineering degrees.

The Wright State Model is designed as a forward-looking curricular model, where students are introduced to mathematical content that they will use in their future engineering science and design courses [13]. However, this model may cause students who are at the lower end of the math preparation spectrum to feel underprepared for Engineering Math or intimidated by the pace or perceived complexity of the topics introduced.

The larger student population in Y2 as compared to Y1 also demonstrated greater variability in the distribution of test scores, apparent across two midterms and the final exam. While no students in Y1 expected the course to be curved, students in Y2 questioned if the course would be curved similar to their concurrent mathematics courses. The greater number of students in Y2 as compared to Y1 also had consequences for the style and process of grading student work. In Y1, with just over 20 students, each exam was graded in its entirety by the grader (either instructor or Teaching Assistant) before moving onto the next one, providing an overall sense of how much each student knew and how they performed on the entire test.

With about 99 students in Y2, exam grading shifted to an assembly-line model where each problem on an exam was graded by the same grader for standardization, fairness, and efficiency. Thus, graders did not see the students' work in the context of the rest of their exams, rather they only saw the single problem they were tasked with grading. This streamlined the grading process and enabled the instructional team to return graded exams within 48 hours. However, in optimizing the grading process in Y2 for speed and fairness, the deeper understanding and holistic view of how each student did on the exam was lost - a trade-off necessitated by the number of students in the class. Prior research has indicated how moving towards such an assembly-line or factory model of engineering education can result in dehumanizing students and viewing them as numbers (their total score on an exam) rather than people with individual needs, desires, and identities as growing engineers [14].

Building friendships, relationships, and peer networks

Another aspect of Engineering Math that appears to be consistently important to students is that the class gives them time, space, and structure to create relationships. Relationships are formed with the instructor and TAs, but potentially even more importantly, with other students. Since almost all students in this course are first-time, first-year engineering students, and this course is offered in their first term, it is one of the first chances for students to form peer networks and study groups. This class is intense: it meets for six hours each week, with two hours devoted to hands-on lab work and one hour of recitation problem-solving, resulting in students seeing each other and actually interacting with one another more often than in most or all other first-year classes.

Even for students who chose to drop Engineering Math, making friends was something they greatly valued from the course. All three students who dropped the class and consented to an interview with the research team mentioned that they made friends in the Engineering Math class and that they were still friends with those students after dropping the course. One student explained:

> What I found really fascinating is that, I remember in my first office hour visit, almost the entire class was there to do homework, and so we all got to know each other, we helped each other – it was a lovely environment, I really loved that. Everyone was so supportive, we all became friends, basically, we helped each other – it was amazing. No other class gave me this experience – I really loved that.
>
> *~ Omar, pseudonym, Y2 student who dropped after week 5*

This student clearly believed the social environment of Engineering Math was consequential for their overall experience in the class, distinct from any of their other classes taken in the first semester. Despite choosing to drop the class prior to completion, the feeling that "we all got to know each other" in a collaborative, helpful environment was "lovely." The emphasis on how much this student "loved that" leaves little doubt that the positive social interactions enabled by the class were meaningful to this student.

This same interviewee, an international student, went so far as to say that the relationships formed with peers during the class were one of the reasons the student chose to return to campus for a second semester instead of going home to their country of origin. Clearly, the opportunities for peer-to-peer connection engendered by this class had far ranging effects, beyond simply getting homework done or learning math concepts through engineering applications.

Data from student reflection questions also supports this finding, as in response to the prompt asking students, “If you were going to tell a new student just starting Engineering Math and their college career one thing - what would it be?” one student replied:

> I would tell them exactly what I told myself, which would be that proper planning and smart studying (time effective) is one thing that [one] must try to learn early on. I would also tell them that University is not like high school where you would have one cluttered group of friends, You would most probably have friends (or people you would like to befriend) in almost every class you’re in and therefore your social circle might seem weird initially, but it'll all even out with time so one should not worry about such matters. Moreover, I would tell them that almost everyone around is probably as nervous, scared and shy as they are and that usually the best way to make a friend is the break the ice. Otherwise it would be pretty hard.
>
> *~ Raoul, pseudonym, Y2 completer*

This student helps contextualize the process of adjusting to college social life, in comparison to a high school world where cliques are common and one may have a single “cluttered group of friends.” Indeed, Engineering Math enabled students to reach out and befriend peers in lecture, lab, and recitation sections, which could be “weird” initially but as Raoul assures us, will “all even out with time.” Implicit in his response is the lessons learned about how to “make a friend” and “break the ice” - vital information for surviving as an engineering student on a big public college campus.

