Implementing the Wright State Model for Engineering Mathematics at University of Detroit Mercy

Dr. Shuvra Das
Professor, Mechanical Engineering
University of Detroit Mercy
4001 W. McNichols Road
Detroit MI 48221

Abstract

It is well known that many motivated and capable students abandon engineering programs when they encounter difficulties with the Calculus sequence. This results in the profession losing out on talented engineers. Engineering educators have worked on a variety of approaches to alleviate this problem. A fairly well-known approach, first proposed by faculty from Wright State University, involves teaching an Engineering Mathematics class to freshmen engineering students. This class, typically taught by engineers (and not mathematicians), covers only those topics from the entire Calculus curriculum that are actually used in early engineering courses such as Physics, Statics, Dynamics, Circuit Theory, etc. Passing this course allows students to continue into freshmen and sophomore level engineering classes while they are still continuing to finish the traditional sequence of Calculus courses. This class was recently added to the engineering curriculum at University of Detroit Mercy. In this paper the author will present the course content and the experience of teaching it to the engineering students along with its impact on retention, and student success. Specifically, the ability of these students to handle engineering science courses without having finished the calculus sequence will be discussed with data from the initial offerings.

1. Introduction

The 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 struggling with the Calculus sequence. An extensive survey of the many studies that have been done to investigate this problem can be found in [1]. Many of these students would have made very successful engineers but 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 since 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, consisting 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 [5]". The impact of the calculus reform movement is discussed in many publications including [2-4].

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 if taking some of the early engineering courses. Many of these students are women, underrepresented and first generation. Detroit Mercy 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 [6] to address the problem.

2. Wright State Model and its Implementation

Reform and the classical approaches are about changing teaching methods. Wright State model [7] 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 pre-requisite 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 Calculus sequence but only the topics that are actually used in the Engineering Science 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. The Calculus sequence 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 [8]. 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 at Detroit Mercy to address this problem of student retention in engineering. The report [6] 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 every year. The Fall class is 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 pre-requisite classes such as algebra and pre-calculus. The textbook used for the Detroit Mercy class is the same textbook that Wright State used [8] 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. At Detroit Mercy 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 pre-requisite 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 the Calculus sequence 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 classes.

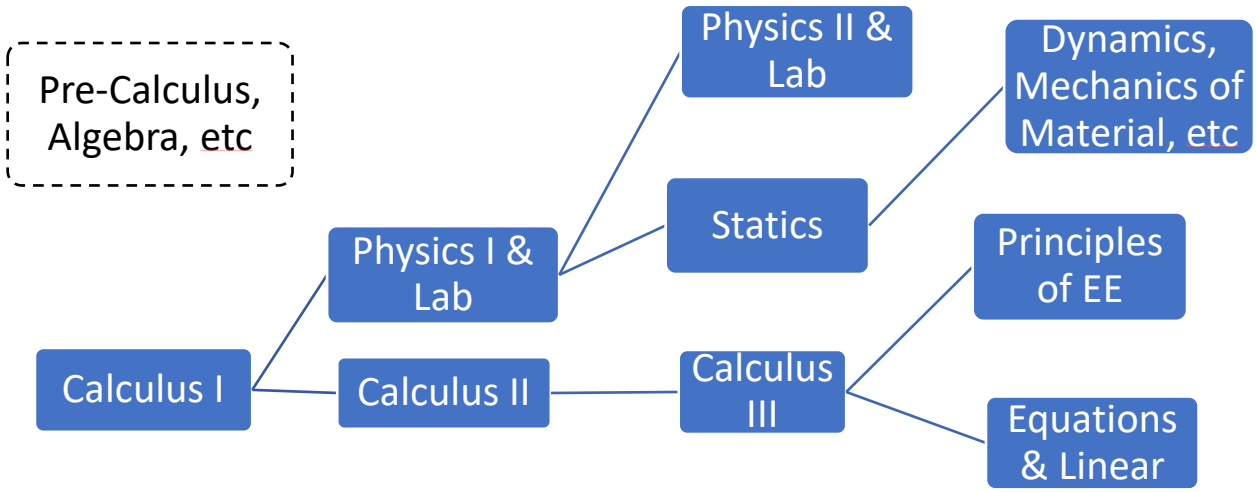

Figure 1: Partial flow-chart prior to the introduction of ENGR 1234.

