Results From the Implementation of Wright State Model for Engineering Mathematics at University of Detroit Mercy

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Difficulties with Calculus in engineering curriculum leads to many students abandoning engineering programs. This significant loss to the profession is not a new problem. A well-known approach to address this, first proposed by Wright State University, involves teaching an Engineering Mathematics class to freshmen engineering students. Taught by engineers, this course only covers topics that are actually used in early engineering courses and was recently added to the curriculum at University of Detroit Mercy. Using data from the initial offerings this paper discusses the experience of teaching it and the impact on retention and student success in early engineering courses.

Keywords: Calculus sequence, Wright State Model, retention, Engineering Mathematics

INTRODUCTION

Mathematics requirement of every engineering program in the United States is a set of standardized courses. This set of courses is well known across the engineering education community as the Calculus Sequence and is typically a three-course sequence of Calculus along with a course on Differential Equations. This is a bare minimum and most programs have additional required mathematics courses such as Linear Algebra and/or Probability and Statistics. In many engineering programs across the country the Calculus sequence works as a filter to "weed" out a lot of students from Engineering. This results in many students who start college wishing to study engineering dropping out after a few semesters of struggles with the Calculus sequence. An extensive survey of the many studies that have been done to investigate this problem can be found in (Felszeghy, 2010). Many students who could have otherwise been very successful engineers leave the discipline demoralized and with a sense of inadequacy. A large percentage of students affected are first generation college students, women and minorities. This is not a good situation as the profession loses valuable talents who could be very successful engineers.

The traditional method of calculus teaching emphasized building mathematical intellect and skills through rigor and hard work, in a way quite similar to athletic training. During the 1980s, a great debate started about whether and how the failure and attrition rates in calculus courses can be addressed by reforming the traditional calculus teaching methods. This discussion resulted in the calculus reform movement and formation of two camps, the classical and the reform camp. The Classical Camp, consisted of those who thought that the proposed reforms would "merely weaken the calculus curriculum, substituting

faddish pedagogy for rigor and hard work." According to the Reform Camp, "traditional calculus education has lagged behind most other disciplines in integrating technology into the classroom" and therefore calculus teaching should include "computer-based learning, group study, reliance on learning by concrete examples, and verbal analysis of mathematical problems." According to the Classical Camp, too much reliance on computers and technology would increase the "risk that students will learn more about manipulating a particular computer program than about calculus in general" and "obscure important ideas" (Petechuk, 2020). The impact of the calculus reform movement is discussed in many publications including (Lavelle et.al, 2005, Hensel et.al, 2008, Koch et.al, 2006).

Until 2015, calculus was taught at Detroit Mercy in the standard course sequence MTH-1410 (Calculus I), MTH-1420 (Calculus II), and MTH-2410 (Calculus III) using Howard Anton's textbook. This textbook is neither completely traditional nor purely reform style. This is a contemporary text which incorporates the best features of calculus reform yet preserves the main structure of an established and well-tested calculus course. The Calculus sequence is a prerequisite for Physics classes, Statics and Circuits. Many students coming to college are not ready for calculus. Many of these students who struggle in the calculus sequence end up giving up on engineering without even having the opportunity of taking some of the early engineering courses. Many of these students are women, underrepresented and first generation. We cannot afford to lose so many talented and motivated students and neither can the profession. In 2015 we did a study of the different reforms and decided to adopt the Wright State Model (Dasgupta, 2015) to address the problem.

WRIGHT STATE MODEL AND ITS IMPLEMENTATION

Reform and the classical approaches are about changing teaching methods. Wright State model (Wright State Model Website) provides a third way. Wright State researchers proposed an approach where the Calculus Sequence still remains a key component of ABET accredited engineering curriculum but the prerequisite structure is revised significantly through the introduction of a new course on Engineering Mathematics. Wright State first proposed this model and started offering this new course that is taught in the freshman year by engineering faculty. The course content covers topics in mathematics that are actually used in some of the early engineering courses such as Statics, Dynamics, Circuit theory, etc. In this course no attempt is made to teach all the materials taught in the entire calculus curriculum but only the topics that are actually used in the early engineering classes. Also, all the lessons and problems used are set up in the context of engineering situations that students will encounter in other engineering classes. This course is used as the prerequisite for early engineering courses such as Physics I and II, Statics, Dynamics, Circuit Theory, Mechanics of Materials, etc. Thus, students who are successful in this Engineering Mathematics course are allowed to move onto some of the early engineering courses. They are still required to finish the Calculus Sequence but essentially have four years to do so. Once students are able to take some of the early engineering classes and are successful, their motivation to continue in engineering is increased and they are then more likely to finish the program. Calculus does not act as a filter either. Wright State's experience and their publications indicate that they have witnessed a significant increase in engineering student retention after this approach was launched.

The textbook used for this class is the same one that is used by Wright State (Rattan and Klingbeil, 2015) The topics covered in this new course on Engineering mathematics are:

- Basic Algebraic Manipulations, linear and quadratic equations (1.0 weeks)
- Trigonometry (1.0 weeks)
- 2-D Vectors (1.0 weeks)
- Complex Numbers (1.0 weeks)
- Sinusoids & Harmonic Signals (1.0 weeks)
- Matrices & Systems of Equations (1.0 weeks)
- Basics of Differentiation (3.0 weeks)
- Basics of Integration (3.0 weeks)

- Differential Equations (3.0 weeks)

Students at Detroit Mercy faced some of the same struggles that was observed at Wright State and other universities prior to the adoption of the Wright State model. In 2015 an internal study was conducted to address this problem of student retention in engineering. The report (Dasgupta, 2015) strongly recommended that we adopt the Wright State Model. In Fall 2016 the course Introductory Mathematics for Engineering Applications (ENGR1234) was first offered. Subsequently, it has been offered both in Fall and Winter semesters the first two years and only in Fall after that. Two of the four engineering programs (Mechanical and Civil) made this class a requirement in their curriculum but two other programs didn't. Students entering Electrical engineering or Robotics programs were sometimes placed in this class if the advisor deemed that they needed additional mathematics training prior to taking the Calculus Sequence, but this class was not a requirement for the two majors. The Fall classes were larger and majority of students in the Fall class are new Freshmen. The Winter class is smaller and consists of a mixture of students who are in Pre-engineering or were originally admitted with significantly weaker background in mathematics and have been taking many prerequisite classes such as Algebra and Pre-calculus. The textbook used for the class is the same textbook that Wright State used (Rattan and Klingbeil, 2015) and the class has been taught by an engineering faculty member since the first offering. The Wright State class has both a lecture and a laboratory component. In the laboratory, students perform physical experiments to illustrate the mathematical concepts covered in the lecture as well as Matlab-based modeling and simulation exercises derived from the theory learned in class. We already had a freshman level Introductory class on Matlab applications in Engineering. So, no laboratory component was included in ENGR1234.

