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# Performance in Calculus II for students in CLEAR Calculus: A causal comparative study

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## Abstract

Calculus is one of the greatest intellectual achievements of the world and is the main gateway for students that are heading into the fields that will power the economy of the 21st century. However, over 25% of students fail U.S. calculus courses each year and end up changing majors. It is important for educators and researchers to try to improve student success and find ways to increase STEM major retention. The purpose of this study was to compare the performance between students that are in traditional and non-traditional calculus II courses based on their preparation in either traditional or non-traditional calculus I. By the end of the study, non-traditional calculus II students performed approximately the same on every test and overall in the class. On the other hand, traditional calculus II students that took traditional calculus I performed better on the three tests, but their overall performance in the course was approximately the same as the students that took non-traditional calculus I.

## Introduction

One of the biggest problems in calculus education is the large number of students that are leaving the STEM field during or after introductory calculus. This is a serious issue, because the U.S. economy is in need of more STEM majors throughout the next decade (Ellis, Kelton, & Rasmussen, 2014). In order to increase the retention of STEM majors, calculus education reform has been on the rise throughout the country.

The research that has been conducted up to this point has suggested various ways to improve calculus education. Calculus classes are normally structured in two different ways. The traditional structure is a lecture-based class where the instructor lectures and students listen and take notes. The non-traditional way that calculus is taught is through lab-based practices. This second method is more student-centered, and the overarching idea that has appeared in the literature is that calculus instruction should be more student-centered. Student-centered instruction leads to more effective learning (Pascoe & Stockero, 2017). The evidence in support of active learning strategies is strong, but it is difficult to get large numbers of faculty to implement these practices (Hayward & Laursen, 2017). The time is now for calculus educators along with mathematicians to work together to develop the best practices for calculus understanding and STEM major retention (Rasmussen, Marrongelle, & Borba, 2014).

One area that little research has been conducted on is student success when transitioning between classes that are structured differently. Students either take traditional or non-traditional calculus I followed by traditional or non-traditional calculus II. This study compared the success of calculus II students that took either traditional or non-traditional calculus I. The hypothesis for this study is that there is no difference in achievement in calculus II based on students' calculus I modality.

The results of this study are important, because it will improve our understanding of the research that already exists. Also, if students are more successful after taking a certain sequence of classes, then educators and advisors will be able to enroll students in classes that give them a higher chance of success, thus increasing the retention of STEM majors.

This is a causal-comparative study that used a chi-squared test on the distribution of the students calculus I grades. A Kruskal-Wallis test was used to compare the difference between the median scores of the students on three tests and a final. Before conducting the study, an extensive review of the literature that already exists was conducted. The following chapter looks at research that has already taken place.

## Literature Review

After reviewing the literature, there were four themes: Importance of calculus, STEM (Science, Technology, Engineering and Mathematics) major retention, how students learn calculus, and how calculus is taught. These themes will be discussed in the order listed.

## Importance of Calculus

Calculus has been celebrated as being one of the greatest intellectual achievements of western civilization. The subject drips with power and beauty. It rendered thousand-year-old questions immediately transparent (Dawkins, Epperson, 2014). Calculus I is the main gateway for collegiate students heading into the technical and scientific areas that will power the economy of the 21st century (Bressoud, Carlson, Mesa, & Rasmussen, 2013). However, over the next decade, approximately one million more STEM majors beyond the current level of STEM graduates will be needed to meet the demands of the US workplace (Ellis, Kelton, & Rasmussen, 2014). Future teachers, engineers, doctors, economists, scientists, and mathematicians study calculus concepts and techniques, and taking a course in calculus is often thought to be a pinnacle of intellectual achievement by citizens of the world (Rasmussen, Marrongelle, & Borba, 2014). Calculus is both the most important entity in secondary mathematics and the gateway for students taking advanced classes in science and engineering (Dawkins & Epperson, 2014). A strong foundation in calculus is needed to be successful in earning a degree in engineering (Vestal, Brandenburger, & Furth, 2015).

