An Application-Oriented Course to Improve Student Performance in Mathematics Courses

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An Application-Oriented Course to Improve Student Performance in Mathematics Courses

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An Application-Oriented Course to Improve Student Performance in Mathematics Courses

Abstract

This is an evidence-based practice paper. Performance in pre-calculus and calculus courses has a strong impact on student success, retention, and graduation in any engineering school. One of the important reasons why students perform poorly in these courses is their failure to make the connection between concepts of mathematics, and engineering problems and applications. Without making this connection, students lose interest in their mathematics courses, resulting in high failure rates. This also strongly affects students' chances to make satisfactory academic progress within their degree, as mathematics and science courses are usually pre-requisites or co-requisites to their core engineering courses. This is a serious problem and must be addressed if students' retention and graduation rates are to be improved. Starting Fall 2016, New Jersey Institute of Technology (NJIT) is offering a new course: Analytical Methods for Engineering Applications (ENGR101). This is an application-oriented course based on the Wright State University model adopted by over 40 colleges and universities. ENGR101 specifically targets students that are ill-prepared in mathematics based on the performance of a mandatory placement exam that all incoming first-time full-time first-year students take. All students placed in either of the two pre-calculus courses would take ENGR 101 in their first or second semester. Throughout the course, students are introduced to engineering problems and applications that rely on concepts of mathematics. Although this course has only been offered three times thus far, preliminary results are very encouraging. We found that students taking ENGR101 mostly did better in their pre-calculus courses than students who did not take ENGR101. An improvement in performance was also seen in their subsequent-semester mathematics courses. We are committed to offer this course for at least three consecutive years to assess the short-term and long-term effect on students' academic progress, performance in mathematics courses, and retention and graduation rates. This paper includes information about setting up such a course and the challenges that needed to be met. It also presents the results of our analysis thus far, including a comparison of the performance in mathematics courses of the participants against a control group.

Introduction

Incoming first year students at our mid-size STEM institution should ideally start in calculus I in the mathematics sequence before they can advance to sophomore-level core engineering courses. However, a high percentage of these students are placed into remedial pre-calculus courses, and do not reach calculus I until their second semester, or even their second year. At our institution, for each student who is placed in a calculus-I course, there is another student who is placed in one of the two pre-calculus courses. This distribution has only slightly improved despite a significant increase in the average student profile in terms of SAT/ACT scores and high school GPA. Moreover, a high percentage of those that are placed into calculus fail or withdraw, and are unable to make timely progress in their major. A key detrimental factor contributing to this is that a majority of the incoming first year students are considered to be underprepared in mathematics. Our university is exploring various options to help these students reach calculus I as soon as possible. Pre-calculus summer boot camp is one of programs successfully implemented at our institution [1]. Other initiatives include: 1) developing sample placement

tests for students to practice under the same environment as the original test, 2) making a placement calculator for students to input the scores from the practice placement tests to determine their likely mathematics placement, and 3) establishing a strong outreach to educate students about the impact of their mathematics placement on their engineering curriculum and motivating them to do better on the placement test [2].

Students placed into pre-calculus courses also lose their drive to do well in these courses as they find it difficult to establish a connection between mathematics and engineering. Therefore, they struggle to keep up with the coursework. In addition to a loss in motivation, any delay in entry to calculus I or failure in calculus I is almost automatically equivalent to at least one additional semester of stay at college. More often than not, this leads to students switching to non-engineering majors or leaving the university altogether. It is fine for students to switch majors or leave the institution for the right reasons, but it should not happen for a lack of support or for failing to make the connection between mathematics and engineering courses and to see the big picture. In an attempt to solve this problem, our institution decided to offer an "Engineering 101" introductory course loosely based on the Wright State University (WSU) engineering mathematics education model, starting in Fall 2016.