Figure 1 shows a partial prerequisite structure for some of the earlier mandatory courses in engineering prior to the introduction of the new course. As is clear from this figure, students who ran into early difficulties with Calculus gets held back from the engineering classes. Figure 2 shows the revised flowchart after the new course was implemented. Proceeding with some of the early classes in Engineering is now decoupled from the completion of the Calculus Sequence.

FIGURE 1
PARTIAL FLOW-CHART PRIOR TO THE INTRODUCTION OF ENGR 1234

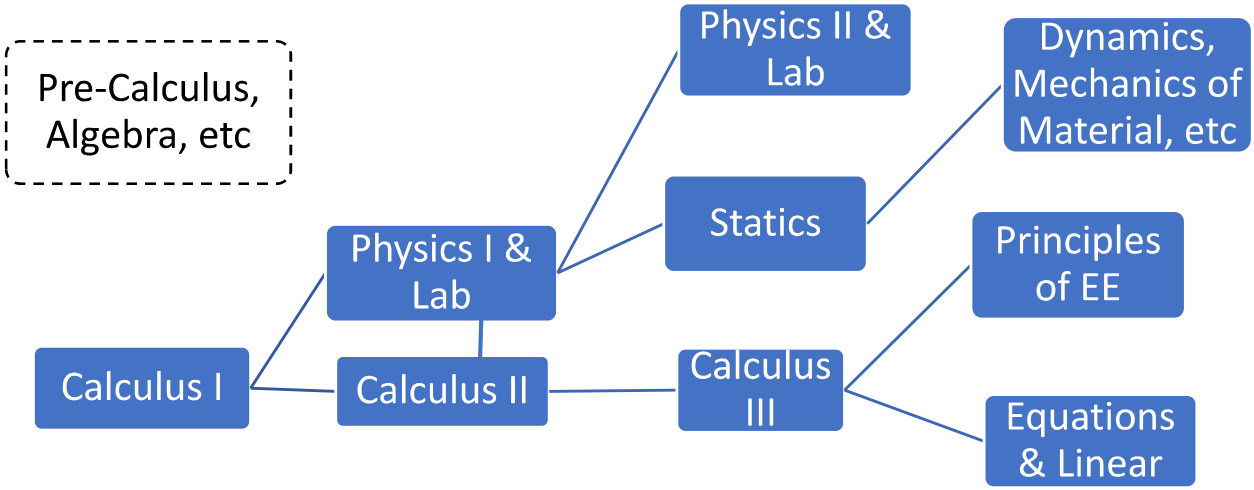
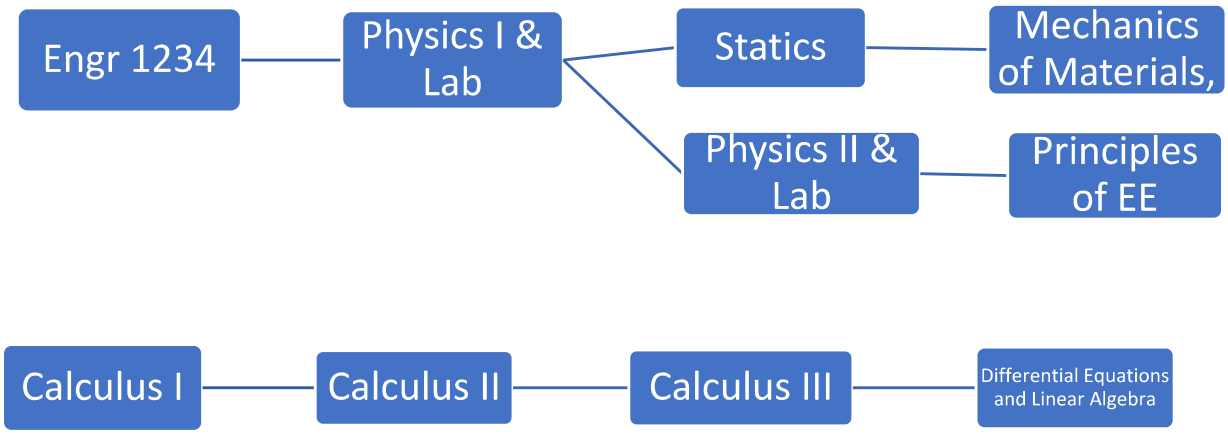