## STEM Major Retention

Despite the obvious importance that calculus plays in our society, research suggests that many students struggle to be successful in a calculus course and even students that are successful in calculus classes still struggle to use calculus concepts to solve non-routine problems. The average failure rate in US calculus courses is over 25% (Dawkins & Epperson, 2014). Every year, an average of 600,000 first-year college students take calculus; 250,000 out of 600,000 students fail (Treisman, 1992).

Introductory calculus is one of the largest choke points for undergraduate students pursuing a STEM degree (Dibbs, 2016). It is known to be a filter, discouraging all but the strongest students from pursuing a career in science or engineering (Bressoud, Carlson, Mesa, & Rasmussen, 2013). Introductory calculus has often been linked to students' decisions to leave STEM majors. Calculus is one of the most challenging obstacles and a necessary first step on the way to a STEM career (Ellis, Fosdick, & Rasmussen, 2017).

Research suggests that switching from a STEM major to a non-STEM major is not necessarily an event, but a process based on the collection of curricular, instructional, and cultural issues (Ellis, Fosdick, & Rasmussen, 2017). Treisman (1992) states that mathematics courses depend on the courses that precede them, so it makes it difficult for students to improve their performance once they are having difficulty. The combination of this with the speed and intensity of freshman courses give them no time to keep up in the course.

Students also cite their lack of a perceived relationship with their instructor along with the inability to seek help as one of the main reasons for switching majors (Dibbs & Patterson, 2016). Instructional experience in first year mathematics courses is a major factor in determining whether or not a student will continue to pursue a STEM degree (Ellis, Kelton, & Rasmussen, 2014). US students who leave STEM degrees often cite traditional and uninspiring instruction that focuses only on memorization rather than actual understanding as being one of the main reasons for leaving (Ellis, Kelton, & Rasmussen, 2014). Another potential shortcoming is that calculus curriculum and student assessments have changed little in the past 50 years. A study that compared recent calculus I tests with tests from 1986-1987 revealed that the percentage of items that require students to either demonstrate or apply an understanding of an idea was not very different (Bressoud, Carlson, Mesa, & Rasmussen, 2013). A different study discovered that a disconnect between calculus content and intended major to be another reason that students decide to leave the STEM field (Voigt, Rasmussen, & Apkarian, 2017).

**How Students Learn Calculus**

In order to understand the various reasons for students switching majors, one must first understand how research suggests that students learn calculus. Students' prior knowledge in mathematics affects their success in subsequent courses. So, students may struggle in calculus due to a lack of trigonometry and algebra skills (Vestal, Brandenburger, & Furth, 2015). Data from a separate study suggests that algebraic fluency is a necessity for university classes, and a large amount of calculus failure can be attributed to a lack of pre-calculus concepts and skills (Dawkins & Epperson, 2014). Students who withdraw from calculus courses often exhibit algebraic illiteracy (Dawkins & Epperson, 2014).

A different study used Piaget's theory of abstraction to develop a certain order of tasks that students need to undertake in order to understand calculus concepts. In order for students to conceptualize a topic, they must abstract, generalize, and relate to one another (Oehrtman, 2008). Mathematical statements, including definitions, theorems, and mathematical claims, are a main part of mathematics curriculum at every level. However, mathematics education research has shown that students often struggle with both understanding mathematical statements and determining whether or not they or true (David, Roh, Sellers, & Damours, 2017). Instruction that begins with formal definitions moves in the opposite direction from which abstraction should naturally occur (Oehrtman, 2008). If a formal understanding is to eventually develop, it will be built on concepts that already make sense to students due to their prior knowledge (Oehrtman, 2008).

How students learn calculus depends on the tasks that students are asked to complete. These tasks can be broken down into two different types. Lower-level demand tasks simply ask students to perform a memorized procedure, whereas higher-level demand tasks require students to think conceptually and make connections (Miller, 2017). Student learning is greatest in classrooms where higher-level tasks are performed, and these higher-level tasks are the most difficult to enact (Miller, 2017).

