AN ABSTRACT OF THE THESIS OF

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Abstract approved:

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About twenty years ago, a large, rural, doctoral granting institution with an undergraduate population of approximately 24,000 in the pacific northwest of the United States established the Math Excel program. Students would attend lectures three times a week for 50 minutes like a traditional course, and they would also attend two workshops per week that are two hours each, in contrast to traditional courses with a 50 minute recitation once per week. For several years the university would offer a few sections of Math Excel for several 100- and 200-level mathematics courses each term. During the 2013-2014 academic year, the university dedicated all sections of Math Excel to a particular section of calculus and implemented a Math Excel section of a calculus every quarter with the sequence of courses consisting of differential calculus, integral calculus, and vector calculus. A Math Excel version of differential calculus, integral calculus, and vector calculus were offered during fall term, winter term, and spring term respectively. The purpose of this thesis is to investigate how students in the Math Excel calculus courses performed compared to students in traditional calculus courses. First, a logistic regression model will be used

to model the relationship between pass rates and enrollment in a Math Excel calculus course after controlling for predictor variables and a two-sample t-test will be performed to compare pass rates of students in a Math Excel calculus course and a traditional calculus course. Next, a linear regression model will be used to model the relationship between grade points and enrollment in a Math Excel calculus course and a two-sample t-test will be performed to compare grade points of students in a Math Excel calculus course and a traditional calculus course. Finally, a two-sample t-test will be performed to examine if there is a difference in average grade earned for students that took a Math Excel calculus course in the previous term and students that did not. In each of these cases I found that there is not significant evidence that the Math Excel program has a greater effect on student pass rates, grades, or future grades in calculus courses than traditional versions of the calculus courses. Based on these results, I suggest that more data is gathered to see if there is a change in the results, an in depth analysis of students' demographics and activities outside the classroom, and looking at the instructor effect and execution in the classroom in order to understand how and whether the Math Excel program benefits students in different ways.

Quantitative Study of Math Excel Calculus Courses

by
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APPROVED:

Major Professor, representing Mathematics

Chair of the Department of Mathematics

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Christopher Watkins, Author

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Chapter 1: Introduction

Science, technology, engineering, and mathematics (STEM) continue to be major areas of focus in the United States. However, less than 40% of students in the United States that begin college with an interest in STEM actually complete a degree in a STEM field (Freeman et al., 2014). A large factor in a student's success in a STEM field is their experience in first year mathematics courses, which have historically low pass rates. In response, researchers have argued that the "status quo is unacceptable" in first year mathematics courses, such as calculus, that are stepping stones toward a STEM degree (Saxe & Braddy, 2015). Research has found that the most common form of instruction, lecturing, is not the most effective type of instruction and lecturing has been attributed to low success rates in mathematics courses. In contrast, research has shown that students learn better through active, student-centered instruction (Laursen, Hassi, Kogan, & Weston, 2014). In particular for calculus, traits identified in successful calculus programs include building communities of practice, construction of challenging and engaging courses, and using student centered pedagogies and active learning strategies (Bressoud & Rasmussen, 2015).

There has been a call in the United States to incorporate active learning approaches in mathematics instruction. Specifically, in 2016, the Conference Board of the Mathematical Sciences (CBMS) called for investing time and resources into active learning that will be incorporated into post-secondary mathematics courses (CBMS, 2016). One active learning technique that is being used in mathematics courses is the Mathematics Workshop Model (Treisman, 1992). The Mathematics

Workshop Model involves active learning techniques where students take more time during the week to collaborate together to solve problems. The problems that students solve are more difficult than those in a traditional course and instructors challenge students to develop a deeper understanding of the content. Pioneered by Uri Treisman's Emerging Scholars Program, many adaptations can be found around the country (Treisman, 1992).

About twenty years ago a university in the pacific northwest of the United States established the Math Excel program that is based on Treisman's model. Students would attend two workshops per week that are two hours each in addition to the 50 minutes lecture three times a week. Traditional courses would only meet for 50 minutes in a recitation class in addition to the 50 minutes lecture three times a week. For several years the university would offer a few sections of Math Excel for several 100 and 200 level mathematics courses each term. During the 2013-2014 academic year, the university dedicated all of the sections of Math Excel to a particular section of calculus and implemented a Math Excel section of a calculus course every quarter. A section of Math Excel differential calculus, integral calculus, and vector calculus were offered during fall, winter, and spring term respectively.