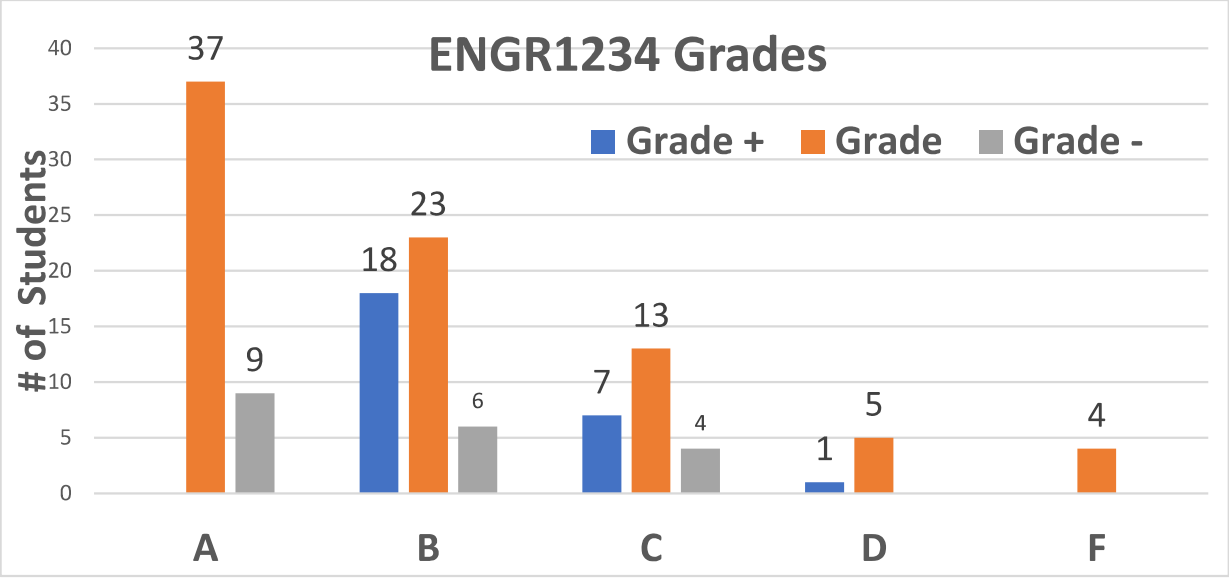
FIGURE 2
PARTIAL FLOW-CHART AFTER THE INTRODUCTION OF ENGR 1234



RESULTS AND IMPACT

One of the authors (Shuvra Das) of this article was the instructor for ENGR1234 for the first four semesters (Fall and Winter semesters of 2016-17 and 2017-18) and the other author (Kirstie Plantenberg) taught it in Fall 2018 and Fall 2019. We have excluded the group from Fall 2019 class in all our discussion and data presentation here. During the first three years a total of 127 students took this class. In this section we discuss results obtained by tracking the performance of these students in the ENGR1234 class as well as subsequent classes that they have taken. The goal was to develop an understanding of the impact this class was having on student preparedness, concept mastery, and success. Figures 3 -7 show the grade distribution of the students who took ENGR1234 in one of the five semesters mentioned. Figure 3 shows the grades obtained in ENGR1234. Many students took other mathematics classes while they were taking ENGR1234 and Figure 4 shows their grade distribution in those math classes.

FIGURE 3
GRADES IN ENGR1234



Figures 5 - 7 show grades received by students in relevant STEM classes that were taken in the following three semesters. These indicate how these students are performing in courses where the prerequisite is now ENGR1234 and not a calculus class. In many foundational courses we require a C grade or better for the course to be accepted as a prerequisite. Grade distributions in most courses show overwhelming majority of the students were passing with a C or better grade. This is a very good sign since ENGR1234 is being used as a prerequisite for these classes. Also, since the students are coming with different levels of preparedness they are in different classes. While taking ENGR1234, majority of the students are either taking Pre-calculus or Calculus I. If we consider non-math classes where concepts from ENGR1234 are used extensively the grades in Physics I and II and Statics are very encouraging.