**Calculus Instruction**

Research examining students' success in introductory mathematics courses consistently shows that students are not learning the intended material (Voigt, Rasmussen, & Apkarian, 2017). In fact, multiple studies have revealed that students that achieve a high grade in introductory calculus actually have a weak understanding of the course's key concepts (Bressoud, Carlson, Mesa, & Rasmussen, 2013). These results put in question whether or not the traditional calculus curriculum is preparing students to use ideas of calculus in future courses (Bressoud, Carlson, Mesa, & Rasmussen, 2013). Ongoing efforts to reform calculus instruction arise from concerns that students are learning calculus as simply a series of algorithms without conceptual understanding (Dawkins & Epperson, 2014). Most mathematics departments are aware and value characteristics of more successful calculus departments, yet they aren't always successful in applying these features at their own institutions (Voigt, Rasmussen, & Apkarian, 2017). Studies show that the content knowledge that professors have is not a predictor of quality instruction and student outcomes (Miller, 2017). Therefore, the mathematical knowledge that instructors have gained throughout their own education may not be the same as the content knowledge that is needed to be a successful teacher (Miller, 2017). Knowing something for oneself or for communication with a colleague is not the same as knowing it in a way that one could explain it to a student (Miller, 2017). One may wonder why design research in calculus isn't very common. One idea is that the calculus reform movement in the 1990's was dominated by curriculum development projects led by mathematicians who did not have extensive educational research expertise (Rasmussen, Marrongelle, & Borba, 2014).

Research has explored the various instruction techniques that are used in calculus education. Traditional lectures are still predominant in higher education. However, many authors report on initiatives to improve student engagement (Weurlander, Cronhjort, & Filipsson, 2017). Reformations have led to a shift from an emphasis on procedural understanding to conceptual understanding. One idea is that the utilization of technology that allows students to visualize and work hands-on with data will enhance conceptual understanding (Childers, Chamberlain, Kemp, Meadows, Stalvey, & Vidakovic, 2017). Student-centered instruction is another common form of instruction. This consists of classroom practices such as whole-class discussion, students giving presentations, and group work (Ellis, Fosdick, Rasmussen, 2017). An oral presentation is a classroom practice where students share their ideas verbally, and check their own doubts in order to have a better conceptual understanding of material (Hasan & Hajra, 2017).

A predominant version of student-centered learning is lab-based calculus. This is a calculus class where students attend a lecture course four days of the week and a lab on the fifth day (Vestal, Brandenburger, Furth, 2015). A lab manual is used to provide the appropriate algebra and trigonometry skills that are needed to be successful in introductory calculus. An example of one of the sections in the lab manual is a section on the difference quotient that is covered a few days prior to the learning of derivatives (Vestal, Brandenburger, Furth, 2015). The lab consists of quizzes, a final exam, and worksheets that are completed in groups determined by the students or by major (Vestal, Brandenburger, Furth, 2015).

## Methods

The purpose of this study is to compare the performance between students that are in traditional and non-traditional calculus II courses based on their preparation in either traditional or non-traditional calculus I. Our null hypothesis is that there are no performance differences between the two calculus II classes. This section consists of the following elements in order: design, justification of design, study and sample population, instrumentation, data collection, and data analysis.

## Design

This is a causal-comparative study. This design is beneficial to our study, because causal-comparative design seeks to discover relationships between independent and dependent variables (Gall, Gall, & Borg, 2013). The goal of a causal-comparative study is to determine whether or not the independent variable affected the outcome, or dependent variable (Gall, Gall, & Borg, 2013). One reason that this design is best for this study is the fact that students can't be randomly assigned to classes. Another reason is that we must use existing classrooms.