The purpose of this study is to investigate how students in the Math Excel calculus courses performed compared to students in traditional calculus courses. First, a logistic regression model will be used to model the relationship between pass rates and enrollment in a Math Excel calculus course after controlling for predictor variables and a two-sample t-test will be performed to compare pass rates of students in a Math Excel calculus course and a traditional calculus course. Next, a linear regression model will be used to model the relationship between grade points and enrollment in a Math Excel calculus course and a two-sample t-test will be performed to compare grade points of students in a Math Excel calculus course and a traditional calculus course. Finally, a two-sample t-test will be performed to examine if there is a difference in grade points for students that took a Math Excel calculus course in the previous term and students that did not. After exploring the differences between Math Excel students and traditional students, the hope is to find statistically significant evidence that the Math Excel program has an effect on student performance. After interpreting the analysis, recommendations for future work will be made.

Chapter 2: Literature Review

In this chapter, I introduce the research studies on teaching and learning in calculus that relate to this study. First, I discuss the benefits of inquiry and active learning as a form of teaching as opposed to traditional lecture style teaching. Next, I describe the Mathematics Workshop Model that was developed by Uri Treisman and universities that have implemented a program based on this model. Then, I review the current state of calculus. Finally, I will bring these ideas into the context of my study and introduce my research questions.

2.1 Inquiry and Active Learning

Lecturing has been the most common method of instruction in universities since they were founded in Europe over 900 years ago (as cited in Freeman et al., 2014). Failure rates for students in traditional lecture are 55% higher than students in classes with more active approaches to instruction (Freeman et al., 2014). A considerable amount of university mathematics departments have seen a declining number of mathematics majors and are aware of their need to develop effective and creative curricula as well as effective and innovative instructional practices (Rasmussen & Kwon, 2007). It has been suggested by K-12 mathematics education researchers that the teacher must “proactively and consistently support student’s cognitive activity without reducing the complexity and cognitive demands of the task” (Henningsen & Stein, 1997, p. 546). Students should not be expected to think, reason, and solve mathematical problems in the correct way if they are not engaged in active processes during class (Henningsen & Stein, 1997). A teaching practice that was found to support "high-level student engagement" was teachers' insistence that students provide meaningful explanations (as cited in Henningsen & Stein, 1997).

There are many theories of learning that push for students to develop their own understanding of course material rather than traditional lecturing methods (Freeman et al., 2014). Research in both education and cognitive science have shown evidence that students learn better through active, student-centered instruction in college sciences and mathematics (Laursen, Hassi, Kogan, & Weston, 2014).

In the meta-analysis conducted by Freeman et al. (2014), it was found that active learning increased examination performance by just under a standard deviation, and lecturing increased failure rates by 55% in STEM courses. The increase of achievement in active learning courses was consistent across all STEM disciplines, in all class sizes, course types, and course levels (Freeman et al., 2014). The researchers also found that active learning increased the final grade of students by 0.3 grade points, and if a student was in the 50th percentile of a class with traditional lecturing, they would move up to the 68th percentile of that class with active learning (Freeman et al., 2014). A recent study from the National Center for Educational Statistics found that there are gaps of 0.5 and 0.4 in grade point averages for first year bachelor's and associate's students in STEM courses between those who end up leaving their STEM program and those who stay in their STEM program (as cited in Freeman et al., 2014). This 0.3 grade point increase that Freeman and colleagues associated with active learning would help those that leave STEM achieve a similar level of performance level to those that stay in STEM fields (Freeman et al., 2014).

It is important to note that researchers refer to active learning in many different ways such as Inquiry-Based Learning (IBL), Inquiry Oriented instruction (IOI), and active learning. I will describe each of these more thoroughly as I address the studies that use these terms to describe teaching. All of these descriptions of learning have features that engage students more meaningfully in mathematical activity than lectures do, and all of them have been proven to improve student-learning outcomes when compared to traditional lectures.