FIGURE 4
GRADES IN MATH COURSES TAKEN AT THE SAME TIME AS ENGR1234

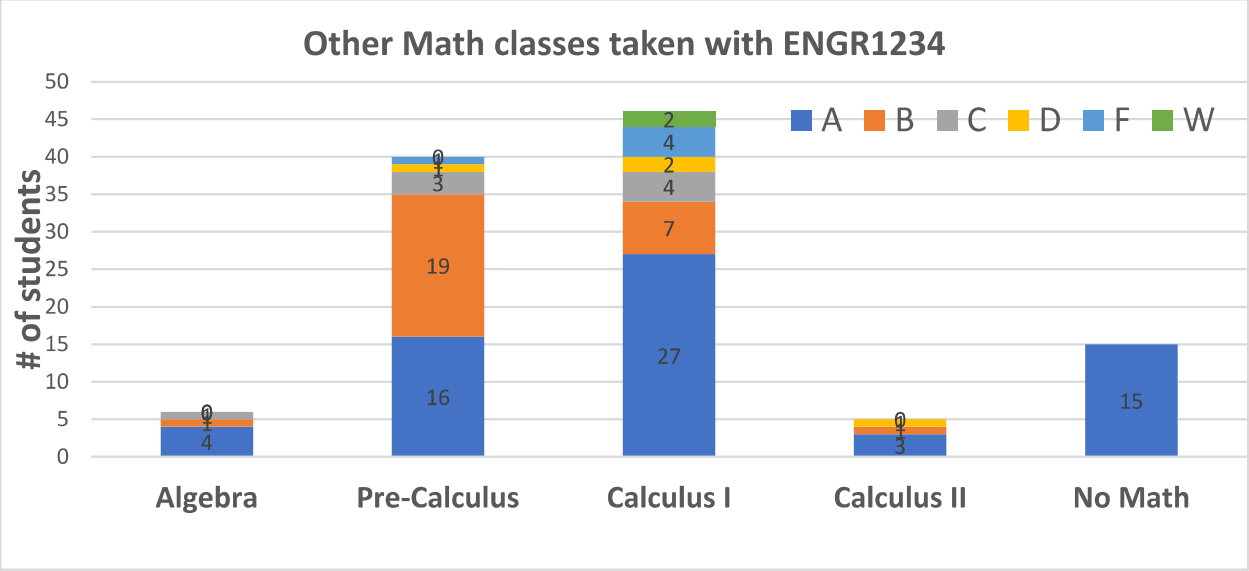


FIGURE 5
GRADE DISTRIBUTION IN MATH/SCIENCE CLASSES TAKEN ONE SEMESTER LATER

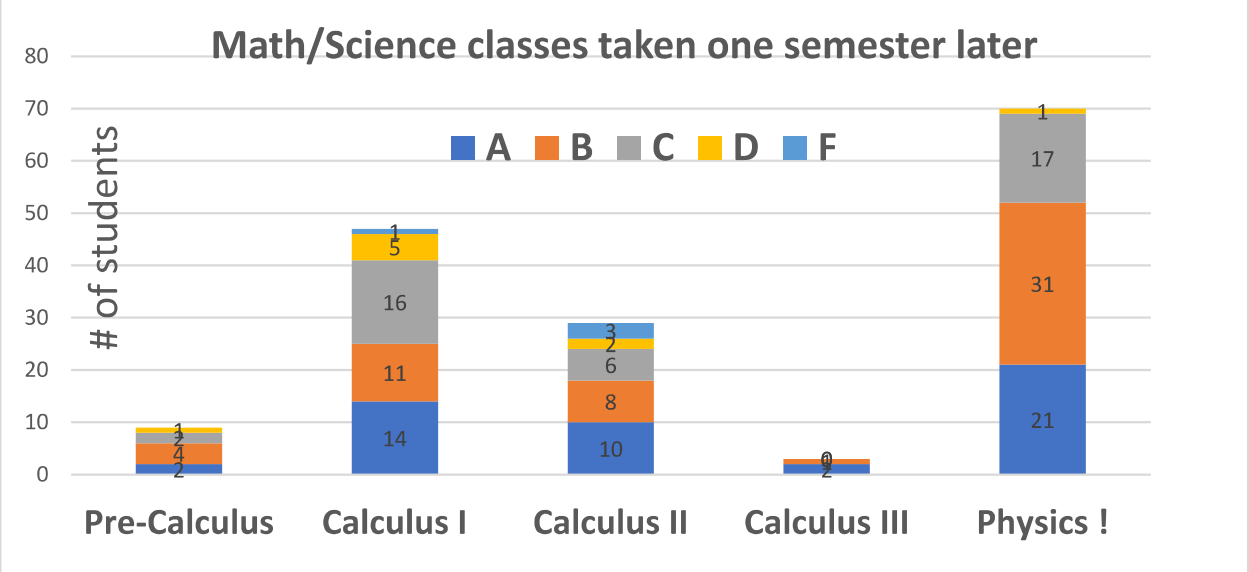


FIGURE 6
GRADE DISTRIBUTION IN MATH/SCIENCE CLASSES TAKEN TWO SEMESTERS LATER

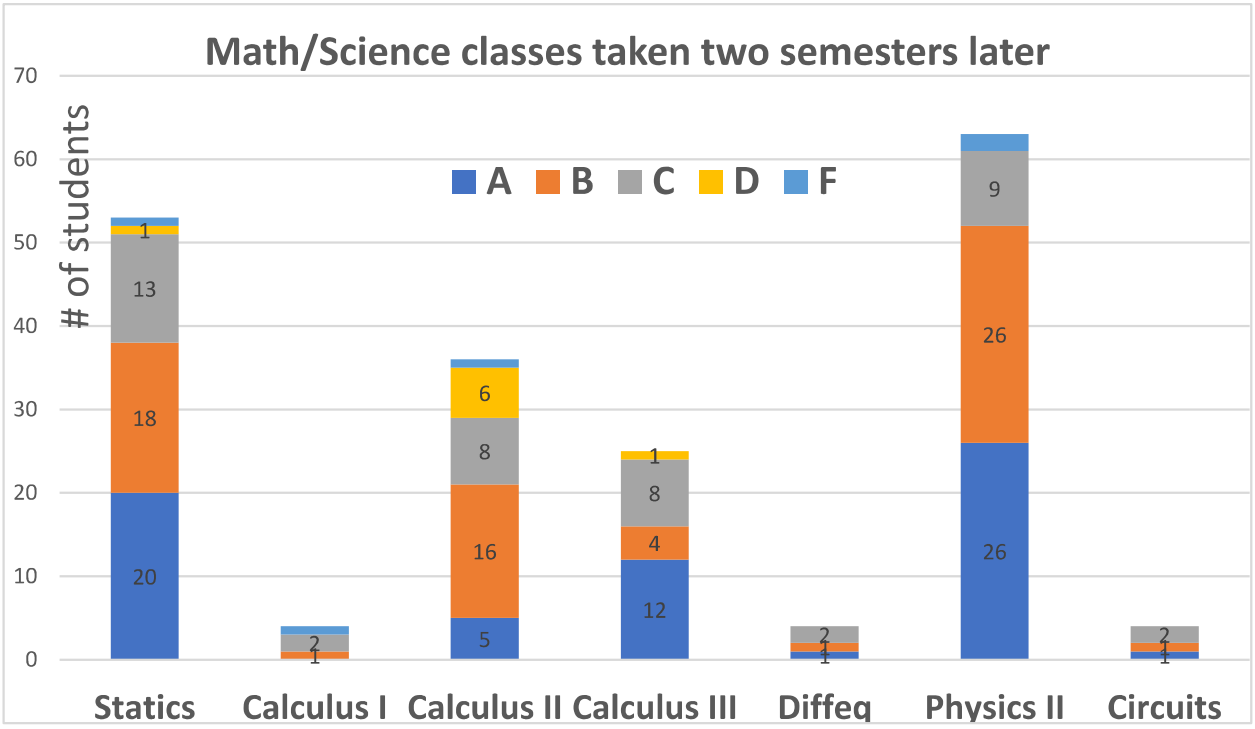
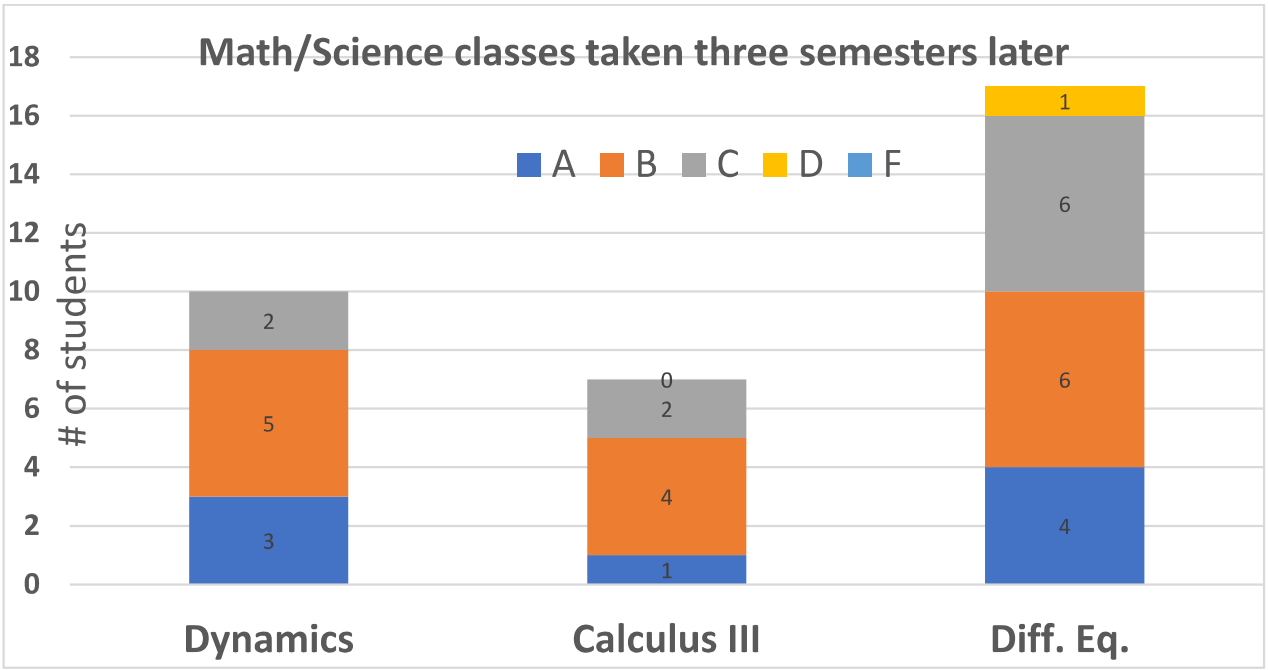


