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Understanding students' experience and achievement in a redesigned engineering math class

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Understanding students' experience and achievement in a redesigned engineering math class

Abstract: A redesigned engineering math sequence was implemented from fall 2016 to spring 2020, and the study focused on data collected during fall 2018 and spring 2019 from a single class with a sample size of 25. The results of the study suggest that the redesigned sequence positively impacted students' material mastery, communication, collaboration, and metacognition. Although the sample size was small, and the results were not statistically significant, it was found that students' view of math and perception of their preparedness may play a role in their participation and how they interact with the material, with peers, and with the instructor and TAs.

Keywords: engineering math, Calculus, active learning, redesign

Introduction

Core curriculum for engineering students should provide at least five things to lead to students' further academic success and prepare them for the job market: 1) material mastery, 2) communication, and collaboration, 3) software/programming skills, 4) learning and metacognition, and 5) confidence. Students in traditional lecture-based classrooms may not be taught these skills [1][2]. Numerous studies have shown that active and cooperative learning classes are better at addressing these than traditional lecture-based classes [3]. Some examples of Active learning (AL) and Cooperative learning (CL) [4] are 1) Flipped classroom, 2) Student presentation, 3) Student projects, 4) Student discussion, and 5) Student group work.

A traditional calculus class is often content-driven and does not prepare engineering students for further coursework and careers in engineering. At our engineering school, we offer a traditional three-semester calculus sequence with 3 different starting points. Depending on their prior mathematical background, students have the option to begin their first semester with Calculus I, Calculus II, or Multivariable Calculus. In 2016, a two-semester honor's engineering math sequence was developed for the students with the strongest math background who would typically begin with Multivariable Calculus in their first semester. The sequence enhances the traditional calculus curriculum by addressing gaps in Calculus I and II skills, providing a more in-depth exploration of Multivariable Calculus topics, and introducing challenging topics and projects [5][6]. The motivation of this redesigned sequence was: 1) to expose students to more applied topics and real-world applications in Calculus [7], 2) to better prepare them to move forward for their advanced courses and their engineering career [8], and more importantly, 3) to promote their learning experience by incorporating active learning practices and opportunities to develop their communication skills and teamwork experience [9].

Students were eligible to take the course if they had obtained approved college credit for Single Variable Calculus II or if they had scored 5 on the Advanced Placement Calculus BC exam. They were given the choice to enroll in either the traditional Multivariable Calculus course or this 2-semester sequence. The course was advertised to attract students with a strong interest in math, and students self-enrolled in the class. This sequence has been offered from Fall 2016 through Spring 2020, with a total of 108 students enrolled.

Purpose and Research Questions

Gaining a deeper understanding of the impact of this revamped sequence, as well as identifying the specific characteristics of students (such as their view towards math, their level of preparedness, and their motivation for taking the course) that make them more or less likely to succeed, could be essential to shaping active learning classrooms for all. This study was guided by two research questions:

1. Is there evidence that the redesigned sequence provides students with material mastery, communication and collaboration, and metacognition of learning?
2. What relationship, if any, exists between who the student is at the start of class and the student's experiences in class?

Description of the redesigned engineering math class

Topics Covered:
Some applied topics from Calculus I and Calculus II are commonly omitted in high school calculus classes. This course begins with those topics, including Newton's method, Simpson's rule, and applications of integration to physics and engineering (such as work, hydrostatic pressure and force, and moments and centers of mass). Based on prior experience and surveys of calculus instructors, the course also includes topics that are most frequently identified as challenging for students, including the representation of functions as power series and the Taylor and Maclaurin series. This leaves ample time to cover all the essential concepts of multivariable calculus in 1.5 semesters. It allows for a more thorough treatment of multivariable calculus topics than can be achieved in a single-semester course and offers the opportunity to explore additional challenging topics and projects.

Course Design:
The course design incorporated various active learning practices to enhance student engagement and understanding. Before each class session, students were expected to complete a reading quiz based on the assigned material. The quiz comprised five questions, including four content-related questions and one short answer question aimed at identifying areas of difficulty. Another approach was to start the class with a few warm-up questions and a brief discussion, helping students ease into the session in a more interactive way. This activity also allows the instructor and students to assess how well they understand the topic from their assigned reading before class.