Students also found relationships with the instructor of the course to be a meaningful development as a process of participating in the Y2 pilot. On the last day of the Y2 course, evaluators asked the students to “give Professor X a written, anonymous gift. It can be a critique, a compliment, or a suggestion ─anything you want; it’s your gift.” Students were made aware that their handwritten “gifts” were meant to be anonymous, and would be transcribed and depersonalized if they self-identified. Results from the 89 student “gifts” to their professor were quantitatively aggregated in a word cloud, as shown in **Figure 1**. Many of the gifts were long - half or full page hand-written. Even though students had separately reported that they worked hard, learned a lot and yet did not overwhelmingly love the Engineering Math course, they clearly thought very highly of their professor and their own learning - with “thank,” “appreciate,” “helpful” “enjoy,” “fun,” “care,” “work,” “teach,” “love,” “learning,” “hard,” and “best,” dominating their free-form feedback. Also common were the terms “passion,” “interest,” amazing,” “attitude,” and “try.” Thus the human component of being in an intense, well supported learning environment came through when students were free to express thoughts about their experience in a personalized fashion. Of note is that although the students were invited to provide a critique to their professor, only very few did, as students overwhelmingly expressed their appreciation for a great learning experience.

Figure 1: Word Cloud generated from "Give Your Professor a Gift" Data

Y2 Assessment outcomes

Multiple assessment strategies were employed to triangulate the benefits and struggles associated with the course. All courses in the engineering college are required to use the campus-provided Faculty Course Questionnaire (FCQ), filled in individually by students as they reflect back on the course and teaching team. By choice, the Engineering Math assessment team sought qualitative input via the Student Group Interview process as described below. Selected Results from both types of assessment are detailed below.

Key takeaways from FCQ data

Students found the course to be intellectually challenging, with 51% reporting it to be at the highest challenge level (6/6), and another 32% reporting it to be quite challenging (5/6). Likewise, 33% reported their learning from the course at the highest level (6/6) with another 35% reporting they learned a lot (5/6). Key findings that likely scaffold these results include that students worked a LOT in and for this class, with 61% of students reporting that they worked at least 10 hours weekly on the course. And, they were supported in their learning by a caring and effective instructor: 84% of students rated the instructor's effectiveness as high (5/6 or 6/6) and

81% rated her as being highly effective at encouraging student interest in the course content (5/6 or 6/6). But, even though students felt intellectually challenged, worked hard, reported that they learned a lot, and appreciated the course instructor and TA's, only 63% of the students rated the course highly overall (5/6 or 6/6).

Themes from Student Group Interview data
An hour-long, class-idea driven student group interview process to reach consensus of the strengths of the Y2 Engineering Math course, as well as suggestions for future improvements, was employed. Ideas for both categories were generated through a group-based process that required consensus of three or more students to get an idea presented for further whole-class discussion and subsequent individual voting. Each individual student privately voted (on a Likert scale of 1-5) on the extent to which they personally agreed that the identified strengths of the course actually were, and the extent to which they agreed (or not) that each suggestion for improvement would improve future offerings of the course.

Students overwhelmingly agreed that access to a somewhat private, and dedicated classroom lab (97%) with in-class printing (94%), having effective TAs (91%) and a good instructor (89%), and having abundant office hours (83%) were the paramount strengths of the course. From a structure and content perspective, students appreciated being able to do test corrections (90%), learn MATLAB (83%), use a class learning management system (84%), and have real-world context for their learning (88%). Likewise, 87% found that the course provided a valuable preview of future engineering classes and topics ─ an important course implementation goal of the institution.

Takeaways for Implementation in Y3 and Beyond
The challenges of larger-scale implementation in Y2 are numerous but unavoidable, as the Y2 class size of ~120 students is the realistic standard for a first-year Engineering Math course in our college of engineering. From the perspective of course designers and instructors, the need to make the class scalable but still successful is paramount for continued implementation. If the Engineering Math course in Y3 and beyond becomes integrated into the long-term offerings in the college, the expectation is that student demographics will closely mirror those in the Y2 pilot.

It is also expected that the Engineering Math Lab used for lab and recitation will continue to see high demand from other courses, restricting its availability to Engineering Math students. Messaging around using the space and control of the space becomes an issue that needs to be carefully considered. If the Engineering Math Lab existing as a counterspace or at least a dedicated resource for students in the class is a critical feature of the success of the pilot course, making sure other events, populations, and courses do not takeover will be vital. Additionally, from the lessons learned in Y2 about the needs of students to have their questions answered expediently, particularly during the first few weeks of the semester, a greater availability of TA office hours and high-touch resources may be warranted for future implementations of the course.

With the larger Y2 class size, student assumptions or expectations about the format of the course became evident: lectures as passive rather than active; grades as curved based on the distribution rather than individually earned; and generally seeing the course as "another math class" as opposed to an entirely different kind class with its own culture, expectations, and environment. From an instructional standpoint, the challenge of ensuring that students see the course as distinct and different from their other concurrent math courses is critical to prevent Engineering Math from being absorbed by default into the prevailing climate of standardization and dehumanization prevalent in traditional engineering courses and large-scale required mathematics courses common in the undergraduate engineering curriculum.