FIGURE 7
GRADE DISTRIBUTION IN MATH/SCIENCE CLASSES TAKEN ONE SEMESTER LATER



During the first three years of this class eighteen students out of the 127 who took the course left engineering or left the university shortly after finishing the course. It was important to explore who these

students were and what they did after leaving the discipline. Table I summarizes some data for all the students who left the program. Based on the best information that was available it seems six students dropped out and there is no information about their current status (indicated as "dropped out" in the table). Seven students changed major and are pursuing other career options ranging from a degree in Mathematics to Cybersecurity. These are very good outcomes because the earlier the students can determine their true calling the better it is. If math is the reason for their switching (and as the table indicates that it probably is not the reason for everyone) it is good to be able to do it after one class rather than a series of classes. Three or four students transferred to other 4-year universities, or community colleges for a variety of reasons. Of the students who "dropped out" a number of students were very weak in mathematics and who also failed in ENGR1234. The rest passed ENGR1234 but did not achieve a good GPA mostly due to their poor performance in other courses taken at the same time. In these cases, the causes that can be attributed to their situation may relate to the challenges that many freshmen students face as they try to adjust from being a high school student to a college student.

TABLE 1
THOSE WHO LEFT ENGINEERING (SORTED BY GPA): 18 STUDENTS

ENGR1234 Grade	GPA	Reason	ACT Score
A	4	Switched Major: Biology	29
A	3.99	Switched Major: Mathematics	34
A	3.76	Moved to University closer to home	28
B	3.27	Switched Major: Nursing	32
C-	2.83	Switched Major: Cybersecurity	20
C+	2.76	Moved to Another University	International Student
D	2.76	Switched Major: Business	24
C	2.7	Switched major: Cybersecurity	1130 (SAT)
C	2.69	Switched Major: Accounting	21
C	2.62	Dropped out	23
F	2.62	Dropped out	16
B+	2.57	Most likely transferred elsewhere	24
B+	2.52	Taking classes at Community College	25
D	2.19	Dropped out	26
F	2.08	Dropped out	19
C	1.71	Dropped out	26
C-	1.37	Dropped out	24
F	0.72	Dismissed and readmitted	1020(SAT)

Table II shows our retention data for engineering programs from 2009 through 2018. It provides both the first year's retention as well as the second year's retention data. First year's retention data is indicative of freshmen college adjustment issues as well as dropping out or transferring early from any program. Second year's retention data is a lot of times more meaningful because if students leave a program after more than one year of persistence in a discipline it could indicate deeper problems, such as sustained academic difficulties and/or financial or other problems. Anecdotal evidence also indicates that a factor that affects this number from the second year is the struggle with the Calculus Sequence. The data in this table shows that retention rates in our engineering programs during the second year varied quite a bit from one year to the next. The first time that did not happen is with students who started in Fall 2016. The retention rate of 71.9% remained the same in the second year for this group of students. This is also the year when ENGR1234 was first introduced and the prerequisite structure changed as described earlier. This piece of data by itself is quite encouraging. This however has not remained the case for the class of 2017. And for the class of 2018, it is too early to have that data available. It is therefore hard to draw any conclusions from

the retention data alone because not all majors have adopted the course as part of the required curriculum, while this data is for the entire engineering cohort. It will, however, be worthwhile tracking this data over the long term to see if there is much improvement in the retention rate.

TABLE 2
ENGINEERING RETENTION RATE

Start Year	1st-2nd year retention	2nd-3rd year retention (based on original enrollment numbers)
Fall 2009	**48.1%**	**33.3%**
Fall 2010	**84.6%**	**73.1%**
Fall 2011	**60%**	**48%**
Fall 2012	**69.8%**	**60.5%**
Fall 2013	**65.6%**	**50%**
Fall 2014	**80.8%**	**76.8%**
Fall 2015	**66.7%**	**57.8%**
Fall 2016	**71.9%**	**71.9%**
Fall 2017	**76.5%**	**58.8%**
Fall 2018	**75.9%**	**??**

STUDENT SURVEY

For the students who took ENGR1234 and continued onto other course in the curriculum, we were interested to know what was their perception of the impact of ENGR1234 on their level of preparedness for other classes. We conducted a survey among this population. There were six questions in the survey to be answered on a 5-point scale (strongly disagree to strongly agree). There was one additional question for written feedback. The survey was not conducted at the conclusion of ENGR1234 but several semesters after the students took the class. It could be distributed only among the 72 students who took the class during 2016-17 and 2017-18 academic years because they were far enough removed from the course for the survey to have made sense. About 40 students responded to this survey.

The first six questions were:

Q1. *Concepts learned in ENGR1234 helped me better understand concepts in Physics I*

Q2. *Concepts learned in ENGR1234 helped me better understand concepts in Physics II*

Q3. *Concepts learned in ENGR1234 helped me better understand concepts in Statics*

Q4. *Concepts learned in ENGR1234 helped me better understand concepts in Dynamics*

Q5. *Concepts learned in ENGR1234 helped me better understand concepts in other Mathematics classes (Calculus I, II, III, Diffeq.)*

Q6. *If I did not take ENGR1234 but took all the other Mathematics classes I have taken, I would have more difficulty in Physics, Statics and Dynamics.*

The responses for the six questions are summarized in Figures 8 through 13. The responses highlight the impact of the course. Here are some of the conclusions that can be drawn from the data:

- ENGR1234 has a stronger impact on student performance in Physics I (Mechanics) than in Physics II (Electricity and Magnetism)

- ENGR1234 has a very strong positive impact on student performance in Statics and Dynamics
- ENGR1234 seems to have a strong positive influence on students' ability to perform well in other Mathematics courses
- As per the response to Q#6 ENGR1234 was a valuable addition to the curriculum and students feel the course is helping them a lot

FIGURE 8
SURVEY RESPONSE TO QUESTION #1 (CONCEPTS LEARNED IN ENGR1234 HELPED ME BETTER UNDERSTAND CONCEPTS IN PHYSICS I)