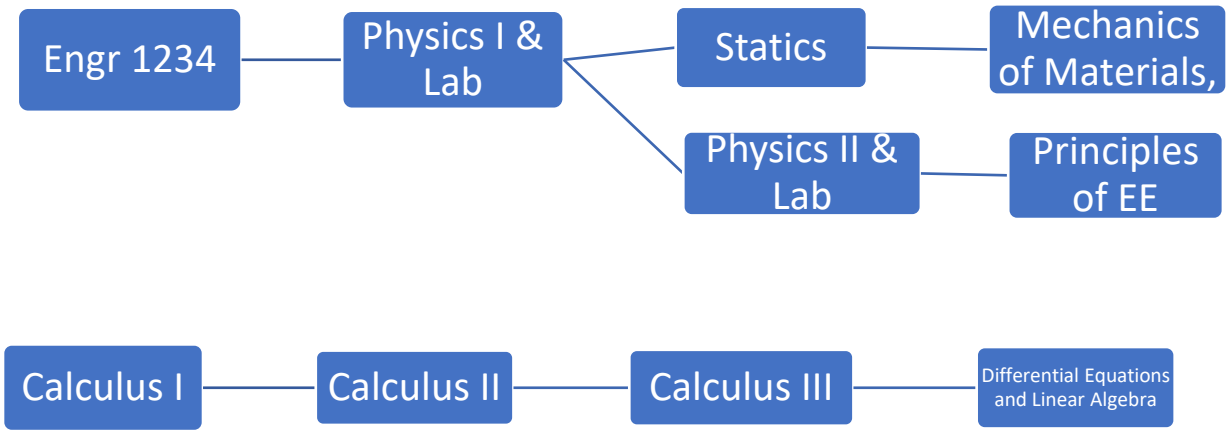

Figure 2: Partial flow-chart after the introduction of ENGR 1234.

3. Results and Impact

The author of this article was the instructor for ENGR1234 at Detroit Mercy for the first four semesters (Fall and Winter semesters of 016-17 and 2017-18). During this time a total of 76 students took this class. In this section we discuss results obtained by tracking the performance of these 76 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 and learning. Figures 3 -7 show the grade distribution of the students who took ENGR1234 in one of the four semesters mentioned. Figure 3 shows the grades obtained in ENGR1234. Many students took other math classes while they were taking ENGR1234 and figure 4 shows their grade distribution in those math classes. Figures 5-7 show grades received by students in Math and Science classes that they took in the following three semesters. These indicate how these students are performing in courses where the pre-requisite 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 pre-requisite. 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 Math class 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.

