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Modification and Assessment of a First-Year Engineering Course to Improve Students' Calculus Readiness

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Abstract - **In this paper, we describe the modification and evaluation of a first-year engineering program at a western public university. Primarily motivated by the desire to improve students' readiness for and performance in subsequent calculus classes, we adopted a modified version of the Wright State integrated mathematics curriculum at our institution. The curriculum we describe and evaluate in this paper integrates the engineering mathematics focus of the Wright State curriculum with engineering design activities intended to create a course that is both engaging for students and effective at preparing the students for future mathematics and engineering coursework. Given the motivation for our modification and the focus of the new course is on improving students' performance and retention in calculus, we evaluated the effectiveness of the new course by longitudinally tracking students' success and persistence in subsequent engineering mathematics courses. The results of these analyses show that students' participating in the new course are not performing significantly better than their peers from earlier years, and international students seem to be fairing worse under the new curriculum. Potential reasons include misalignment of the lecture and laboratory activities associated with the course and changes in the student population, especially international students, that are not captured in the model.**

Index Terms – Calculus readiness, course modification

BACKGROUND

Math represents a significant barrier to student success and persistence in undergraduate engineering programs, and universities have invested significant time and resources to address this issue [1]. Wright State University developed a first-year engineering curriculum focused on teaching math in an engineering context, resulting in significant increases in students' ability to be successful in subsequent math and engineering courses [2]–[5]. The success of the Wright State model has resulted in the adoption of this approach by many other first-year engineering programs and the development of an accompanying textbook [6]. Inspired by the improved academic achievement and persistence of engineering students at Wright State University, we made the decision to explore implementing this model at Boise State University in the fall of 2013.

Prior to modification, the traditional Introduction to Engineering (ITE) class taught from fall 2011 to spring of 2014 contained four modules: consumer product testing and design of experiments, a manufacturing module, a module on circuits, and a renewable energy module. The first three modules each lasted approximately two weeks, while the last module involved designing and building a small-scale generator and wind turbine over a period of seven weeks. In the fall of 2014, we redesigned this course based on the Wright State model, which involved significant modifications to both the lecture and laboratory components of the course. We modified the lectures to focus on the mathematics topics emphasized in the Wright State curriculum, including trigonometry, vectors, solving systems of equations, and derivatives and integrals. We also incorporated using Matlab, with an emphasis on using it as a tool to solve engineering mathematics problems. New laboratory activities included analysis of forces in a truss and mathematical model of falling bodies.

Implementation of the curriculum began with a pilot of the new version of the course in the fall of 2013, with the new course implemented for all students enrolled in the Introduction to Engineering course in the fall of 2014. For a complete description of changes to the courses and our modification process, please see [7].

METHOD

The participants in this study are all students who enrolled in Introduction to Engineering (ITE), from fall 2011 through spring 2016. The students who had taken ITE, and then completed at least one subsequent sophomore level engineering class were selected. The participants comprised a sample of 813 students, with 13.6% female and 23.1% international students. Of the students taking the class, 35.8% were first time full time students, with an average age of 21.6 years. 20.3% of the students were non-traditional with their age being greater than 23 years.

We received permission from the university's Institutional Review Board to gather demographic and longitudinal data from the university data warehouse. The demographic data collected consisted of gender, international status, age, and first-time fulltime student status. We also collected academic data, including university GPA, semester the student took ITE, ITE final course grade, math sequence course grade (Calculus 1, 2, 3 and 4), statics and dynamics course grades, circuits 1 and 2 course grades, and civil engineering 1 and 2 course grades.

The traditional ITE course was taught from the fall 2011 through spring 2014. Then the course was revised to the math-based version, which has been taught for fall 2014 through spring 2016. A coded variable was created which indicates which version of the course each student took.

For each student a composite engineering grade was calculated by finding the average of all subsequent engineering course grades. This composite score was used as the primary measure of success for this study. To explore the effects of changing the course, we analyzed these data using SPSS version 24 to evaluate whether the students' likelihood to succeed was effected by the version of ITE taught.

Two primary confounding factors exist that may affect the results of these analyses. At the same time that we were revising the ITE course, the math department was revising the calculus sequence taken by all engineering majors[8]. This consisted of revising most of the curriculum and instructional methods which significantly improving the student outcomes. There also have been large fluctuations in the number of international students in the ITE class. The percentage of international students has varied from 5.8% in the spring of 2011 to a high of 37% in the spring of 2016. At the same time the university has changed the English proficiency requirements so that the students now entering have better English skills.