WSU has developed a model with National Science Foundation (NSF) funding to increase student retention and motivation. This model is currently being tested at or has fully been adopted in 40+ engineering schools nationwide [3-4]. The idea is to teach mathematics to incoming first-year students using an application-oriented, hands-on introductory course. This course provides an overview of relevant topics in engineering analytical methods from core sophomore-level engineering courses. These topics are reinforced through extensive examples of their use in lab exercises. Topics include algebraic manipulation of engineering equations; use of trigonometry, vectors and complex numbers, sinusoids and harmonic signals, systems of equations and matrices in engineering applications; and basics of differentiation, and integration.

The WSU model has been successfully implemented since 2004. At WSU, every department requiring this course saw an increase in first-year retention in 2004-2005, as compared to baseline data averaged over the prior four years. Overall, WSU saw first-year retention increase from 68.0% to 78.3%. In addition to first-year retention, this model has had a significant impact on student performance in calculus at WSU. Of the students ultimately enrolled in calculus I, 89% of those who had formerly taken this course earned a "C" or better, compared to only 60% of those who had not [5].

The goal of this paper is to analyze the effectiveness of ENGR 101, a similar course offered at NJIT. The following sections discuss the mathematics sequence followed at our university, framework of the course and the analysis and results obtained in detail.

The Mathematics Sequence

As a standard practice in many four-year colleges, NJIT also requires all incoming first-year students to take a mathematics placement examination. The result of the placement examination is used to gauge the student's background and competency in various mathematics topics and determines the level of mathematics (calculus I or pre-calculus) the student will begin in his/her first semester. For engineering students, this is particular crucial; as the calculus sequence is a prerequisite to many core engineering courses. Any delay in the completion of calculus I would

have drastic impact on the student's time to graduate. Figure 1 shows the mathematics course sequence followed by engineering students.

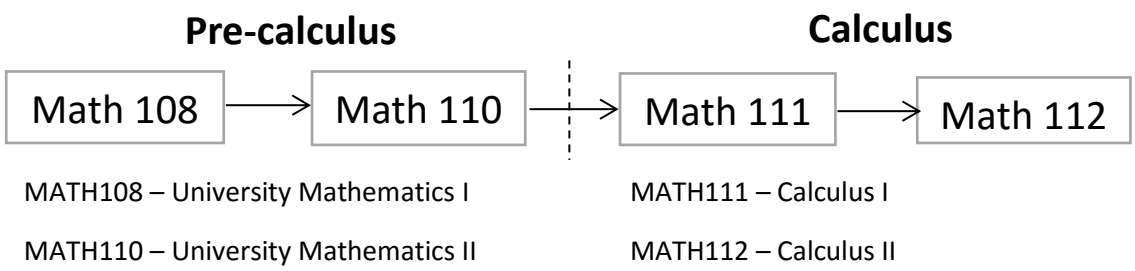

FIGURE 1- THE PRE-CALCULUS COURSE SEQUENCE FOR ENGINEERING STUDENTS

Students placed in either of pre-calculus courses (MATH108 or MATH110) are required to take ENGR101. Students placed into MATH111 (calculus I) can choose to take ENGR101, if they want to, but very few actually chose to. MATH108 students taking ENGR101 were offered an opportunity to retake the mathematics placement exam at the end of the semester. Student who did well on the placement exam were able to skip MATH110 and jump to MATH111, thereby saving a course. The new placement test scores only counted if the student successfully completed both MATH108 (C or better grade) and ENGR101 (D or better grade).

Course Framework

The course, ENGR 101, is a 4-credit course meeting for 90 minutes of lecture two times a week, and 90 minutes of recitation and 90 minutes of lab meetings once a week. The total population of students is divided into a group of 80-90 students per lecture and 25-30 students for both recitation and lab. The course has been significantly revised from the original WSU model to cater specifically to students, who are taking pre-calculus and are one to two terms behind the expected starting point. A tentative course outline for both the lecture and lab portion is shown in Table 1 and 2.