Laursen, Hassi, Kogan, and Weston (2014) studied inquiry-based learning in undergraduate mathematics courses at four universities where students construct, analyze, and critique mathematical arguments. In this case, IBL is defined as "a method of instruction that places the student… and their interaction at the center of the learning experience" (AIBL, 2016). In an IBL classroom, students would present solutions to problems then have their peers review the solution and ask questions (AIBL, 2016). If there were problems with the solution that cannot be fixed by the students, the instructor would step in for guidance (AIBL, 2016). In IBL courses, students' own ideas moved the course forward and students worked on solutions in groups or alone with the guidance of instructors (Laursen et al., 2014). Laursen and colleagues found a multitude of positive effects, including: (1) students in IBL mathematics classes had greater learning gains than students in non-IBL mathematics classes on all of the researchers' measures (understanding and thinking, positive attitude about mathematics, and collaborative gains in working with others); (2) collaborative work developed communication skills, and furthered peer interdependence of IBL students while helping each other; (3) the confidence of IBL students increased while the confidence of non-IBL students decreased; (4) IBL benefitted both men and women as "… data suggest that IBL approaches leveled the playing field by offering learning experiences of equal benefit to men and women, while non-IBL courses were more discouraging and less effective for women in particular" (Laursen et al., 2014, p. 412).

In another study of an inquiry-oriented approach in undergraduate differential equations by Rasmussen and Kwon (2007), students reinvented many key mathematical ideas and methods for analyzing the solutions to differential equations, encountered challenging tasks, and looked at three different approaches to solving a differential equation. Students would learn by being given challenging problems, discussing problems with others, and explaining how they solved a problem (Rasmussen & Kwon, 2007). This inquiry learning served two functions, first "to enable students to learn new mathematics through engagement in genuine argumentation" and second "to empower learners to see themselves as capable of reinventing mathematics and to see mathematics as a human activity" (Rasmussen & Kwon, 2007, p. 190).

Rasmussen and Kwon (2007) found that there was not a significant difference between students in inquiry and non-inquiry differential equations classes on routine tests however, the inquiry students scored significantly higher on conceptual problems. In addition, in modeling and qualitative/graphical problems, the students in inquiry-based classrooms did significantly better than students in non-inquiry classrooms (Rasmussen & Kwon, 2007). The results suggest that the inquiry-oriented approach "can help students build the type of conceptual understanding that makes mathematics meaningful to them. It can facilitate students' development of mathematical reasoning ability. It can positively influence their beliefs about knowing and doing mathematics" (Rasmussen & Kwon, 2007, p. 194).

In a similar vein to Rasmussen and Kwon (2007), Inquiry Oriented Instruction (IOI) is a project-based approach (AIBL, 2016) where students develop their own reasoning and instructors help develop the formal way of reasoning mathematically (Johnson, Keene, & Andrews-Larson, 2015). In an IOI classroom, students are given difficult mathematical tasks where they discover mathematical relationships and concepts through their own thought and discussions with their peers (Johnson et al., 2015). Instructors inquire into a students' thinking during mathematical tasks to guide them in using their own thinking to develop new ideas (Johnson et al., 2015).

As we can see from the studies cited above, active learning has been shown to have a positive impact on science, engineering, and mathematics (STEM) students, yet few instructors have yet to incorporate active learning in their classrooms. This change is critical since fewer than 40% of students in the United States who enter a university with an interest in a STEM field finish with a degree in a STEM field (as cited in Freeman et al., 2014), with their degree switching due to the instruction they experience in STEM courses (Seymour & Hewitt, 1997). In addition, recent studies have shown that the work force demand for STEM majors has been increasing from 1971 to 2009, but the number of students pursuing a STEM major in the United States remains constant at about 30% nationwide (Ellis, Kelton, & Rasmussen, 2014). A 2012 President's Council of Advisors on Science and Technology report called for a 33% increase in STEM majors in the United States and an increase in retention rate to

50% would help meet a large portion of that goal (as cited in Freeman et al., 2014). The call for an increase in STEM majors can be answered in part by abandoning traditional lecturing in STEM courses in favor of active learning (Freeman et al., 2014). In 1997 Seymour and Hewitt found that students in the United States who leave STEM degrees often mention traditional lectures that emphasized rote memorization rather than conceptual understanding and applications as one of the major reasons for leaving their STEM major (as cited in Ellis et al., 2014).

Active learning has been found to benefit students in other disciplines as well. For example, at Washington University a computer science 3 course (CS 3), algorithms and data structures, was transformed into an active learning format by three instructors (Sowell, Chen, Buhler, Goldman, Grimm, & Kenneth 2010). Two instructors had positive experiences with the active learning format and found that students were more engaged, interested, and generally got more out of the class when they participated in the discussion (Sowell et al., 2010). In addition, other techniques that were successful included recording traditional lectures, brief quizzes at the beginning of class to encourage student preparation, and exercises with multiple solutions and multiple levels of depth (Sowell et al., 2010). Though there is more work to be done on active learning in computer science, there are benefits to using active learning in computer science.