During class, students were grouped into teams of four and provided with a worksheet that contained starter problems, leading to a mini-lecture and discussion lasting 20 to 25 minutes. The focus of class time was on the development of conceptual understanding and communication skills through think-pair-share activities and student presentations. At the end of each session, students were asked to sign up and present the solutions to the worksheet problems. All students were expected to participate in the class presentation and discussion. The warm-up, class presentation and group work accounted for 12% of their total grade.

After class, weekly homework was assigned through WebAssign. In addition to the online submission, some problems were chosen occasionally from WebAssign or in-class worksheets to be written out for submission—these problems were graded based on completeness, correctness, and neatness/readability. Students worked on several course projects in their teams of four. Team formation was based on the Comprehensive Assessment for Team-Member Effectiveness (CATME), taking into account scheduling conflicts and diversity considerations.

Assessments:
Low-stakes check-for-understanding quizzes are given every other week to assist students in gauging their grasp of fundamental concepts. Mid-terms and the final exam present students with a series of problems to evaluate their ability to integrate concepts and methods from class discussions and group work. Each exam is divided into three sections: Section I includes conceptual questions (True/False and/or multiple-choice), Section II involves essential problems requiring students to show their work and display their understanding, and Section III involves the application of concepts. Students are encouraged to articulate their thought processes, and credit is awarded for effort and the quality of their exploration.

Methods

This study was conducted at an engineering school of a four-year, R1 public research university with roughly 22,000 students. The purpose of the study is to understand the impact of the redesigned curriculum of a calculus sequence on students.

Participants
All 25 students who took the engineering math sequence in Fall 2018 and Spring 2019 were participants, with 21 completing all three surveys. Of the 21 participants, 15 were male and 6 were female.

Data Collection
The impact is evaluated using both qualitative and quantitative methods. Data sources include placement test scores, pre-course and post-course surveys, and final exam grades. This sequence is a two-semester sequence. All first-year students took a placement test prior to arrival. The pre-course survey was administered during the first week of class of the first semester. Two post-surveys were conducted at the end of the fall and spring semesters using modified Student Assessment of Their Learning Gains (SALG) surveys [10]. The surveys included questions about students' attitudes towards math, skills, learning, and metacognition, as well as questions about their overall experience in class.

Data Analysis
The placement test scores of students in the traditional multivariable calculus class and those in the redesigned sequence were compared using Welch's t-tests at a significance level of 0.05. This was done to assess course preparedness. Additionally, Welch's t-test was utilized to determine any difference in the performance of the two groups on the common final exam problems.

We assigned Likert responses of 1=not applicable, 2=not at all, 3=just a little, 4=somewhat, 5= a lot, and 6= a great deal to each question on the surveys. The pre-course scores were compared with the averaged scores from the post-first semester and post-second semester, and paired t-tests with a significance level of 0.05 were conducted to determine whether there was an improvement in students' communication, collaboration skills, and metacognitive awareness. In addition, open-ended survey response questions were used to collect qualitative data on students' perceptions of their preparedness, motivation for taking this class, and their experiences in the class. The data were coded and analyzed for emerging themes and patterns.

Results

Question 1: Is there evidence that the redesigned engineering math sequence provides students with material mastery, communication and collaboration, and metacognition of learning?

Material Mastery
Eligible first-year engineering students have the option of selecting either the traditional 1-semester course or the redesigned 2-semester sequence. In Fall 2018, 25 students opted for the redesigned sequence while 226 students enrolled in the traditional course. Prior to the course start, the author compared the placement scores of both groups and found no significant difference in their performance (p-value=0.31). The placement test consisted of 60 questions, with 30 pre-calculus, 15 calculus I, and 15 calculus II questions. Each question was scored on a 1-point scale. Additionally, all students took a final exam that included 17 common conceptual questions worth 31 points. The Welch's t-test was used to compare the performance of both groups, and it revealed that students in the redesigned track performed significantly better upon completing the course (p-value<0.001). Please refer to Table 1 for a detailed comparison of the students' performance. Overall, it seems that the redesigned sequence is more effective in providing material mastery for students compared to the traditional track.

Table 1. Students' material mastery pre- and post-course

	Placement test scores (60 points)		Final exam common questions (31 points)	
	Redesigned	Traditional	Redesigned	Traditional
Mean	39.80	41.82	28.80	26.03
Standard Deviation	8.28	7.97	2.55	4.03
Observations	20	160	25	226
p-value	0.31		<0.001*	

Communication and Collaboration
To assess communication and collaboration, the mean responses to three survey questions were used. These questions are "Assess how confident you are in the following skills":

- Communicate mathematical ideas in writing with clarity and coherence
- Orally communicate mathematical ideas with clarity and coherence
- Work effectively with others on math problems

Students' communication and collaboration skills significantly improved over the course of two semesters (p-value<0.001). See Table 2 for additional details.