TABLE 1- TENTATIVE COURSE OUTLINE FOR THE LECTURE PORTION

Week 1	Application of Algebra in Engineering – Linear Equations and Quadratic Equations
Week 2	Application of Trigonometry in Engineering - One and Two-Link Planar Robots
Week 3	Introduction to Vectors, Free Body Diagrams
Week 4	Exam#1, Introduction to Complex Numbers in Engineering
Week 5	Sinusoids and Harmonic Signals in Engineering
Week 6	Systems of Equations and Matrices in Engineering
Week 7	Introduction to Derivatives in Engineering Application of Derivatives in Dynamics
Week 8	Exam #2, Application of Derivatives in Electrical Circuits
Week 9	Application of Derivatives in Mechanics of Materials

Week 10	Application of Integrals in Engineering Application of Integrals in Statics
Week 11	Application of Integrals in Dynamics
Week 12	Exam #3
Week 13	Applications of Integrals in Electric Circuits Further Examples of Integrals in Engineering
Week 14	Summary and Review

TABLE 2- TENTATIVE COURSE OUTLINE FOR THE LAB PORTION

Week 1	Introduction and Meet the Lab TA's
Week 2	Introduction to MATLAB and Basic tools used in MATLAB.
Week 3	Built-in MATLAB Functions. Manipulating Matrices in MATLAB.
Week 4	Plotting in MATLAB.
Week 5	Lab #1: Application of Algebra in Engineering: The One-Loop Circuit (Virtual Lab)
Week 6	Lab #1A: Application of Algebra in Engineering: The One-Loop Circuit (Physical Lab)
Week 7	Lab #2: Trigonometric Relationships in One and Two-Link Planar Robots
Week 8	Lab #3: Measurement and Analysis of Harmonic Signals
Week 9	MATLAB: User Controlled Input and Output
Week 10	Lab #4: Systems of Equations in Engineering: The Two-Loop Circuit (Physical Lab)
Week 11	MATLAB: Symbolics, Selection Structure and Logical Functions
Week 12	Lab #5: Derivatives in Engineering: Velocity and Acceleration in Free-Fall
Week 13	Lab #6: Integrals in Engineering: Work and Stored Energy in a Spring
Week 14	MAKE UP LAB WEEK

Course Analysis: Quantitative

For the Fall 2016 and Spring 2017 semesters, first-year College of Engineering (COE) students from biomedical engineering, chemical engineering, civil engineering, computer engineering, electrical engineering, and engineering science (ESC) programs, who are not placed into calculus I, were enrolled in ENGR 101. Engineering science at our institution is for (i) still-deciding first-

year engineering students and (ii) students who need more attention and supervision, especially in the first year of education. The mechanical engineering and industrial engineering programs (MIE) opted not to participate in the program during its first year offering and hence in turn provided us with an opportunity to use their students as a control group. In addition, there were several students who were eligible to be enrolled in ENGR101, but could not be accommodated due to schedule conflicts. They also served as part of the control group and helped with comparison of results. The control group was similar to the treatment group as both populations are first-time full-time first-year students, who are underprepared in mathematics and placed in a pre-calculus course using a standardized placement test. With the success of the first year of ENGR 101 in Fall 2016, the Fall 2017 offering of the course had MIE students also taking the course.

As mentioned before, primary objectives of this pilot program were to help students make a connection between concepts of mathematics and their common engineering applications, and to help them do well in pre-calculus and subsequent mathematics courses. Therefore, for analysis, comparison of passing rates in pre-calculus classes taken alongside ENGR 101 were done for both the Fall 2016 and 2017 semester offerings. Fall semester is when our institution gets the majority of first-time full-time freshmen engineering students. Passing percentage in mathematics was chosen as the criterion for comparison as high failure rate in first-year mathematics is a key detrimental factor in low retention and graduation rates. MATH 108 engineering students who took ENGR 101 were compared to those who did not take ENGR 101. Similarly, MATH 110 engineering students who took ENGR 101 were compared to those who did not take ENGR 101. A test of difference of proportions (z-test) was performed to check the statistical significance of the effectiveness of the course. The results for both Fall semesters are given in the tables 3 and 4 below.

