Study of Pre- and Post-Course Knowledge Surveys in a Calculus I Course

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Abstract

A pre- and post- surveys were developed based on key concepts in pre-calculus and calculus I. The pre-survey was administered to measure students' prior knowledge at the beginning of the term. The same survey was conducted on the last day of semester to assess knowledge gained because of the course experience. Data was collected in two sections of Calculus I in Fall 2021, one employed engineering application seminar and the other used the traditional methods. The objectives of this study were to (1) assess the amount of exposure first-year students have to calculus I prior to this course and (2) to assess student learning because of various pedagogical techniques used. This paper discusses the analyses of pre and post survey results, the pedagogical approaches used, and suggestions for future research.

Keywords

Calculus, Pre- and Post-Survey

Background

Early student departure from engineering programs has become a grave concern in an era of declining interest among youth in pursuing a future in technology [1-2], coupled with high global demand for qualified engineering graduates[3]. Several strategies have been proposed and implemented to increase retention in engineering programs [4-7]. Some of the most used techniques consist of addressing attrition related to calculus courses [6-8]. Some institutions have offered calculus courses with significant engineering content highlighting the applicability of calculus topics to solving engineering problems [5-6]. The Citadel is embarking on a project to improve the calculus experience of engineering students to enhance learning and promote retention. In this study, a new and improved section is used as an experimental and a traditional calculus section as a control.

Experimental Calculus Section

Experimental Calculus section was taught with both face-to-face and online components. The face-to-face component was led by a math instructor. The face-to-face component was held three times per week in 75-minutes sessions. Topics covered during instruction included: trigonometry, limits, continuity, derivatives, and integrals. Typical sessions included lecture time with intermittent problem-solving sessions. Online instruction and support were also used to help students engage more deeply with course materials. Content was managed by a separate instructor who coordinated with the face-to-face instructor to ensure alignment of activities and learning outcomes. Weekly, students were required to post and respond to questions on the online discussion board, which required them to demonstrate conceptual mastery of topics. In addition, students completed weekly journal submissions, which required critical reflection of course preparation, performance, and application to civil engineering.

Weekly, students attended an engineering seminar, hosted by a civil engineering faculty. The seminar was designed to provide students with tangible examples of how course material would connect with students' future classes and profession. Activities were related to early engineering fundamentals courses (e.g., Statics, Dynamics, and Mechanics of Materials), as well as applications of specific civil engineering subdisciplines (e.g., Structural, and Geotechnical engineering) (Table 1). The engineering faculty worked closely with course instructors to ensure that seminar activities aligned with recent course topics. Seminar deliverables accounted for 20% of the course grade.

Table 1. Application seminar activities

Spring and Bungee Cord	Determining the stiffness and developing linear model.
Trusses	Applications of right triangles, laws of sine and cosine
Water Balloon Launcher	Determining the range, maximum height reached, and the hang time
Shear strength of soil-Mohr's Circle	Drawing Mohr's Circle and determining the friction angle of soil.
Instantaneous vs. Average	Investigating the instantaneous rate of change and average rate of change
Position, velocity, acceleration	Investigating the relationships among position, velocity, and acceleration (y, y', y'')
Beam-Shear and Moment	Investigating the relationships between shear force and bending moment.
Material Testing Project	Material testing of aluminum, Cold-rolled steel, and Mild steel. Determining the modulus of elasticity and ultimate strength of each material
Beam-Slope and deflection	Determining maximum deflection in a beam; (2) Given a deflection function, determine slope, bending moment, and shear force.
Optimization Project	Minimize the amount of concrete needed to line an irrigation channel in a shape of trapezoid with area of 150 ft^2

Traditional Calculus Section

The control group was a traditional Calculus I course. This section meets 4 times per week, with three 50-minute lectures and one 75-minute group work session each week.
The emphasis of the course is on computing derivatives of functions using the basic differentiation rules (chain rule, product rule, etc.). The course starts with a chapter on computing limits, leading up to the limit definition of the derivative. After a chapter on computing derivatives, the course covers applications of derivatives including optimization,

related rates, and curve sketching. The course concludes with a unit introducing integration to help prepare students for Calculus II.

A required feature of all calculus courses at The Citadel is a pass/fail standardized exam on derivatives that is taken on the computer and is worth 10% of the course grade. Students are allowed to re-take the exam until they pass, up to 3 times per day. This exam was instituted 12 years ago at the request of the School of Engineering for accreditation purposes. To prepare students for this exam, there is a heavy emphasis on computing derivatives of functions quickly and correctly.

Pre- and Post- Survey

Pre- and post-surveys were conducted to assess the impact on student learning on the calculus content at the beginning and at the end of course. The pre-survey was administered to measure students' prior knowledge at the beginning of the term. The same survey was conducted on the last day of semester to assess knowledge gained because of the course experience. The 10 questions pre- and post-survey are shown below.