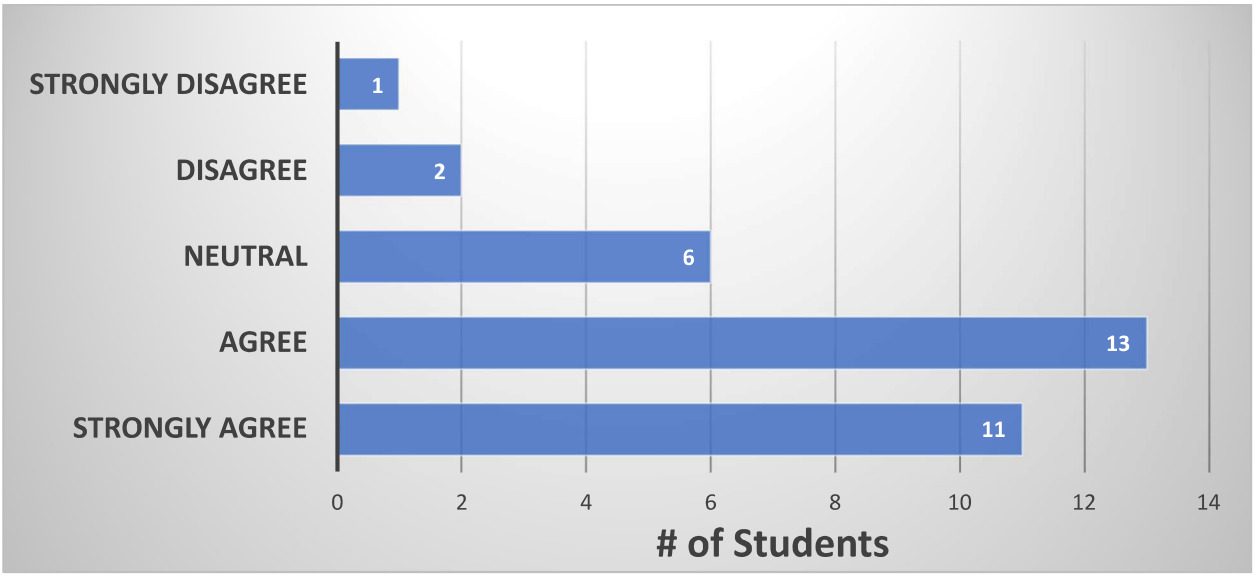


FIGURE 9
SURVEY RESPONSE TO QUESTION #2 (CONCEPTS LEARNED IN ENGR1234 HELPED ME BETTER UNDERSTAND CONCEPTS IN PHYSICS II)

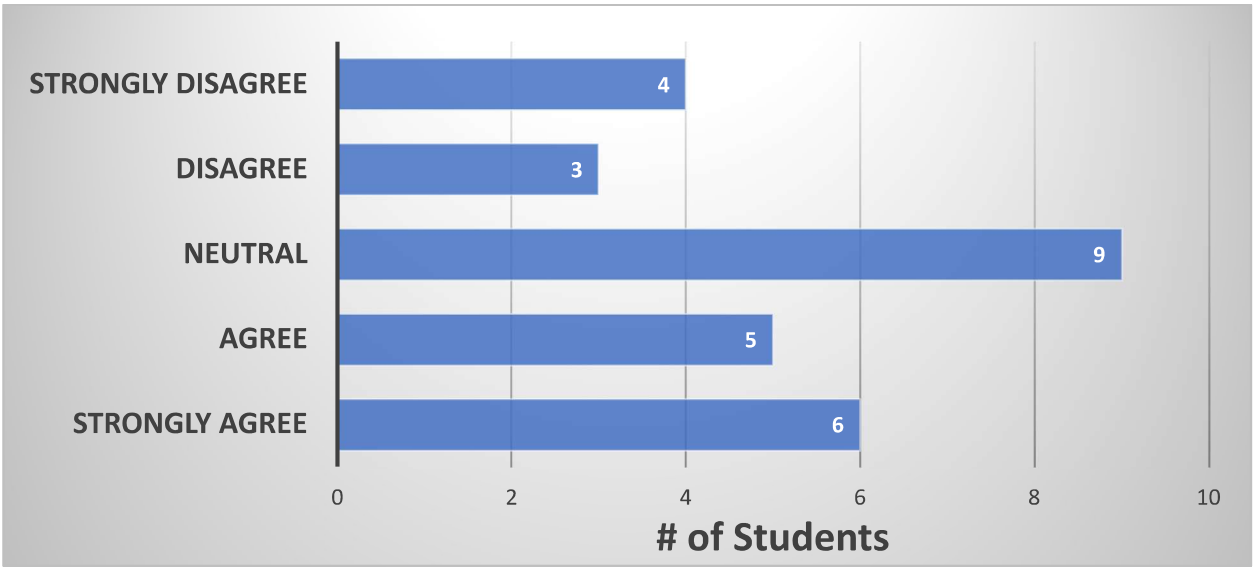


FIGURE 10
SURVEY RESPONSE TO QUESTION #3 (CONCEPTS LEARNED IN ENGR1234 HELPED ME BETTER UNDERSTAND CONCEPTS IN STATICS)