## Study Population & Sample

Sample population is the particular group of subjects that participate in a study (Gall, Gall, & Borg, 2013). In this case, the sample population is calculus students enrolled in calculus II during the spring semester of 2018. This study was conducted at a rural research university in the southern part of the United States. This university's enrollment is approximately 12,000 students. Of the 12,000 students, approximately 60% are female and 40% are male. Also, approximately 50% of the students are white, with the other 50% being non-white.

Students taking this class are primarily industrial engineering, constructional engineering, electrical engineering, physics, math, and computer science majors. The math majors are both pure math majors and pre-service teachers. The instructors are either tenured or tenured track professors. The non-traditional class has 31 students, whereas the two traditional classes have 30 and 29 students. Both the traditional and non-traditional classes take place five days a week, but they are structured differently. The traditional class consists of instruction on Monday-Thursday, with Friday being used for recitation. The non-traditional class is structured a certain way each week: Monday, Wednesday, and Thursday are used for instruction; Tuesday is lab, and Friday is used for recitation.

## Instrumentation

This study is a quantitative study, thus reliability and validity standards were maintained. This section discusses how the reliability and validity standards were upheld throughout this study.

***Reliability.*** Cronbach Alpha was used to determine the reliability of the instrument. Our goal is to achieve a Cronbach Alpha of at least 0.6, but preferably it will be closer to 0.8 (Gall, Gall, & Borg, 2013). Research involving class tests will have a Cronbach Alpha closer to 0.6, whereas surveys will be closer to 0.8.

***Validity.*** There is a plethora of ways to measure validity. The ones that were used in this study are external validity, internal validity, content validity, and face validity. These various types of validity are discussed below.

The external validity that this study has is ecological validity, because we studied real classrooms. By studying actual classrooms, we were able to preserve the environment where our treatments naturally occur (Gall, Gall, & Borg, 2013).

Internal validity had the potential to be a problem in this study, because there may be confounding variables. A few examples of confounding variables in education are prior knowledge, native language, gender, and first time college students. To combat this, we described the sample at the beginning of the study, thus disclosing any potential issues, and the issues were included in our model if they are significant.

This is extremely important in our quantitative study, because it is based on classroom tests. This study has content validity, because all of the instructors' tests were developed using a test blueprint matrix weighted by classroom time spent on each objective (Thorndike & Thorndike Christ, 2013).To ensure face validity, we will have other university staff members examine our instruments being used.

**Data Collection**

The Honors student collected data for this study at the end of the spring semester of 2018 in traditional and non-traditional calculus II courses. The data collected were: student demographic information, previous calculus I grade, whether or not the student was a repeater or non-repeater, current calculus II class, calculus II test grades, calculus II final exam grades, and calculus II final course grades. The data was collected during the last week of class or after grades are recorded. Demographic data was collected during class, and the rest of the data was collected via emails from the instructors. The data was collected using spreadsheets from the instructor.

**Data Analysis**

In order to analyze the data, students were sorted into four groups: TT, NT, TN, and NN. The TT group consisted of students that took traditional calculus I along with traditional calculus II. The NT group consisted of students that took non-traditional calculus I and traditional calculus II. The TN group consisted of students that took traditional calculus I and non-traditional calculus II. The final group, NN, consisted of students that took both non-traditional calculus I and non-traditional calculus II.

The first statistic that was used is the chi-squared test on the distribution on calculus I grades. The reason for using this test is to observe whether or not all of the classes started on the same level in calculus II.

The next statistic that was used is the Kruskal-Wallis test. The reasoning behind using the Kruskal-Wallis test is that it will be looking for differences between the median scores. We looked at median scores, because our sample population is fairly small. This test was used to compare the groups TT and NT for three tests and a final. Furthermore, it was used to compare the groups TN and NN for four tests and a final. Since there are different numbers of tests and no common items, we cannot do any direct comparisons between classes on classroom tests, but we can compare subgroups within each test.

Finally, a Chi-squared test of the final course grade distributions was conducted to see if the final grade distributions in each class are significantly different from the initial grade distributions in traditional and non-traditional calculus.