TABLE 3 – COMPARISON OF PERFORMANCE IN MATH108 FOR STUDENTS WHO TOOK ENGR101 IN FALL 2016 AND FALL 2017 WITH THE CONTROL GROUP

MATH108	Pass	Total Number of Students	z Value	Statistically Significant?
Students who took ENGR101 - Fall 2017	81%	53	2.34	Yes
Students who didn't take ENGR101 - Fall 2016 (Control Group)	59%	41		
Students who took ENGR101 - Fall 2016	69%	50	0.992	No
Students who didn't take ENGR101 - Fall 2016 (Control Group)	59%	41		

TABLE 4 – COMPARISON OF PERFORMANCE IN MATH110 FOR STUDENTS WHO TOOK ENGR101 IN FALL 2016 AND FALL 2017 WITH THE CONTROL GROUP

MATH110	Pass	Total Number of Students	z Value	Statistically Significant?
Students who took ENGR101 - Fall 2017	65%	95	1.51	No
Students who didn't take ENGR101 - Fall 2016 (Control Group)	54%	86		
Students who took ENGR101 - Fall 2016	75%	75	2.77	Yes
Students who didn't take ENGR101 - Fall 2016 (Control Group)	54%	86		

As seen in Table 3, ENGR101 students in Fall 2017 had a 22% better passing rate in MATH108 than the control group. This result was found to be statistically significant. In Fall 2016, this difference was 10% as compared to the control group. Although, this result was not found to be statistically significant; 10% higher passing rate translates to 5 or more students having saved at least one semester. Table 4 shows that ENGR101 students in Fall 2016 had a 21% better passing rate in MATH110 than the control group. This result was calculated to be statistically significant. In Fall 2017, this difference was 11% which came out to statistically insignificant. Regardless of which mathematics course the student was registered in, we saw at least a 10% improvement in performance in pre-calculus courses in the same semester of the students who took ENGR101. Similar results were observed for the Spring 2017 semester, but since the majority of first-year students take it during Fall, only the results of the Fall semester are presented in this paper.

A comparative analysis was also done to track how students who took ENGR101 in Fall 2016 performed in their mathematics courses taken until Spring 2018. Table 5 shows the progression of MATH108 students in the mathematics sequence. Figure 2 also shows this as a pie chart. As seen in the table and figure, 32% of students in both categories are either on track or ahead. This shows that there is no notable difference in Fall 2016 MATH108 students who took ENGR101 vs. those who did not take ENGR101 in the long-term progress in the mathematics sequence. However, it is important to note that the number of students who are placed one course above their ideal mathematics course is higher for the ENGR101 population, which could represent a better motivation towards mathematics and engineering. There could be two reasons for students to be ahead in the mathematics sequence. 1) Students who retook the placement test and passed and thus skipped a mathematics course. 2) Students who took summer/winter mathematics

courses to move ahead. The retention to the College of Engineering for both populations looks very similar.

TABLE 5 - PROGRESSION IN MATHEMATICS OF STUDENTS WHO TOOK ENGR101 AND MATH108 IN FALL 2016

Registered Math Course in Spring 2018 of Fall 2016 MATH 108 Students	Total Students	MATH110	MATH111	**MATH112**	ONE COURSE ABOVE MATH112	LEFT COE/MOVED TO ENGG. TECH. /LEFT UNIV
With ENGR101	50	6%	22%	**20%**	12%	40%
Without ENGR101	31	13%	16%	**29%**	3%	39%

* Please Note- Bold Column signifies where these students should ideally be in the mathematics sequence.