RESULTS

An independent-samples *t*-test was conducted to evaluate the hypothesis that students who took the math Introduction to Engineering class would be more successful in following engineering classes than students who took the previous version of the class. The student success measurement used here is a mean GPA for following engineering classes. The test was not statistically significant ($p>0.05$) with $t(811)=1.121$, $p=0.263$, which suggests that there is not a significant difference between the students who took the two different versions of this class. Students who took the math based version (M=2.42, SD=1.197) on the average were equally likely be successful as students who took the previous version (M=2.52, SD=1.009). These relationships are shown in Figure 1 below.

A series of post-hoc tests were done to explore the relationships using other measures of student success. These post-hoc tests are listed below with the results summarized in Table 1.

- An independent-samples t-test was conducted to evaluate the effect of class version on the performance of student in a sophomore statics class.
- An independent-samples t-test was conducted to evaluate the effect of class version on the performance of student in subsequent sophomore circuits classes.
- An independent-samples t-test was conducted to evaluate the effect of class version on the performance of students in Civil Engineering classes.
- An independent-samples t-test was conducted to evaluate the effect of class version on the performance of student as measured by overall GPA at the university.

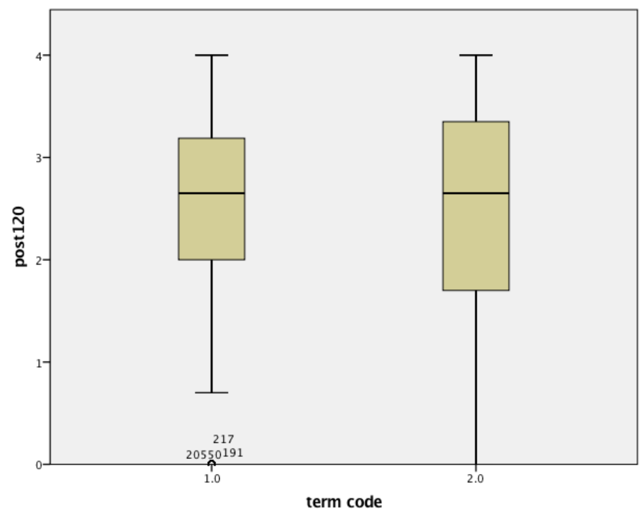

FIGURE 1
COMPARISON OF MEAN ENGINEERING GPA FOR ORIGINAL (1.0) AND MATH-BASED (2.0) INTRODUCTION TO ENGINEERING COURSES.

TABLE I
COMPARISON OF MEANS IN SUBSEQUENT ENGINEERING COURSES

Dependent variable	N	t	P
Statics grade	594	1.735	0.083
Circuits grade	167	-.089	0.376
CE grade	304	1.47	0.142
University GPA	1632	-1.526	0.127

As with overall engineering GPA, these analyses showed no significant difference in subsequent engineering course grades, regardless of engineering discipline.

To evaluate the effects of the class on different populations the following post-hoc analyses were done

- A two way ANOVA test was conducted to evaluate the effect of class version on the performance of male vs. female students.
- A two way ANOVA test was conducted to evaluate the effect of class version on the performance of domestic vs. international students.

A two-way between-groups analysis of variance was conducted to explore the interaction of gender and class version on student performance as measured by the students GPA after Introduction to Engineering. Students were divided into two groups according to their gender, and divided again according to which version of the course they took. The variance of the dependent variable GPA was found to be not equal across groups, as the result of Levine's test yielded a sig=0.000. This suggests that the assumptions have been violated, and though the ANOVA is robust, the results should be viewed as preliminary, and guide further investigations. The interaction effect between gender and version was not statistically significant, F(1, 809) = 1.22, p=0.27. There was a statistically significant main effect for gender, F(1, 809) = 7.74, p=0.009; however, the effect size was small with partial eta squared = 0.9%. These results suggest that there is not a useful difference between gender and class versions, as shown in the boxplot in Figure 2.