1. Explain the significance of the unit circle.
2. Given a plot of velocity vs. time, develop an equation for velocity as a function of time.
3. Explain the meaning of derivative.
4. Given distance as a function of time, determine the rate of change of acceleration at a time t.
5. Given an equation of path traveled by a projectile, determine how long will it take to reach maximum height.
6. Given graph of the velocity of a particle, sketch the graphs of position and acceleration.
7. Describe how you determine the average rate of change for the period from t =a to t = b.
8. Describe how you determine the instantaneous rate of change at t = a.
9. List several applications of derivative.
10. Given a plot of velocity vs. time, explain how you determine the total displacement of the particle between t =a and t = b.

Each of the 10 questions of survey was scored using the following rubric (Table 2): a score of zero (0) was awarded for an incorrect, off-base answer or no answer at all; a score of 0.5 was awarded for a partially correct answer; or score of one (1.0) was awarded for correct answer.

Table 2. Grading rubric for the survey.

Points Awarded per Question	Rubric
0	No credit for incorrect, off-base answer or no answer at all
0.5	Partial credit for partially correct answer
1.0	Full credit for correct answer

Figure 1 illustrates the mean score for overall and each question on the pre- and post-survey. The pre- and post-survey mean overall score range from 10% to 13% and 47% to 69%, respectively. Figure 1 also analyzes students' performance on each question on the pre- and post-surveys.

Students' performance at below 15% level on Questions 1, 3, 4, 6, 8, 9, and 10 of the pre-survey is an extremely poor performance, indicating little to no prior experience with these concepts. Students performed poorly on both the pre- and post-surveys on Questions 4 and 5. This suggests that students have a poor understanding of rate of change of acceleration, determining the time it takes to reach maximum height, and determining the vertex of parabola. Ninety-one percent on the pre-survey and thirty-two percent on the post survey revealed the misconception about the rate of change of acceleration at a time t (Question 4). Question 5 deals with determining the vertex of a parabola, a topic normally covered in high school algebra. The mean pre-survey score for all participants was 11% and the mean post-survey for all participants was 30%. Eighty-nine percent of the pre- and 70% on the post-survey exhibited their misconception about the vertex of parabola.

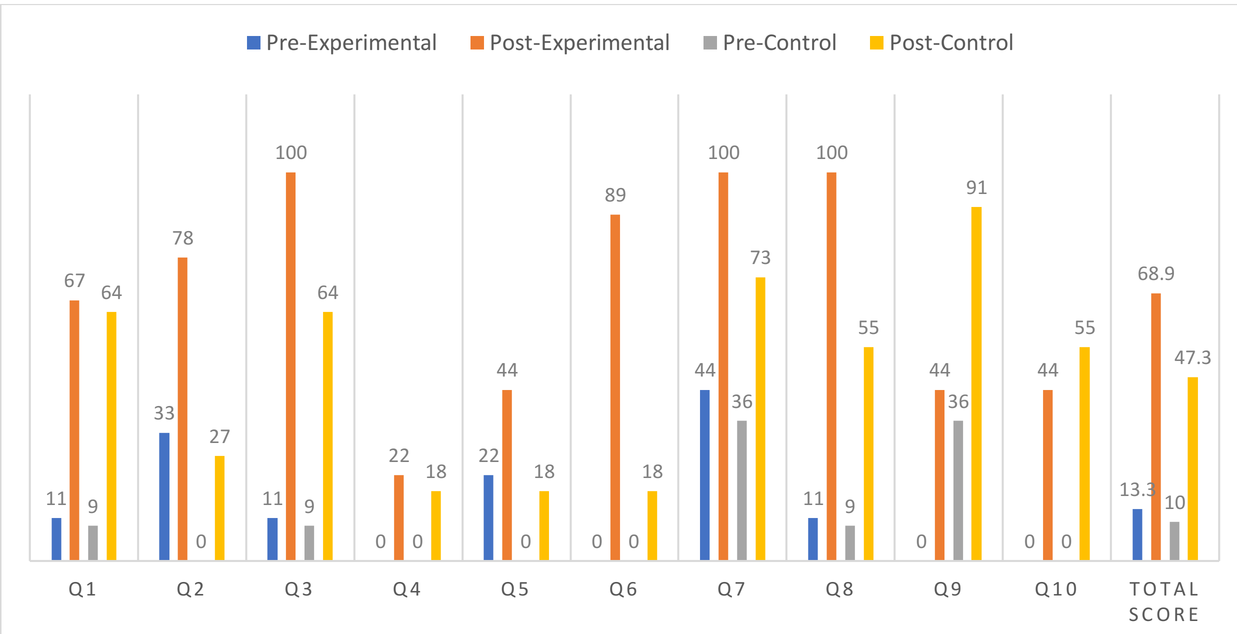

Figure 1. Mean score for overall and each question on the pre- and post-survey

Figure 2 shows the percentage gained on each question and overall. For the experimental section, the highest gains were in Q3, Q6, Q8 and lowest gains were in Q4 and Q5. The experimental section had an overall gain of 55%. For the control section, the highest gains were in Q1, Q3, Q9, and Q10 and the lowest gains were in Q2, Q4, Q5, and Q6. The overall gain for the control section was 37%.