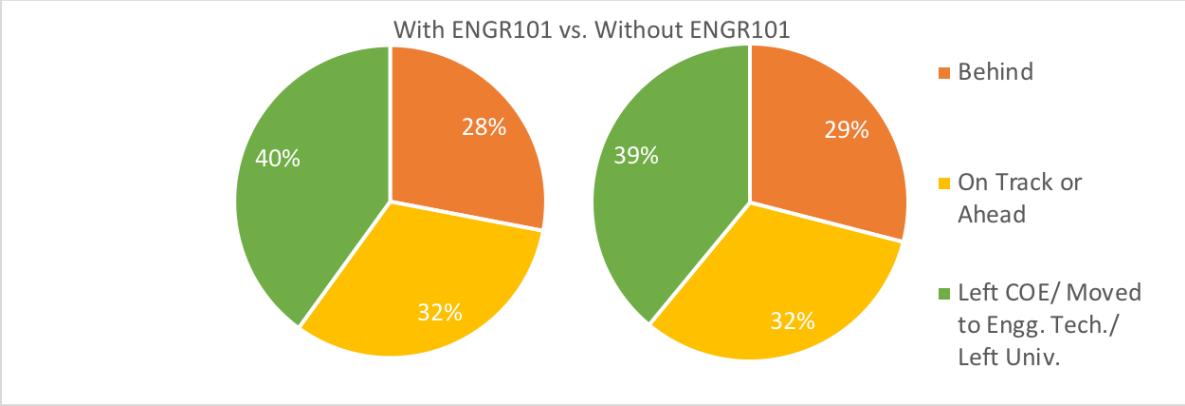

FIGURE 2 – PIE CHART REPRESENTATION OF PROGRESSION IN MATHEMATICS OF MATH108 STUDENTS WHO TOOK ENGR101 IN FALL 2016 VS. THOSE WHO DIDN'T.

Table 6 shows the progression in the mathematics sequence of Fall 2016 MATH110 students who took ENGR101 vs. those who did not take ENGR101. Figure 3 also shows this as a pie chart. As seen in the table and figure, 50% of the students who took ENGR101 are on track or ahead, whereas only 21% are on track or ahead of those who didn't take ENGR101. This is a statistically significant difference, showing that students who took ENGR101 did much better in their mathematics courses in later semesters as well. A 16% difference is observed in the number of students who are placed one course over their ideal placement in the mathematics sequence, which shows that ENGR101 did make a difference in motivating these students to do well in their mathematics courses. A difference is also seen in students who could not be retained in engineering (non-technology majors). Students who took ENGR101 had a 17% less chance of leaving the engineering college or moving to an engineering technology program or worst of all, leaving the university.

TABLE 6 – PROGRESSION IN MATHEMATICS OF STUDENTS WHO TOOK ENGR101 AND MATH110 IN FALL 2016.

Registered Math Course in Spring 2018 of Fall 2016 MATH 110 Students	Total Students	MATH110	MATH111	MATH112	**ONE COURSE ABOVE MATH112**	TWO COURSES ABOVE MATH112	LEFT COE/MOVED TO ENGG. TECH, /LEFT UNIV
With ENGR101	75	1%	9%	14%	**27%**	23%	25%
Without ENGR101	83	1%	18%	17%	**14%**	7%	42%

* Please Note- Bold Column signifies where these students should ideally be in the mathematics sequence.