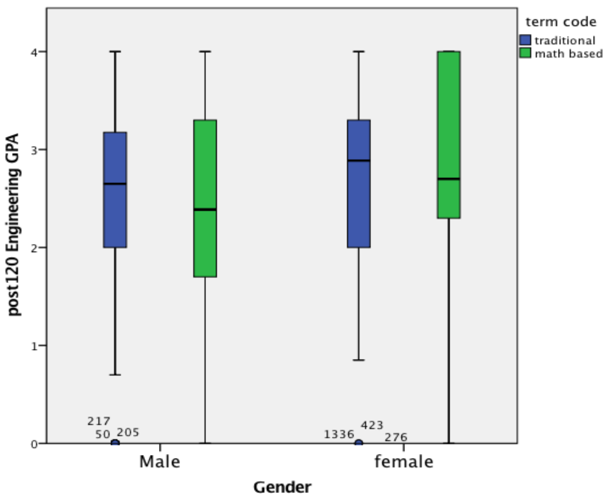

FIGURE 2
COMPARISON OF POST INTRODUCTION TO ENGINEERING BY GENDER

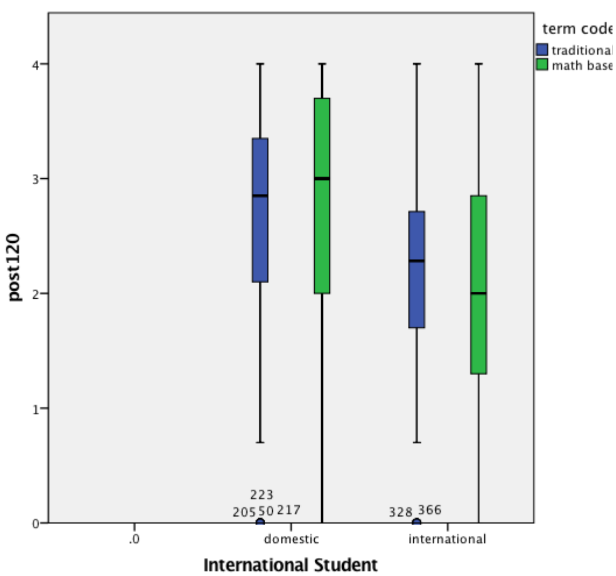

FIGURE 3
COMPARISON OF POST INTRODUCTION TO ENGINEERING BY INTERNATIONAL STUDENT STATUS

Another two-way between-groups analysis of variance was conducted to explore the interaction of nationality and class version on student performance as measured by the students GPA after Introduction to Engineering. Students were divided into two groups according to their nationality, and divided again according to which version of the course they took. The interaction effect between nationality and version was not statistically significant, F(1, 809) = 0.426, p=0.426. There was a statistically significant main effect for nationality, F(1, 809) = 48.1, p=0.000; however, the effect size is on the borderline between medium and small with partial eta squared = 5.6%. These results suggest that there may be a useful difference worth investigating for student nationality, as shown in the boxplot in Figure 3.

DISCUSSION

In redesigning our first-year engineering course to have a stronger focus on developing students' proficiency in mathematics, we expected to see improvements in the grades in subsequent engineering classes for students taught using the modified curriculum. However, the analyses presented in this paper showed that class version had no significant effect upon any of the measures that we used. Likewise, post-hoc analysis of the effect of the course modifications on women in the class also showed no significant gender-based effect of the class version upon student success. A second post-hoc analysis comparing the success of international students to their domestic counterparts suggest that overall international students faired worse, and participation in the math-based course exacerbated the achievement gap between domestic and international students. Take as a whole, these results suggest that overall, students are fairing worse in the modified, math-based course that they were in the prior version of the Introduction to Engineering course.

As shown in Figure 3, the math-based Introduction to Engineering course had a significant negative impact on the average performance of international students. This could be due to lower mathematics proficiency of incoming international engineering students that we were not able to control for in our analyses, or other undetermined factors. This clearly represents an area in need of further exploration.

As the course design evolved, the alignment between the laboratory and lecture components suffered, which may partially explain the lack of success in the model. While the lectures and accompanying assignments and assessments shifted to align with the Wright State model, the less extensive modifications to the laboratory activities resulted in lecture activities that did not consistently prepare students for their laboratory activities, and laboratory activities that did not consistently reinforce or utilize the skills that the students learned in the lecture sections of the class. This experience presents a cautionary tale about the importance of maintaining alignment in the first-year engineering curriculum, and the importance of thoroughly considering how changes to proven curricular models such as the one developed at Wright State University can reduce the effectiveness of the curriculum.

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