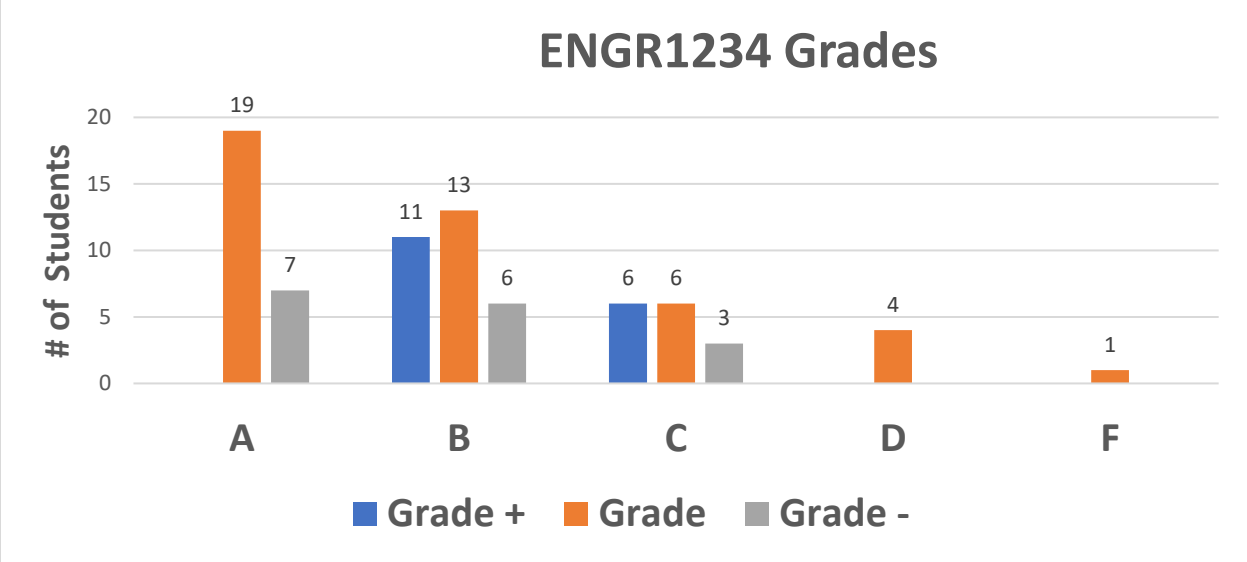

Figure 3: Grades in ENGR1234

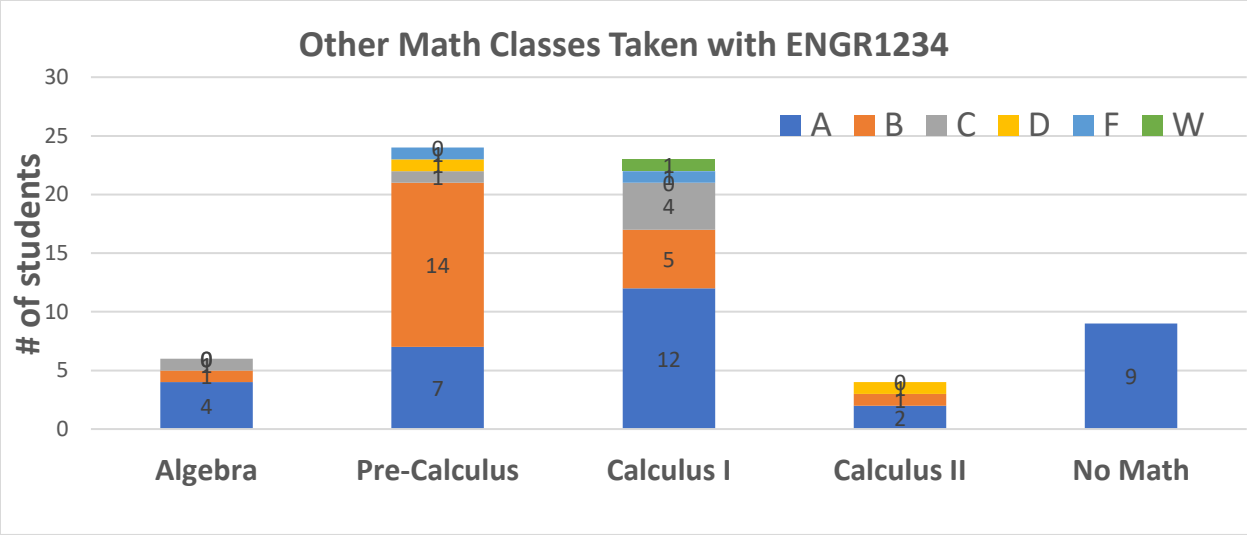

Figure 4: Grades in Math courses taken at the same time as ENGR1234

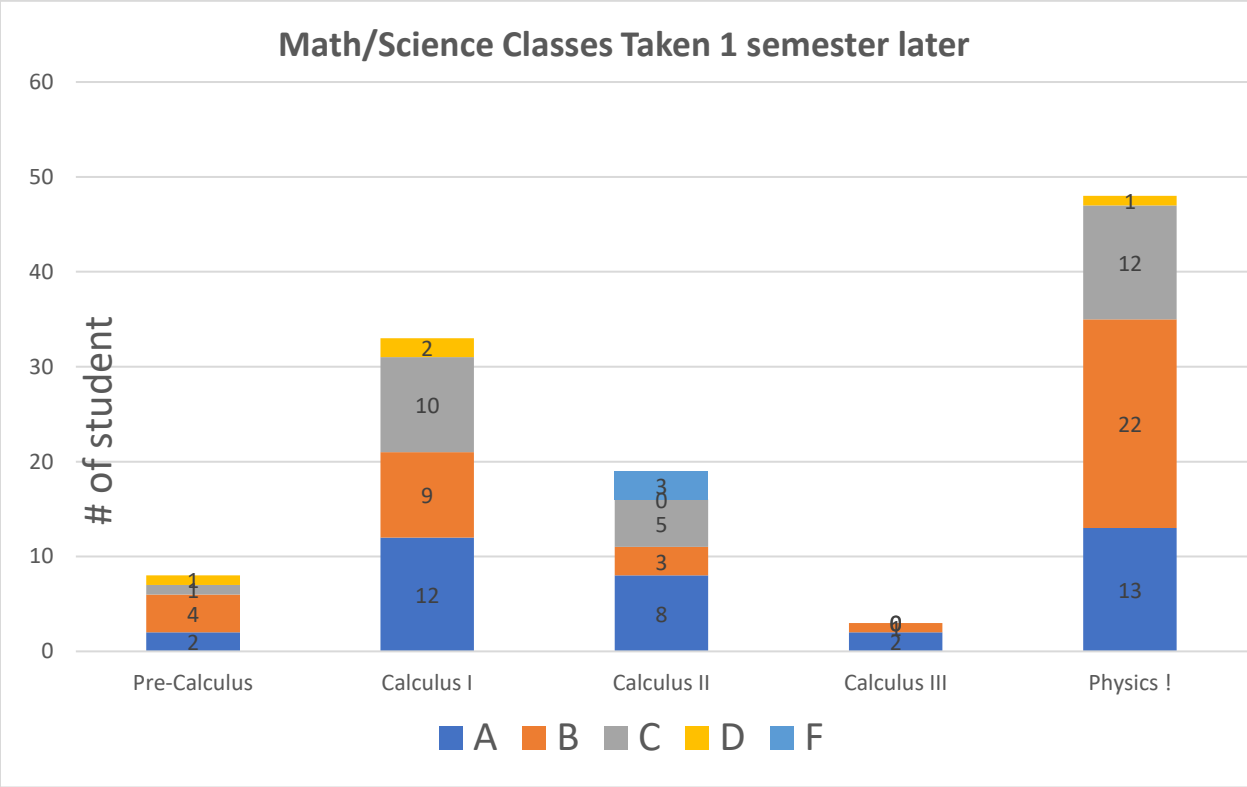

Figure 5: Grade distribution in Math/Science classes taken one semester later

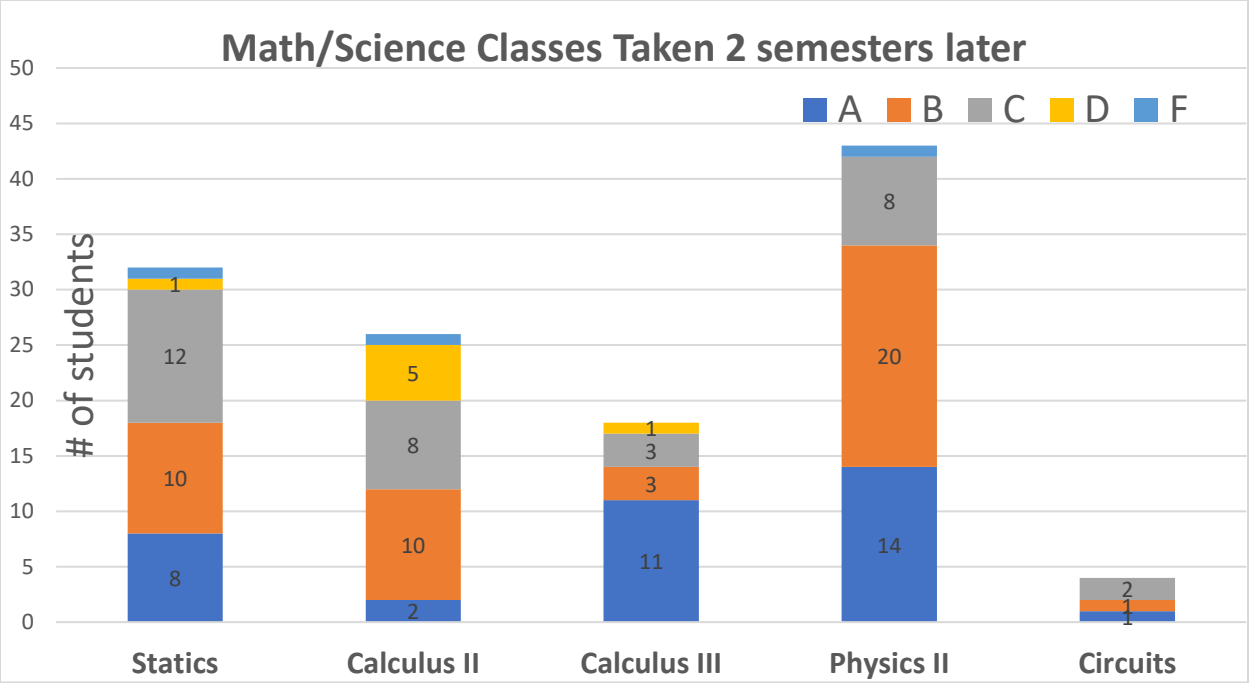

Figure 6: Grade distribution in Math/Science classes taken two semesters later

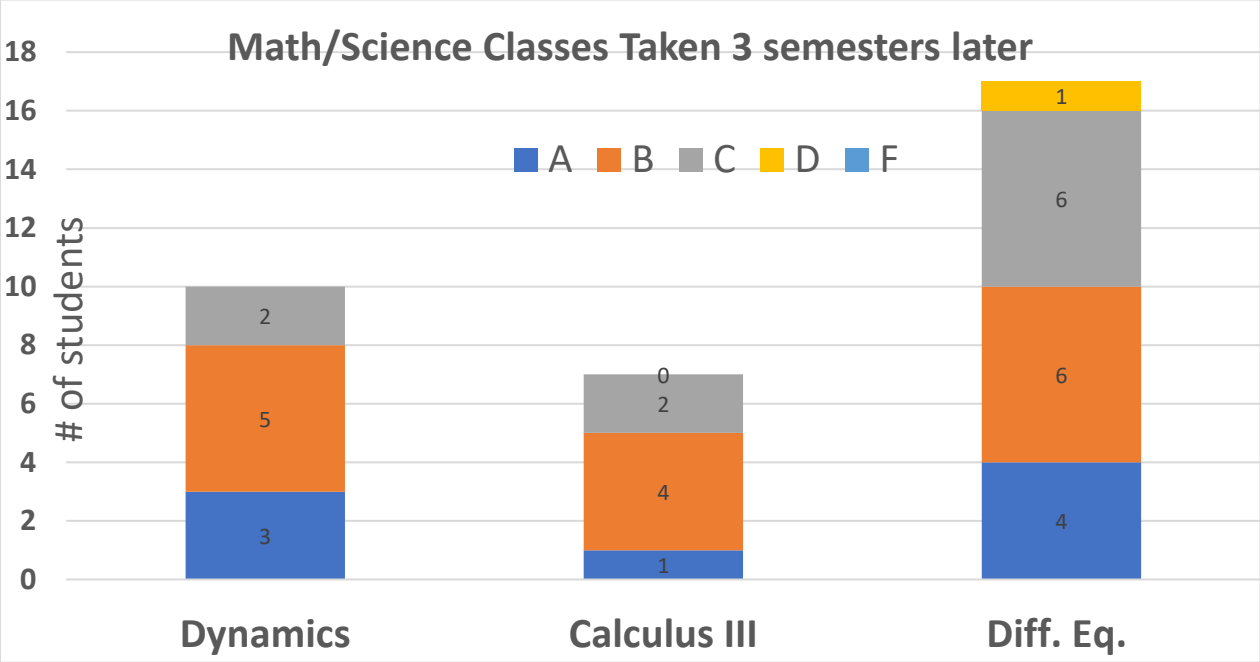

Figure 7: Grade distribution in Math/Science classes taken one semester later

During the first two years of this class fifteen students out of the 76 who took the course left engineering or left Detroit Mercy. It was important to explore who these students were and

what did they do 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 5 students dropped out of Detroit Mercy and we have no information about their current status (indicated as "Dropped Out" in the table). Six 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 schools, community college or 4-year universities for a variety of reasons. Of the students who "Dropped Out" one student was very weak in mathematics and was the only student 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. 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 I: Those who left Engineering: 15 students