Despite evidence of the efficacy of active learning, the incorporation of this classroom strategy has been relatively slow. Recently, the Common Vision project was formed as a joint effort of the American Mathematical Association of Two Year Colleges (AMATYC), the American Mathematical Society (AMS), the American

Statistical Association (ASA), the Mathematical Association of America (MAA), and the Society for Industrial and Applied Mathematics (SIAM). This effort focuses on modernizing undergraduate programs in the mathematical sciences (Saxe & Braddy, 2015). The report by Saxe and Braddy (2015) for the Common Vision project "focuses on specific areas that require significant further action from the mathematical science community to improve undergraduate learning, especially in courses typically taken in the first two years" (p. 1). First year and second year mathematics and statistics courses function as gateways to many majors and are crucial for preparing citizens who are mathematically and scientifically literate (Saxe & Braddy, 2015). The authors of the Common Vision project assert "the status quo is unacceptable" in undergraduate mathematics classes, and so they have a goal of effecting changes in undergraduate mathematical classes in order to maintain a viable workforce in the United States (Saxe & Braddy, 2015). The changes will necessitate efforts to "update curricula, scale up the use of evidence-based pedagogical methods, and establish stronger connections with other disciplines" (Saxe & Braddy, 2015, p. 35). There is significant support for reforming undergraduate instruction in mathematical sciences from influential groups such at the White House Office of Science and Technology Policy, the National Academies, and the Association of American Universities (Saxe & Braddy, 2015). All seven of the curricular guides the Common Vision report are aligned in their vision of instruction: "instructors should present key ideas and concepts from a variety of perspectives, employ a broad range of examples and application to motivate and illustrate the material, promote awareness of connections to other subjects, and introduce contemporary topics and their applications" (Saxe & Braddy, 2015, p. 12). The guides also call for moving away from the use of traditional lecture as the sole instructional delivery method in undergraduate mathematics courses and stressed the importance of moving toward environments that incorporate multiple pedagogical approached with oft-cited examples being active learning models (Saxe & Braddy, 2015).

The Conference Board of the Mathematical Sciences (CBMS) recently called upon "institutions of higher education, mathematics departments and the mathematics faculty, public policy-makers, and funding agencies to invest time and resources to ensure that effective active learning is incorporated into post-secondary mathematics classrooms" (CBMS, 2016). When students are in a classroom climate where they are given opportunities to investigate mathematical problems in groups and communicate with teachers and peers about their work it has a positive impact on their learning (CBMS, 2016). Active learning has been shown to improve students' performance, retention, confidence, and mathematical achievement more than traditional instruction in many studies (CBMS, 2016). CBMS posits that students will have more "meaningful mathematical experiences" if active learning is used to expand on the current work to improve mathematics curriculum and pedagogy (CBMS, 2016). Research has shown that many "effective" classroom practices that supplement other aspects of "effective teaching", such as having students make connections of different elements of a course, fall into the category of active learning techniques (CBMS, 2016). CBMS 2016 suggests that "the more that faculty, departments, institutions, and professional societies can provide time, resources, and support for these communities and their processes of improvement, the better we will be able to support the needs and aspirations of our students"(p. 7). An example of this are the many Emerging Scholars Programs across the United States with the goal of these mathematics workshop programs being "to increase students achievement by creating small diverse communities of learners who work on challenging mathematics in visible and collaborative ways" (as cited in CBMS, 2016).

2.2 Mathematics Workshop Model

In the late 1970's, Uri Treisman began a study at the University of California Berkeley that challenged the hypothesis that African-American and Hispanic students' failures in calculus were due to lack of motivation and educational background (Treisman, 1992). At the time, the problem of minority students failing was seen purely as a social justice issue, and with the number of minority students in college being low it did not affect enrollment (Treisman, 1992). Calculus then (and today), was a major roadblock for minority students wanting to enter careers that depend on mathematics (Treisman, 1992). During the 1976-1977 academic year 6.6% of mathematics bachelor's degrees were given to minority students (Grant & Eiden, 1980). More recently in 2012, only 11.6% of mathematics bachelor's degrees were awarded to minority students (Saxe & Braddy, 2015).