Metacognition of Learning
Metacognition refers to an individual's awareness and understanding of their own thought processes, and it plays an important role in learning and problem-solving in mathematics [11]. As part of the survey, seven questions were used to assess students' metacognitive awareness.

These included modifying problems, persevering, approaching problem-solving with a willingness to try multiple techniques, as well as other habits of metacognitive strategies that include appreciating different perspectives, stretching their own math capacity, and connecting key ideas with other knowledge. The author found a significant improvement in students' metacognition of learning across two semesters (p-value<0.001). See Table 2 for additional details.

Table 2: Student's communication and metacognition in redesigned sequence

Observations=21	Pre-Course Mean (SD)	Post-Course Mean (SD)	p-value
Communication and Collaboration	4.14 (0.48)	5.09 (0.45)	<0.001*
Metacognition of Learning	4.62 (0.41)	5.14 (0.55)	<0.001*

To summarize, the redesigned sequence provided students with evidence of mastery over the material, as well as opportunities for communication, collaboration, and metacognition of their learning.

Question 2: What relationship, if any, exists between who the student is at the start of class and the student's experiences in class?

To answer this question, qualitative data gathered from the open-ended survey questions were coded and analyzed for any emerging themes.

What type of students took this course and what are their motivations for taking this course?
Students fell into four basic groups based on their views of math and sense of preparedness: 1) students who view math positively and feel prepared, 2) students who view math positively but feel unprepared, 3) students who hold a neutral view of math but feel prepared, and 4) students who hold a neutral view of math and feel unprepared. The neutral view of math did influence why students chose to take this course, as they believed it would provide more extended coverage of the material at a slower pace, and this group of students also expressed a sense of unpreparedness. On the other hand, the feeling of preparedness did not impact why students chose to take the course. Roughly half of the students mentioned reasons such as smaller class sizes, engineering application, and expectation of in-depth coverage as motivation for taking the course, while others cited their love of math and desire for challenges.

What are students' experiences with the class?
In terms of student experiences, the majority of students enjoyed the class and found the environment positive, and the teaching helpful. They also found their peers to be useful resources and specifically appreciated aspects of active learning. However, two students requested more lecture time. Most students found the pace of the class appropriate. Some students wanted the pace of the course to be faster and others wanted slower. Despite the fact that most students found the atmosphere of the class conducive to participation, only one-third of students fully participated. Participation included peer teaching and learning, interacting with others, and presenting in front of the class. Students with a positive view of math were the only ones to self-report full participation. Regarding group work, students found it challenging to divide the

workload, and some had issues with peers that were unresponsive or did not do their work. Others found the group pace to be too fast.

Do who the student is at the start of class predict their experience in this class?
Linear regression tests were conducted, and the results indicated that neither their preparedness nor their view of math significantly predicted their experience in the class. However, it was found that there was a positive relationship between both their view of math and their preparedness with their overall experience. This suggests that while these factors do not entirely determine their experience in the class, they can play a role in shaping it to some extent. It is important to note that other factors could also be at play, and further research is needed to fully understand the complexities of this relationship.

Conclusion

The two-semester sequence was implemented from fall 2016 to Spring 2020 for a period of four years. However, it was discontinued due to the pandemic and staffing shortage. Although students appreciated the depth approach of this redesigned sequence, some still felt that taking a two-semester sequence put them at a time disadvantage compared to their peers who had taken the traditional one-semester Multivariable Calculus course. Consequently, most eligible incoming students still opt for the traditional multivariable course. It is worth noting that the introduction of the two-semester redesigned sequence did not affect the availability of the traditional sequence, which continues to be offered.

This study focused on data collected in a single class during Fall 2018 and Spring 2019, with approval from the institution's IRB. Despite the limitations of the small sample size, the results were positive, suggesting that the redesigned sequence provided students with a deep conceptual understanding of the material, also opportunities to communicate mathematical ideas to their peers and to collaborate with their peers. Moreover, it enhanced the use of metacognitive strategies by students. Although not statistically significant, students' views of math and perception of their preparedness appeared to contribute positively to their learning experience in the class.

Future work could focus on gaining a deeper understanding of the particular attributes of students that make them more or less likely to thrive in other math courses with active learning structures.

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