ENGR1234 Grade	GPA	Reason	Math ACT
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	2.69	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
C	1.71	Dropped out	26
C-	1.37	Dropped out	24

Table II shows retention data for Detroit Mercy's Engineering programs from 2009 through 2017. 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 in Detroit Mercy Engineering programs there was varied amount of student losses between the first and the second year of engineering from 2009 - 2015. 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 pre-requisite structure changed as described earlier. Is this statistic a result of the new course? It is too early to be able to determine that from just one year's data. Once we get the data from Fall 2017 students we may have a better sense. However, this data is still very encouraging and we believe that the introduction of ENGR1234 had a positive role in this.

Table II: 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%**	**??**

4. Student Survey

All the students who continued in Engineering since taking ENGR1234 are still in their programs. Most of them are at most two years removed from the time when they took the class. We were interested to know what was their perception of the impact of ENGR1234 on their level of preparedness for other follow-up 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. Forty 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 shown 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.

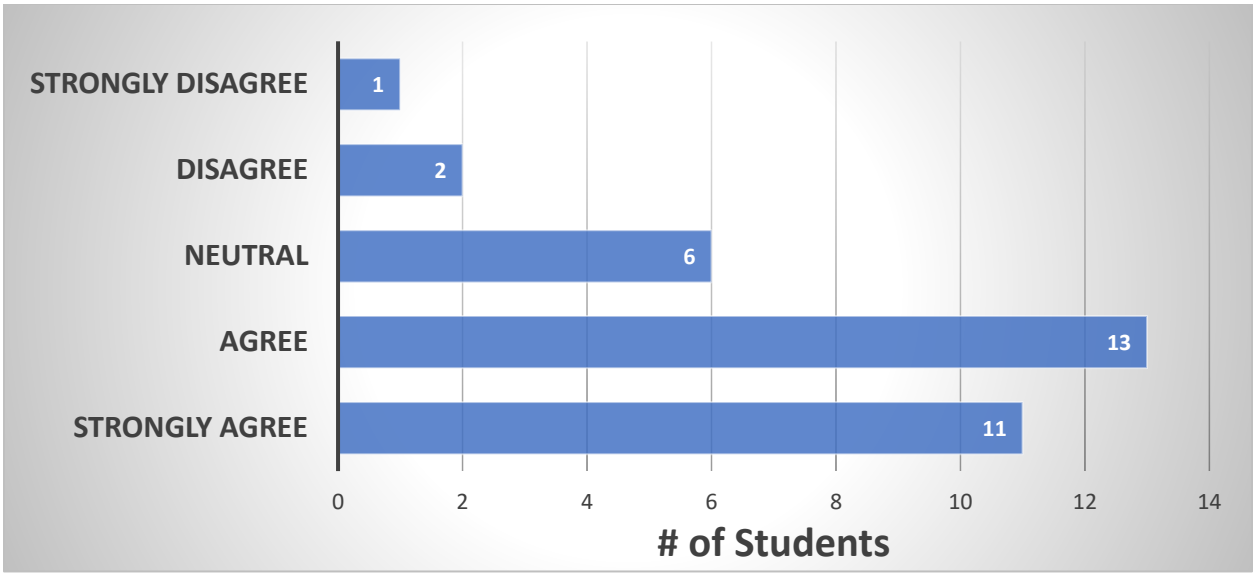

Figure 8: Survey response to Question #1

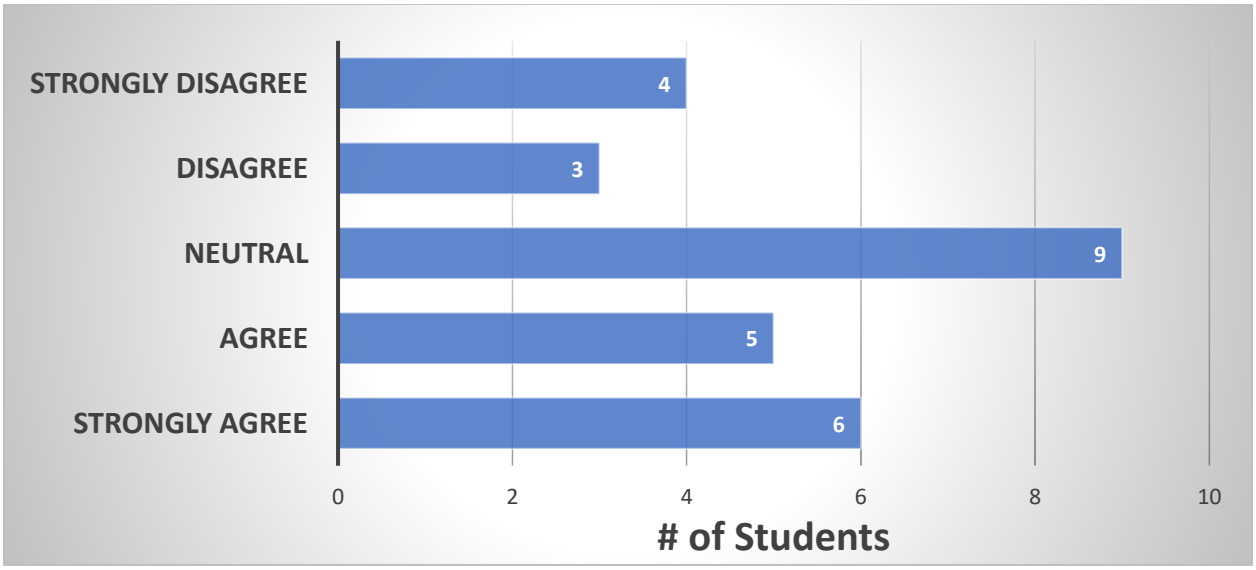

Figure 9: Survey response to Question #2

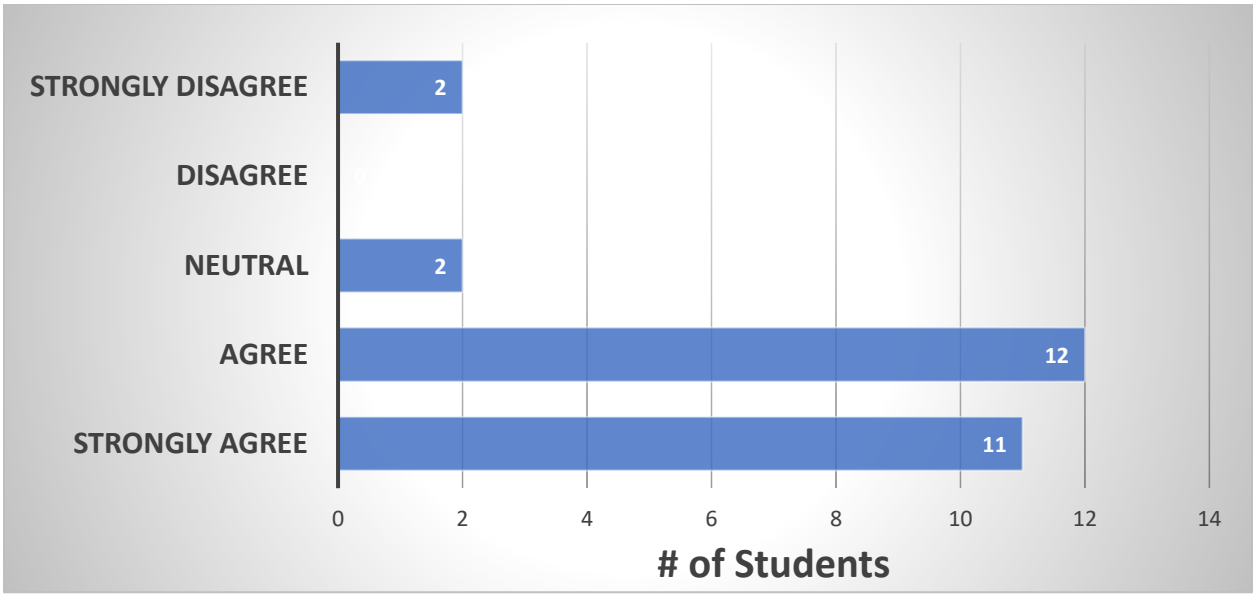

Figure 10: Survey response to Question #3

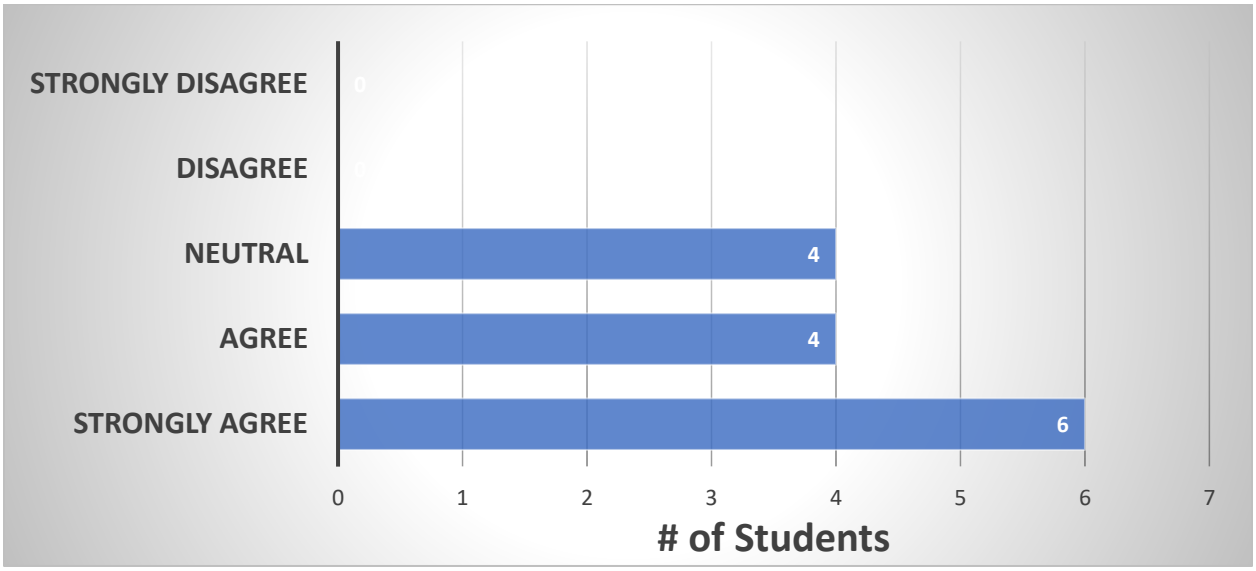

Figure 11: Survey response to Question #4

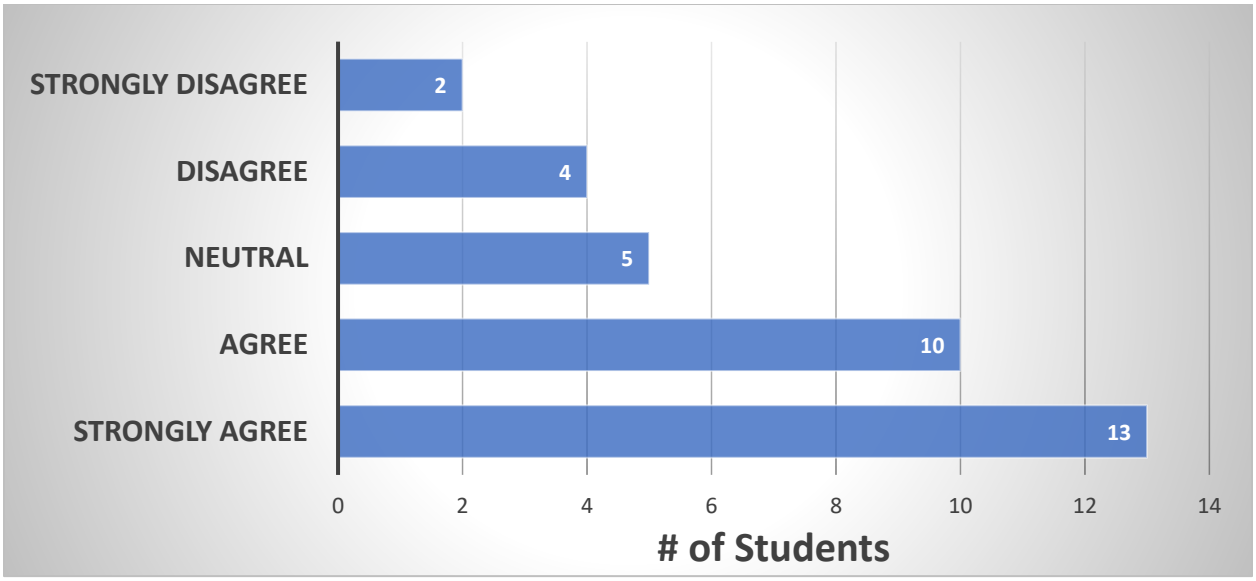

Figure 12: Survey response to Question #5

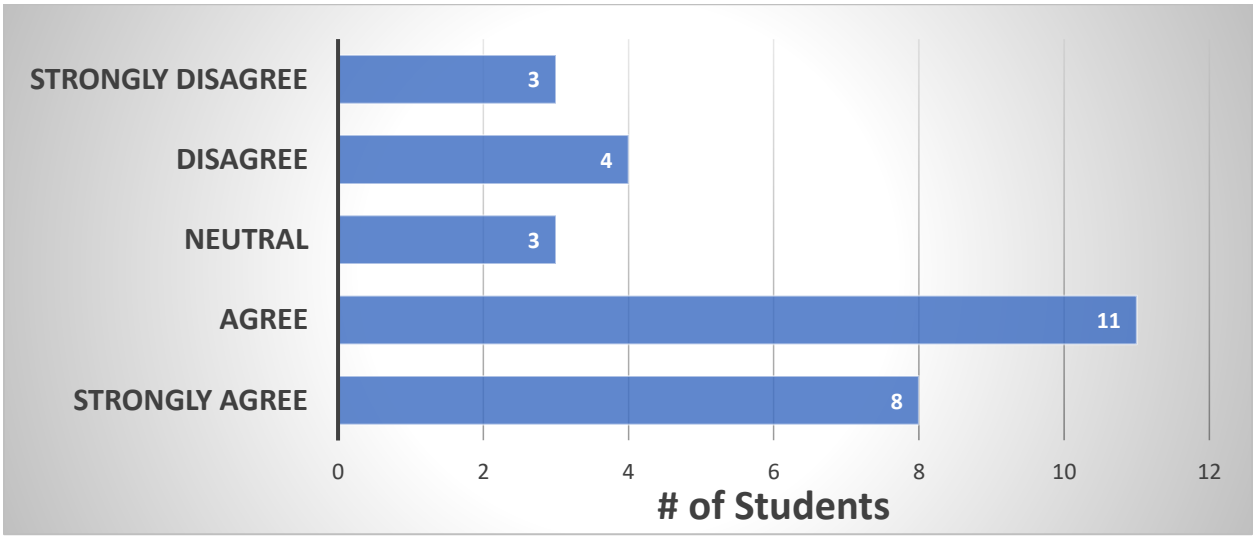

Figure 13: Survey response to Question #6

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. All the student comments are listed here verbatim.