## Results

After presenting the analysis of non-traditional calculus II, the results of the traditional calculus II course will be discussed.

### Non-Traditional Calculus II

The first hypothesis was whether or not the Calculus I grades were the same for NN and TN students. This was tested using a Chi-squared test, and with a p-value of .13, the students' grades were not significantly different. This indicates that the students began the semester with approximately the same prior knowledge from Calc I.

Next, a Kruskal-Wallis test was performed on test 1 grades to see if there was a significant difference between the median grades. However, a p-value of .98 indicates that no such difference exists. A Kruskal-Wallis test was then performed on test 2 results, and the resulting p-value of .77 indicates that there is no significant difference in median grades. The same test was used on test 3, and once again, a p-value of .60 indicates that there wasn't a significant difference in median grades. A p-value of .93 on the fourth test indicates that there was not a significant difference in median grades.

Finally, a Chi-squared test was performed on the two groups' final grades in Calc II. A p-value of .78 indicates that both groups finished the semester with approximately the same level of knowledge.

**Traditional Calculus II**

The first hypothesis that was tested among the traditional calculus II students were their calculus I final grades. This was done using a Chi-squared test. A p-value of .29 indicates that both the TT and NT group began traditional calculus II with approximately the same level of prior knowledge.

The next thing tested on the two groups of traditional calculus II students was there performance on the first test of the semester. A Kruskal-Wallis test was used to see if there was a significant difference between the median grades of each group. A p-value of .03 indicates that there was a significant difference between the median grades of each group. A Kruskal-Wallis test was used on test two grades, and a p-value of .03 indicates that once again, there was a significant difference between the median grades of each group. The same test was used on test 3 grades, and a p-value of .01 indicates that there was a significant difference between the median grades of each group, where the TT group had the higher average in all instances.

Finally, a Chi-squared test was used to see if there was a significant difference between each group's final grades in traditional calculus II. A p-value of .17 indicates that each group finished the class with approximately the same level of knowledge.

## Discussion

Our null hypothesis in this study was that there is no relationship between calculus II students that took either traditional or non-traditional Calculus I. The findings of this study suggest that students in a non-traditional calculus II class perform approximately the same after taking either traditional or non-traditional Calculus I. The labs that take place in non-traditional calculus I did not seem to give students an advantage in non-traditional calculus II. Students did not have the labs in traditional calculus I performed approximately the same as students that did have the labs. Every test that was conducted showed no significance in performance between the NN group and TN group.

In traditional calculus II, the results were a little different. On tests one, two, and three, the TT group performed significantly better than the NT group. However, the final grades of each group were not significantly different. This suggests that the NT group may have took some time to get adjusted to the traditional calculus II format after taking non-traditional calculus I, but by the end of the semester, the NT group's performance was not significantly different in comparison with the TT group. This indicates that the NT students improved steadily throughout the semester.

Dawkins & Epperson (2014) discussed concerns that students are learning calculus as simply a series of algorithms without conceptual understanding. Non-traditional teaching methods attempt to combat this by focusing on conceptual understanding. These methods lead to students being more engaged during class time compared to traditional lectures (Wearlander, Cronhjort, & Filipsson, 2017). Perhaps the students that took non-traditional calculus I learned content in a more conceptual way and struggled to adjust to the process of learning calculus II as a series of algorithms.

One limitation of this study was that demographics were not really taken into consideration. Gender, transfer students, and whether or not the students were retaking the class, were not considered. These are all compounding factors that could have an impact on student achievement.

The results of this study can be significant to academic advisors, because it suggests that the type of calculus I class that students take does not matter when it comes to deciding whether or not students take non-traditional calculus II. Students that took non-traditional calculus I followed by non-traditional calculus II and students that took traditional calculus I followed by non-traditional calculus II performed at approximately the same level on each test throughout the semester and in the overall course.

However, academic advisors may want to be cautious when enrolling students in a traditional calculus II course after the students took a non-traditional calculus I course. Overall performance in the traditional calculus II class was approximately the same, but students that took non-traditional calculus I before traditional calculus II didn't perform as well on the first few tests as students that took traditional calculus I and calculus II.