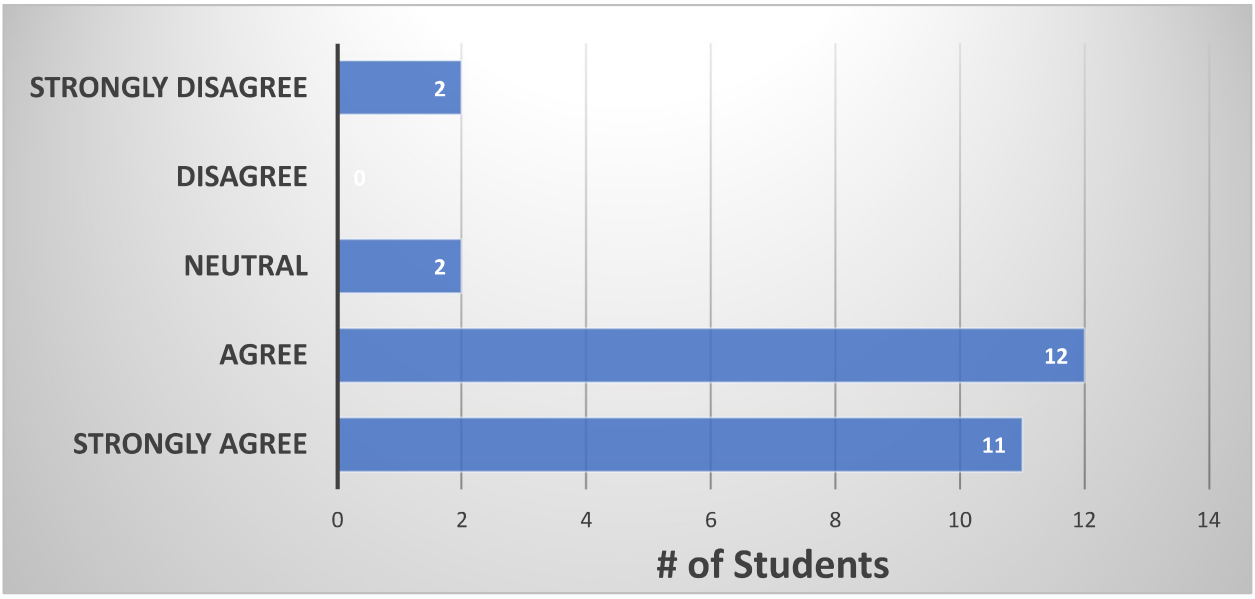


FIGURE 11
SURVEY RESPONSE TO QUESTION #4 (CONCEPTS LEARNED IN ENGR1234 HELPED ME BETTER UNDERSTAND CONCEPTS IN DYNAMICS)

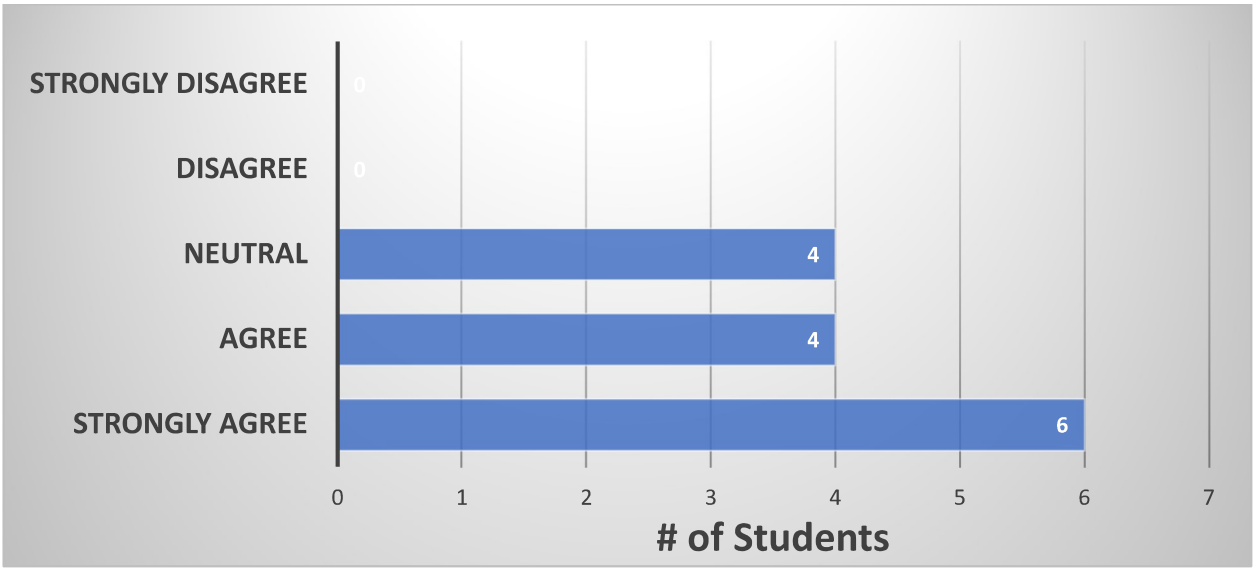


FIGURE 12
SURVEY RESPONSE TO QUESTION #5 (CONCEPTS LEARNED IN ENGR1234 HELPED ME BETTER UNDERSTAND CONCEPTS IN OTHER MATHEMATICS CLASSES, CALCULUS I, II, III, DIFFEQ.)

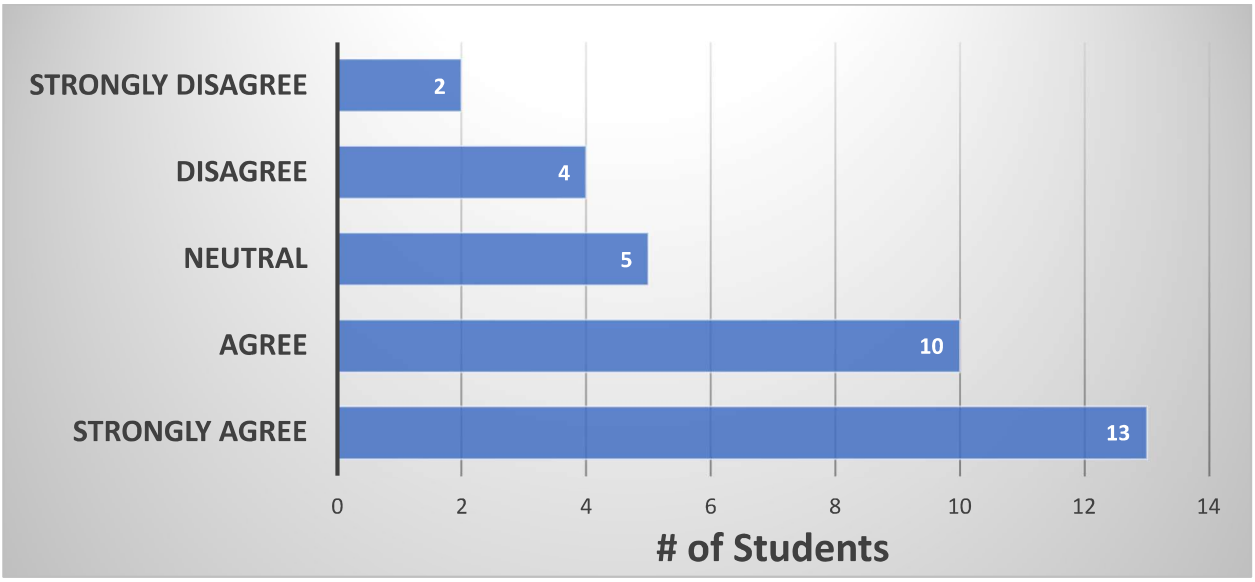
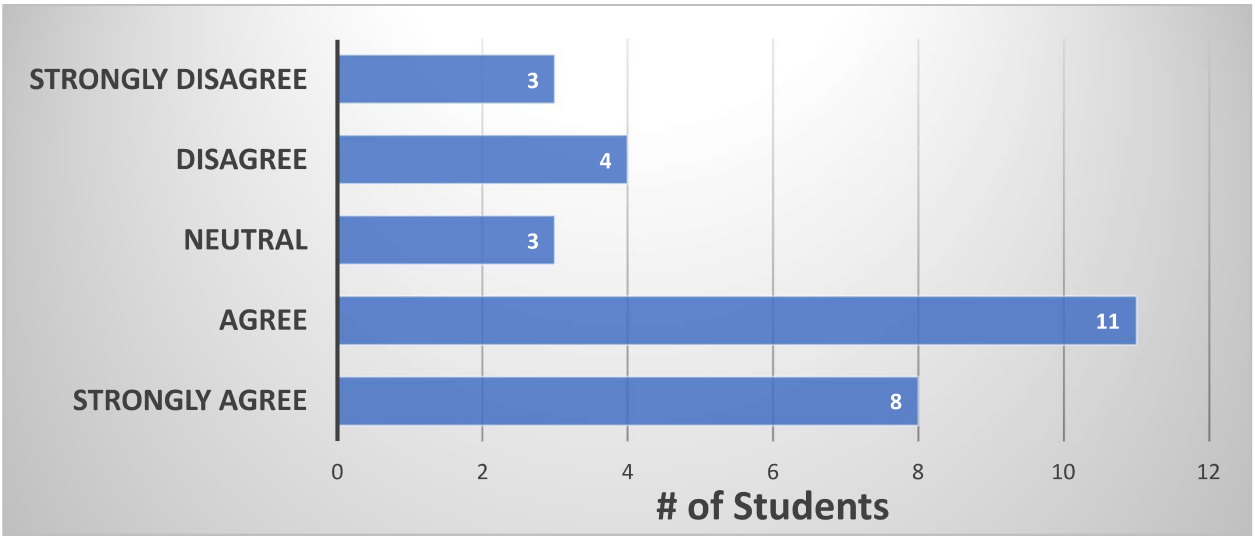