Positive Comments

- I felt that we never learned why we are using the equations in 1234 and then when you take other classes it makes more sense.

- ENGR1234 made other math classes and math based classes easier because I had already covered some of the content in detail in ENGR 1234.
- 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.
- It helped me get a basic understanding of engineering applications and how to problem solve. This helped in Physics II a lot, and as well as in Mechanics of Materials with graphing.
- Engineering 1234 exposed us to a little bit of everything and It definitely did help a little bit in our physics classes it made the biggest impact in our statics classes. Statics when looked back upon is usually not considered to be that hard of a class but for most young engineering students it is their first real/actual engineering course which makes it very difficult for them. All of the work we did with vectors in engineering 1234 really helped me understand the work and concepts of statics. In regards to dynamics I cannot provide any input on it at this point since I have not yet taken the class. If it were up to me I would keep engineering 1234 as a requirement and I would keep Dr. Das as the instructor. I have been at this university at this point for about 2.5 years and Dr. Das is the best professor I have had to this day!
- I feel that ENGR1234 helped me with Physics I and Statics the most.
- I feel the class was run very well, and covered a lot of really important material. The physics and calculus classes I took in high school made the class very easy, however. The pacing in the class was quick, but effective. It didn't help me all that much because my credits did not transfer over from high school, however if I had not taken those advanced classes this class would have been necessary.
- 1234 helped a lot with understanding how to make Shear Moment diagrams and various other concepts that may have needed a little more practice/time to understand
- Professor Das reassured my decision to be an engineer. He went above and beyond what was asked of him as a professor. He was able to teach me material that I had no idea I had the ability to learn. Prof. Das instilled in me a passion for math, problem solving, and engineering. Thanks to his teaching and this class I have become a better student and have better understood later material.
- I have taken Calculus 1 and am currently in physics 1 and calculus 2. ENGR1234 helped me get familiar with derivatives and integrals.
- The new classes were like a fresh reminder of material from 1234.
- Engr 1234 helped give sufficient background to be able to understand core concepts in other classes. Very glad this course was offered.
- ENGR1234 was a fundamental course for the rest of my engineering/mathematics courses that I have taken at UDM. It is easy to say that ENGR1234 was an amazing and essential start to my mechanical engineering career.
- Allowed me to stay on track with physics 1 &2. The class helped with vector problems especially.

- Great teacher really helped me understand basic concepts that helped me going forward
- In my opinion, it helped a lot for basic math classes such as calc 2. But in my opinion if I took statics before it, would've helped a little more with the concepts. The professor is awesome so the class is a lot of fun and dr. Das should continue teaching the class for the benefit of students
- Engineering 1234 is a good introduction course for engineers to get a taste of the math they will be doing for the next four years at the university.
- ENGR1234 gives a wide range of concepts that were a great introduction to all of the other classes mentioned above. Obviously different professors teach differently so some of their concepts will be similar or very different from 1234. I have always been good with numbers and math and physics classes so this may be biased but I do believe this class helped with the following classes. Thanks Dr. Das!
- I feel that engr. 1234 helped me get a good preview of what an engineering curriculum consists of along with covering material from future classes.
- Getting a solid introduction and understanding of vectors from the class made many other classes such as physics 1 & 2, statics, dynamics, and calc 3 much more enjoyable and easier to learn. I already had a basic understanding of derivatives from high school, but the extra practice from the class I'm sure helped with physics, and calc 1 & 2 & even 3. I didn't find much use in the hardest topic (in my opinion) that we covered in 1234 which was differential equations. If differential equations class, the 1234 knowledge didn't apply very much. I feel like that portion in hindsight was less useful, but maybe the basic concepts still helped.
- 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 worthy 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.
- Okay, so I haven't taken statics or dynamics which is why I didn't rank it before. Ive taken calc 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.

- 1234 helped a lot with learning physics concepts and force diagrams. However, I had already taken physics 1 calculus based in high school so those concepts were already familiar to me. The concepts involving differential equations were not as benificial as I didn't have a lot of background for this and didn't take the ideas further along to my other classes.
- I think the main topic ideas I took away from MTH 1234 revolved around the understanding on how different math subjects were incorporated into actual engineering ideas. Its one thing to sit in a class, take notes, then take a test. Its another thing to actually see mathematics come into fruition with objects that are tangible.

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
- There is no point taking this class if I am going to learn the material in Physics, Statics and Dynamics classes. ENGR 1234 did not prepare me for those classes, it was just hard class for Freshmen student.
- 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.

5. Conclusions and Future work

At Detroit Mercy 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 Calculus. 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 four offerings (retention, student comments and grades in Math and engr. Classes) show that this change in curriculum is a success so far. Students are able to be successful in future courses for which ENGR1234 is being used as a pre-requisite. Student comments overwhelmingly indicate that they are seeing advantages in early engineering classes such as 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. 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 pre-requisite mathematics class and the level of mathematics preparedness needed for Engr.1234. Although pre-calculus is what most students are expected to have completed, different advisors have allowed students with a lower level of preparedness to be in this class. We are discussing internally to tighten 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 but data obtained so far is very positive. We should continue to monitor student performance and progress for the next few years.

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