In the data collected by Treisman (1992), he found that over a ten year period, 60% of the African-American students who enrolled in first term calculus at Berkeley received a D or F and in no academic year were there two African-American or Hispanic students who earned more than a B- in any calculus course at Berkeley. The result of a survey sent to faculty at Berkeley showed four widely held beliefs about the cause of minority student's failures, which included lack of motivation, inadequate preparation, lack of family support or understanding of higher education, and income (Treisman, 1992). In response to these beliefs about African-American students, Treisman (1992) said, “These students were admitted to one of the premier research universities in the United States, and we presumed that their problem was motivation! Many of the inner-city students were socially isolated throughout high school; they paid a very, very high price to get to Berkeley. These kids were motivated” (p. 365).

Twenty African-American students and twenty Chinese-American students were chosen for the study, with both groups coming from diverse backgrounds (Treisman, 1992). Years of data from Berkeley showed that African-American students’ calculus grades correlated negatively with their SAT scores with many of the best students failing early (Treisman, 1992). The few successes of African-American students were those who had average mathematical ability (Treisman, 1992).

In studying the African-American and Chinese-American students, it was clear that these groups studied mathematics differently from each other (Treisman, 1992). The African-American students would go to class, take notes, go home, and work on the homework, putting in six to eight hours a week studying for the calculus course (Treisman, 1992). The most important observation was that African-American students typically worked alone, with 18 of the 20 students never studying with a classmate (Treisman, 1992). The Chinese-American students worked for about 14 hours a week, 8 to 10 of which were alone, but in contrast to the African-American students they would work together in the evenings (Treisman, 1992). Chinese-

American students would check each others' answers, edit each others' solutions, and knew exactly where they stood in the class (Treisman, 1992). On the other hand, African-American students did not know what other students in the class were doing as they worked by themselves (Treisman, 1992).

Because students were interested in earning a degree in mathematics or science and disliked the idea of remediation, in 1978 Treisman developed a program for students who saw themselves as prepared that would not be considered remedial. Instead, this program emphasized group work and a learning community that focused on a shared interest in mathematics. The program consisted of an intensive workshop course, which served as an add-on to the regular course. It challenged students, while also providing them with an emotionally supportive academic environment with group interaction (Treisman, 1992). The goal was to not only help students excel at calculus but produce mathematicians (Treisman, 1992). The workshop focused on student strengths rather than on the deficiencies, and built a community based on studying mathematics (Treisman, 1992). Critical to the success of the program was building a community around the entire course and managed by faculty rather than a teaching assistant of tutor (Treisman, 1992). The problems that were given were deep thought-inspiring problems rather than quick, procedural applications of formulas that only had one right answer (Treisman, 1992). The program served all ethnicities, with a majority being minority students that included African-Americans and Latino students. Treisman reported that African-American and Latino students felt comfortable participating in this environment.

The results of the program were powerful, with African-American and Latino students not only outperforming their minority peers but also their White and Asian classmates as well (Treisman, 1992). African-American students in the program whose Math SAT scores were in the low 600's performed at the level of White and Asian students whose Math SAT scores were in the mid-700's. Many of these students became physicians, scientists, and engineers (Treisman, 1992). Treisman (1992) said, "We can no longer offer courses that half of our students fail, nor can we lower our standards. The challenge is to reconfigure undergraduate science and mathematics education in ways that will inspire students to make the choices that we have" (p. 372). Many universities around the country are adapting this mathematics workshop model to help their own students to succeed.

For example, the MathExcel calculus program was developed at the University of Kentucky in 1990, and also inspired similar programs for Chemistry, Physics, and Biology (Freeman, 1997). Like the mathematics workshop model developed by Treisman, the MathExcel program included collaborative workshops with challenging problems, dedicated faculty, and a feeling of community (Freeman, 1997). Prior to MathExcel, the students in MathExcel did not have significantly better mathematical ability as seen by their math ACT scores, which were within two points of the traditional class (Freeman, 1997). However, students in the MathExcel program earned one grade point better than traditional students in six out of seven semesters of the program (Freeman, 1997). In addition, twice as many students in the MathExcel program earned A's and B's than the traditional class, the withdrawal and failure rates were comparatively negligible, and exhibited greater retention rates (Freeman, 1997).

This program inspired the Achievement in Mathematics (AIM) algebra program at Lexington Community College, which consisted of a two-hour workshop with collaboration on challenging problems in addition to normal lectures (Freeman, 1997). From fall 1994 to spring 1996, it was discovered that pass rates were 49% versus 31% in intermediate algebra and average grade point of 2.4 versus 1.5 in collaborative sections versus traditional courses (Freeman, 1997). In addition, in college algebra there was an 82% pass rate in AIM courses versus 51% in traditional courses and an average grade point of 2.4 versus 1.5 in traditional courses (Freeman, 1997).