FIGURE 13
SURVEY RESPONSE TO QUESTION #6 (IF I DID NOT TAKE ENGR1234 BUT TOOK ALL THE OTHER MATHEMATICS CLASSES I HAVE TAKEN, I WOULD HAVE MORE DIFFICULTY IN PHYSICS, STATICS AND DYNAMICS.)



The seventh question was an open-ended question about the overall experience of ENGR1234 and gave the students an opportunity to talk about what they felt most strongly about. Overwhelming number of comments were positive and spoke highly about the usefulness of the material for future classes. It was refreshing to see most students able to refer to specific topics from ENGR1234 and talk about how useful they were in future classes. There were only one or two critical comments mostly related to the lack of

adequate math preparedness. A few sample comments are included here to provide some idea of what the written feedback was like.

Positive Comments

- Okay, so I haven't taken statics or dynamics which is why I didn't rank it before. I have taken Calculus 1,2 and currently am taking diff eq. where matrices are my life now apparently. I didn't go in not knowing anything about matrices because of this class so it helped a lot and I still have my notes from then so it definitely helps! Also, it helped in physics I when we were learning to plot position, velocity, and acceleration. The electrical stuff is coming in now that I'm taking ELEE 2500. I actually plan to go over my notes because what we're doing in class definitely reminded me of things we did in ENGR 1234. Literally, all the math involved in ELEE right now, I can remember having done work like that in 1234. I didn't know anything about circuits then so it was gibberish to me, but now it clicks! Totally recommend keeping the class. I actually saw some homework my friend was working on for statics and it looked something similar to what we did in 1234. I'm definitely holding on to my notes for the next couple of semesters.
- When I took ENGR 1234, the class was challenging because a lot of the material was new to me. At the time I could not understand the worth of the material much but semesters later I applied a lot of the concepts I learned in ENGR 1234 in other classes e.g. centroids in statics, moments and loads on beams in mechanics of materials, velocity, position and acceleration concepts in physics, circuits in Electrical, parked car in incline examples in dynamics and many more. I found this class very helpful and interesting for giving insights to engineering concepts during my freshmen year.
- ENGR 1234 was an excellent preview into how my math classes would apply to engineering. It was the first time I would have to apply the math theories to real scenarios. I would say it was the best class to get ready for statics and mechanics of materials.

Critical Comments

- I feel that I was accidentally put into ENGR 1234 and wasn't ready because I received a very poor grade and I was trying my best. It turned me off of engineering and now I'm in business administration. It is NOT an entry level engineering math class in my opinion.
- ENGR 1234 exposed me to many topics, such as derivatives and integrals, before I had taken calculus. This material was very difficult for me to understand since I was only in pre-calculus at the time. With a knowledge in calculus, like many others had in the class, I would have been able to utilize this learning experience. However, since I lacked that base knowledge, many of the topics held no significance because they were so new to me. I struggled through the class with little to show for it except a low passing grade.

CONCLUSIONS AND FUTURE WORK

A new course, Introductory Mathematics for Engineers, was added to the engineering curriculum in Fall 2016. This was done to increase retention of student population who struggle with the Calculus Sequence. The idea was derived from the work of Wright State University and others who have adopted the Wright State model. Early data from the first five offerings (retention, student comments and grades in math and engr. classes) show that this change in curriculum is mostly successful so far. Students are able to be successful in future courses for which ENGR1234 is being used as a prerequisite. Student comments overwhelmingly indicate that they are seeing advantages in early engineering classes such as Physics I & II, Statics, Dynamics, Mechanics of Materials and Circuits and are able to recognize the specific topics that were covered in ENGR1234 when they encounter the topic again in another class. In their feedback comments students have listed specific topics where they found ENGR1234 useful. There are a few students who had critical comments mostly indicating that the course was too difficult for them, given their preparedness. Since the launch of this course we have had to do some experimentation with prerequisite

mathematics class and the level of mathematics preparedness needed for ENGR1234. Although pre-calculus is what most students are expected to have completed, in the first two years different advisors have allowed students with a lower level of preparedness to be in this class. We have since then tightened this up so that poorly prepared students are put in other mathematics classes prior to them taking Engr 1234. It is still too early to conclusively state if this course is helping with retention and we will continue to monitor retention data for the next few years to measure the impact.

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