If this study was run again, it should use bigger data with more instructors. Ideally, such classes would have relatively equal numbers of traditional and non-traditional students. Future research could also look at student success in classes that follow calculus II. Calculus II is a prerequisite for every advanced math course, so it would be interesting to look at student success in courses like linear algebra or number theory after taking either traditional or non-traditional calculus II. It would also be interesting to look at the success of engineering students that take engineering courses after either traditional or non-traditional calculus II.

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## References

Bressoud, D., Carlson, M., Mesa, V., & Rasmussen, C. (2013). The calculus student: Insights from the Mathematical Association of America national study. International Journal of Mathematics Education in Science and Technology, 44(5), 685-698.

David, E., Hah Roh, K., Sellers, M., & D'Armours, K.. (2017). The role of visual reasoning in evaluating complex mathematical statements: A comparison of two advanced calculus students. Proceedings of the 20th Annual Conference on Research in Undergraduate Mathematics Education, pp. 536-544.

Dibbs, R. (2014). Differential participation in formative assessment and achievement in introductory calculus. Unpublished doctoral dissertation, University of Northern Colorado.

Dibbs, R., & Patterson, J. (2016). Clearing the way for STEM majors in introductory calculus. Proceedings of the 19th Annual Conference on Research in Undergraduate Mathematics Education. pp. 99-110.

Ellis, J., Fosdick, B. K., & Rasmussen, C. (2016). Women 1.5 times more likely to leave STEM pipeline after calculus compared to men: Lack of mathematical confidence a potential culprit. PloS one, 11(7), e0157447.

Ellis, J., Kelton, M., & Rasmussen, C. (2014). Student perceptions of pedagogy and associated persistence in calculus. ZDM Mathematics Education, 46, 661-673.

Gall, M. D., Gall, J. P., & Borg, W. R. (2013). Applying educational research: How to read, do, and use research to solve problems of practice. Pearson Higher Ed.

Hayward, C., & Laursen, S. (2017). Supporting instructional change in mathematics: The role of online and in-person communities. Proceedings of the 20th Annual Conference on Research in Undergraduate Mathematics Education, pp. 646-654.

Hasan, A., & Hajra, S. (2017). Using oral presentations and cooperative discussions to facilitate learning statistics. Proceedings of the 20th Annual Conference on Research in Undergraduate Mathematics Education. pp. 629-637.

Miller, E. (2017). A new methodological approach for examining mathematical knowledge for teaching at the undergraduate level: Utilizing task unfolding and cognitive demand. Proceedings of the 20th Annual Conference on Research in Undergraduate Mathematics Education. pp. 39-52.

Oehrtman, M. (2008). Layers of abstraction: Theory and design for the instruction of limit concepts. In M. Carlson & C. Rasmussen (Eds.), Making the Connection: Research and teaching in undergraduate mathematics education (pp. 65-80).Washington, DC: MAA.

Pascoe, A., & Stockero, S. (2017). Learning to notice and use student thinking in undergraduate mathematics courses. Proceedings of the 20th Annual Conference on Research in Undergraduate Mathematics Education, pp. 195-208.

Rasmussen, C., Marrongelle, K., & Borba M. (2014). Research on Calculus: What do we know and where do we need to go? ZDM Mathematics Education, 46, 507-515.

Thorndike, R. M., & Thorndike-Christ, T. (2013). Measurement and evaluation in psychology and education. Mahweh, NJ: Prentice Hall.

Treisman, U. (1992). Studying students studying calculus: A look at the lives of minority mathematics students in college. The College Mathematics Journal, 23(5), 362-372.

Voigt, M., Rasmussen, C., & Naneh, A., (2017). Variations in precalculus through Calculus 2 courses. Proceedings of the 20th Annual Conference on Research in Undergraduate Mathematics Education, pp. 1001-1008.