Structural aspects of the course, including moving the lectures to a more traditional lecture hall, are being re-considered in Y3 based on the mix of feedback from students in Y2.

Another instructional challenge to address with a larger class size is the wider distribution of incoming math preparation levels among students. Being more strategic about scheduling students into different lecture sections based on their concurrent math class is one potential means to address the two distinct tiers of students enrolled in Y2 and potentially in Y3 (Pre-Calc vs. Calc 1A). However, continuing to sort students based on math placement levels may have the undesirable effect of reinforcing math as a marker of status and progress through undergraduate engineering [15].

Another approach might include administering a concept inventory or diagnostic during the first week of class so the instructional team has better understanding of students' prior knowledge levels and exposure to distinct topics - including quadratic equations, trigonometry, systems of equations, sinusoids, etc. With individual data about students' incoming math preparation levels, instructors could develop specific interventions targeted at boosting students in specific topic areas to supplement the class lectures and help students feel more comfortable with the pace of their learning in the course.

With any intervention, care must be taken to ensure that students do not feel stigmatized as remedial or behind; rather focusing on individual growth and improvement rather than "catching up" to an imagined "normal" progression through undergraduate engineering [14].

Finally, lessons can continue to be learned from the original implementation of Engineering Math at Wright State and from other implementation sites - how do others manage the spectrum of math preparation levels entering this course every fall?

Discussion & Conclusions

Our first research question asked, "What are the consequences, both intended and unintended, of the course expansion from Y1 to Y2 of implementation?" In the findings section we examined how scaling up the course changed the demographics of the students involved, shifting the culture of the course, student expectations of the class, and how it operated on a week-to-week basis. We noted the consequences of becoming a large class, with respect to the environment in lectures, the wider distribution and variation among all measurable student variables, and the opinions of students about the pacing or speed of content delivery in the class. We also observed that the larger class size offered students the opportunity to meet many other first-year, first-time engineering students and build their social networks, a somewhat unexpected benefit of course expansion.

Our second research question asked, “What can engineering administrators and decision-makers learn from this scaling-up process to ensure that the positive outcomes of the course are not lost when the course is expanded?” Our findings have demonstrated that some of the Y1 outcomes may be impossible to replicate at a large scale, particularly the use of the Engineering Math Lab as a *counterspace* or the ability for every student in the class to know one another. However, we hope that the trade-offs are worth it, as with a larger class size more students have more opportunities to experience the course while meeting other students of different majors, backgrounds, academic programs, residence halls, and more. As course designers and instructors, we must remain vigilant to keep Engineering Math from being subsumed by the larger climate of standardization ubiquitous among large-scale, required undergraduate math and science courses, so that students, faculty, administrators, advisors, and teaching assistants are clear that Engineering Math is fundamentally different in its approach, content, and expectations for student learning. Finally, we note that students do appreciate and acknowledge the personal enthusiasm and efforts on the part of the instructional team that this class requires, good reasons for us to keep going.

Implications for first-year programs
A constant challenge of innovating engineering educators is that making sound decisions regarding course scheduling or class size must be made well in advance of research findings. These processes are completely out-of-phase from one another, with time to delve into data and research often shortchanged for the necessity of keeping the program running and booking a classroom before they are all unavailable. Similarly, the time scale to “prove” that an educational intervention is worthy of becoming legitimate and solidified through curricular flowcharts and degree requirements is likely much longer than our planned 3-year pilot program. Now past year 2, we see that there is still much to learn and improve in ways we can optimize this course, at scale, to work for a broad spectrum of students and propel them forward into their engineering coursework. While we have started the work to develop the curriculum and local resources for the class, it will take more semesters of longitudinal tracking as well as cross-departmental collaborating to make this class a mainstay in our college.

Overall, we note that the process of writing a paper like this helps us as researchers, course designers, and instructors, to reflect on the class and examine the consequences of our past choices. While this is just a start to unpacking the effects of our curricular implementation decisions in the second year of the pilot, we note that the ripple effects of this course extend beyond the students enrolled or the personnel involved in administering this class. Simultaneous to our efforts in Y1 and Y2, the college math department has also begun course improvement efforts and culture change efforts in support of success for engineering students. As we continue to strive to eliminate the Calculus 1 bottleneck, we are grateful to have like-minded faculty and staff approaching the same problem, but from a different institutional perspective. With time, we hope to make it to improved engineering persistence and graduation rates for all students.

Going forward, we will continue to track participants from Y1 and Y2, and look deeper at our dataset to consider ways we can continue to improve our course offerings for Y3 and beyond.

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