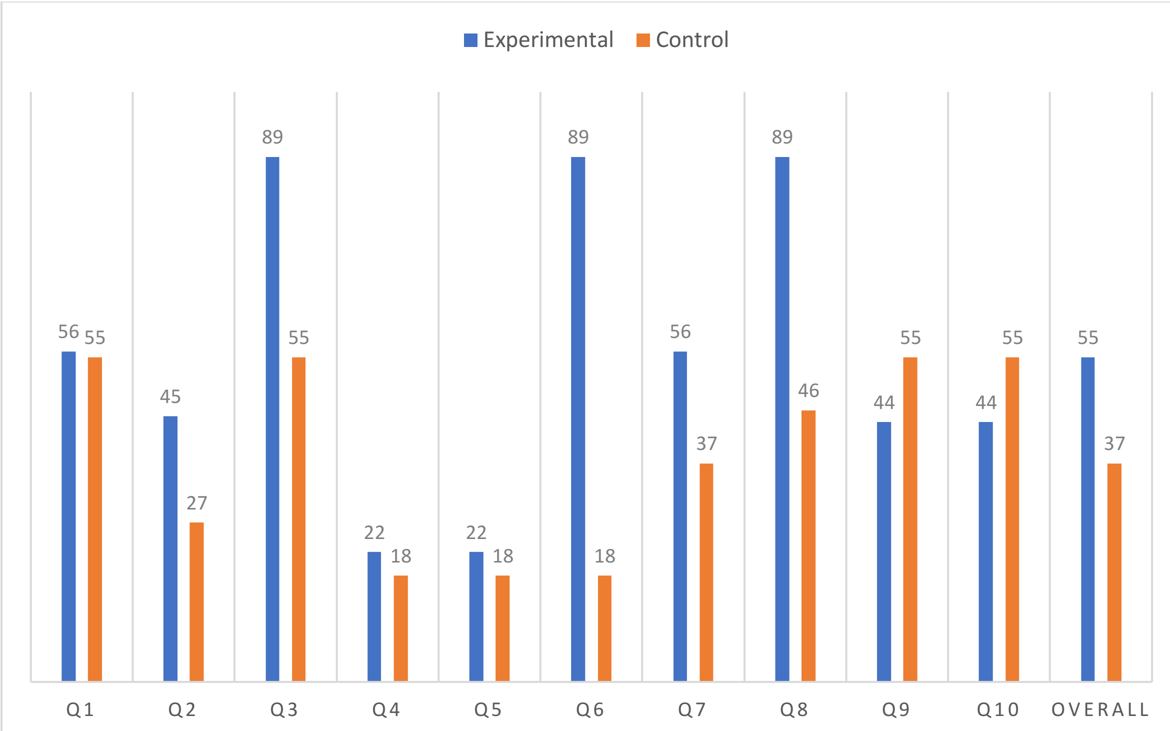

Figure 2. Average percent gained overall and on each question.

The paired sample t-test was conducted for each question to test for statistically significant differences between pre- and post-survey scores at 5% level of significance. Comparison of the students' performances in control and experimental sections showed that all students performed similarly on overall score when measuring conceptual understanding from pre- to post-survey. For the treatment section, Qs 1-3 and Qs 6-10 showed a statistically significant difference between the pre- and post-surveys. For the control sections, Q1, Q3 and Qs 7-10 showed a statistically significant difference between the pre- and post-surveys.

Future Research

There is necessarily a tradeoff in time spent in the classroom on application versus theory. It is important to study the effects of this tradeoff to see if the time spent on applications deepened students' knowledge or motivation or possibly took away from learning of math fundamentals. As the students progress through the academic career, we will track their performance in future courses that rely on calculus, including both mathematics courses (Calculus II, Multivariable Calculus, Differential Calculus) and engineering courses (Statics, Dynamics, Mechanics of Materials).

The knowledge assessment used did not impact the students' course grades, so some students may not have been as focused or thorough as they would be for a graded exam. Future comparisons would incorporate graded assessments into both the experimental and control groups, such as quizzes or exams. With more assessments, we could pinpoint which topics benefit the most from delving into applications.

The preliminary data suggests that incorporating applications and projects into the curriculum positively impacts student learning. It would be interesting to incorporate some of these projects into traditional calculus courses, as many of the students are motivated by applications. This may prove difficult, because the syllabi for the courses in the calculus sequence do not leave much time for more topics.

Conclusions

This study assessed the amount of exposure students have to mathematical concepts prior to the introductory calculus course. This study also assessed the gains in conceptual understanding of mathematical topics as a result of various pedagogical techniques used. The following conclusions can be made based on the study results:

- Students are entering the introductory calculus course with little prior knowledge. The low performance on several of the pretest questions is not surprising, as students are not expected to have wide exposure to these concepts prior to completing a course in calculus. The results show that there are variations in students' exposure to mathematical concepts prior to their first course in calculus.

- Students' pre-survey scores on the algebra and trigonometry questions were lower than expected, even though a course in algebra and trigonometry is a prerequisite for the calculus course. These low scores suggest that students do not adequately retain algebra/trig concepts between their initial exposure in high school and the start of their calculus course.

- Comparison of the students' performances in control and experimental sections showed that all students performed similarly on overall score when measuring conceptual understanding from pre- to post-survey.

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