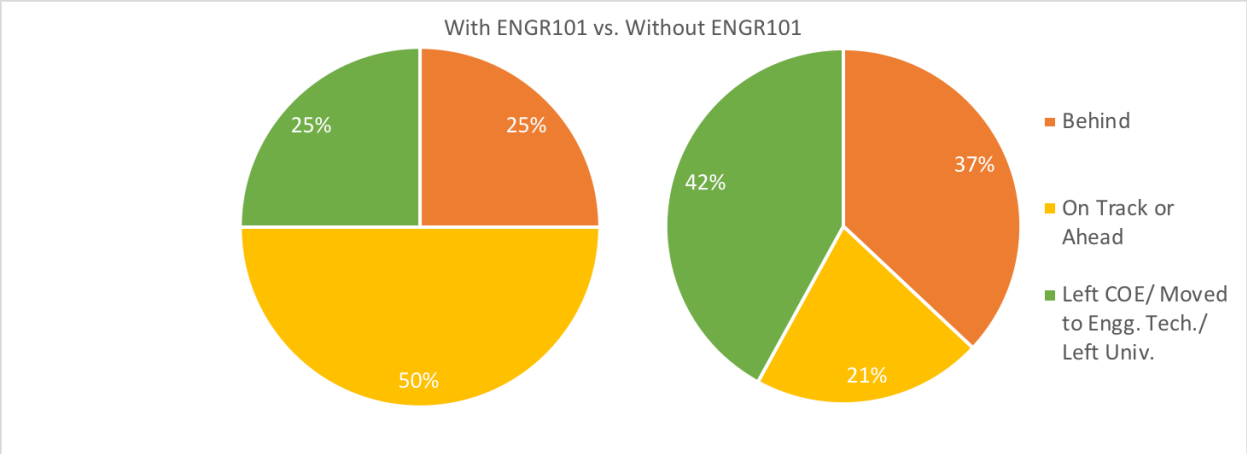

FIGURE 3 – PIE CHART REPRESENTATION OF PROGRESSION IN MATHEMATICS OF MATH110 STUDENTS WHO TOOK ENGR101 IN FALL 2016 VS. THOSE WHO DIDN'T.

As mentioned before, MATH108 Students taking ENGR101 were offered an opportunity to retake the mathematics placement exam at the end of the semester. Table 7 shows that for the Fall 2016 offering, only 2 of the 9 students who retook the placement test were able to skip a course. In Fall 2017, the percentage of students who were placed into MATH111, skipping MATH110, was much higher. Out of 11 students who retook the exam, 9 were able to move to a higher mathematics course. We will continue to offer this opportunity to students in the coming semesters. We will also track the performance of the students who availed this opportunity to skip a course and see if this helped them in the long run in their mathematics sequence.

TABLE 7 – COMPARISON OF PERFORMANCE IN PLACEMENT TEST RETAKE FOR ENGR101 MATH108 STUDENTS

	Total Students who Attempted	Placed into MATH111
Fall 2016	9	2
Fall 2017	11	9

Course Analysis: Qualitative

In addition to doing a quantitative analysis, we also conducted a qualitative analysis. This consisted of gathering feedback from the instructors who taught the course and constructive feedback from students on how to improve the course. The two key recommendations that were made and the actions taken to implement them are:

(1) Offer a different version of this course for MATH108 students with fewer topics and more in-depth study of pre-calculus topics. Newer topics such as Complex Numbers and Matrix Algebra would also be added. We plan to implement this in our next offering in Fall 2018.

(2) Offer more hands-on labs than virtual (computer) labs. For the first two semesters this course was offered, WSU's virtual lab modules were used for all the engineering application labs. In Fall 2017, two labs were changed into hands-on labs. The students expressed appreciation for the hands-on labs, and stated that they understood the concept better. The goal is to continue developing more hands-on labs.

Summary and Lessons Learned

The objective of this paper was to report the findings of offering ENGR 101, a course to increase student retention, motivation, and success in engineering through an application-oriented, hands-on introduction to engineering analytical methods. The course was run for the first time at NJIT during Fall 2016 and Spring 2018 will be its fourth consecutive offering. An analysis was done to evaluate the effectiveness of this course. It was seen that ENGR101 students had at least a 10% advantage in their performance in the same-semester pre-calculus course. For two of the cases (MATH108 engineering students who took ENGR101 in Fall 2017 and MATH110 engineering students who took ENGR101 in Fall 2016) there was a statistically significant difference from the control group. Performance in mathematics courses in the subsequent semesters was notably better for ENGR101 students who took MATH110 in Fall 2016 as compared to those who did not. Performance of ENGR101 students who took MATH108 in Fall 2016 was similar to that of non-ENGR101 students. Eleven students were able to skip a course (MATH110) by retaking the placement test and placing into MATH111.

Overall, the results look very promising, as students who took ENGR 101 did better in their mathematics courses in the same semester and subsequent semesters when compared to students who did not take ENGR 101. Feedback was also collected from instructors and students and these recommendations were either already put into effect, or there are plans are in place to implement these recommendations. The authors have conducted a test to confirm statistical significance of their results. We will analyze the outcomes further, collect data from the next iterations of ENGR 101, and make further suggestions and recommendations.

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