In fall 1986 the Academic Excellence Workshop (AEW) program, based on the workshop model, at California State Polytechnic University, Pomona (Cal Poly) was introduced and focused on calculus but today includes workshops in chemistry, physics and engineering (Bonsangue & Drew, 1995). This program focuses on Native American, African American, and Latino/Latina students with the goal of building a community, academic involvement, and earning a degree in engineering or science and White and Asian American students were not eligible to participate in the program (as cited in Bonsangue & Drew, 1995). Students were enrolled in a traditional calculus lecture section with non-workshop students that met for four hours per week and were responsible for the same homework, classwork, and exams (Bonsangue & Drew, 1995).

In addition to lecture, AEW students met twice a week for two-hour sessions and worked collaboratively on calculus problems with the aid of an upper division minority undergraduate science, math, or engineering (SME) student facilitator

(Bonsangue & Drew, 1995). Students would work alone during the first hour of the workshop then gradually begin discussing problems and comparing solutions (Bonsangue & Drew, 1995). After the first hour Bonsangue and Drew (1995) described the session as “quite lively, with students explaining their solutions and interpretations to one another” (p. 25). Students made the community stronger with other informal social aspects such as sometimes discussing topics that did not have to do with mathematics and bringing in food to eat while they worked (Bonsangue & Drew, 1995). In the workshop the facilitator did not respond to questions with direct answers but rather promoted dialogue to involved students in the mathematical or scientific problem-solving discussions with their peers (Bonsangue & Drew, 1995).

The study of the AEW program used data of calculus students over a five year period (1986-1991), where the students selected into the AEW were not associated with precollege achievement nor was there a statistically significant difference between minority workshop and minority non-workshop students in SAT-math, SAT-verbal, or high school GPA (Bonsangue & Drew, 1995). Minority students in the AEW program achieved 0.6 higher grade points than non-workshop minority students in first and second year calculus (Bonsangue & Drew, 1995). Within three years of entering Cal Poly, only 15% of AEW minority students withdrew from Cal Poly or changed to non-mathematics based majors, compared to 52% of non-workshop minority students (Bonsangue & Drew, 1995). On average, non-workshop minority students required an extra quarter to complete their three quarter calculus sequence with 46% requiring five or more quarters while fewer than 17% of AEW minority students required five or more quarters (Bonsangue & Drew, 1995). Also, 91% of

AEW minority students that were still enrolled in SME programs completed their mathematics requirements while only 58% on non-workshop minority students did (Bonsangue & Drew, 1995).

In comparing AEW students to non-workshop White and Asian American students, Bonsangue and Drew (1995) found that AEW students achieved the same grades as non-workshop White students while achieving slightly (but not significantly) lower grades than non-workshop Asian American students. In addition, after three years, 41% of non-workshop Asian American students and 50% of non-workshop White students withdrew from Cal Poly or changed to a non-mathematics based major versus 15% of AEW students as stated before (Bonsangue & Drew, 1995). Non-minority non-workshop students and AEW students both required an average of 3.7 quarters to complete their three quarter calculus sequence at Cal Poly (Bonsangue & Drew, 1995).

In the study by Bonsangue and Drew (1995), AEW students from 1987-1988 were interviewed with 70% of interviewees reporting that they would not have done as well in their calculus class if they had not been in the AEW program. A majority of AEW students said lasting effects of the workshop were "an early awareness of the academic expectations in technical courses, and a recognition of the need to remain connected to their students, peers, professors, and academic advisers throughout their college careers" (Bonsangue & Drew, 1995, p. 30). The AEW students associated their successful transition to college level mathematics with their experience in AEW and half the students interviewed said that they have consistently formed study groups for their upper division courses (Bonsangue & Drew, 1995).

As another example of a university changing the calculus course based on Treisman's (1992) finding, during the 1998-1999 academic year the mathematics department at Oregon State University (OSU) started the Math Excel Program that was a collaborative workshop aiming to help students achieve higher grades in college algebra, pre-calculus, differential calculus, and integral calculus (Duncan & Dick, 2000). The program was based on the Math Excel program at the University of Kentucky and consisted of three 50-minute lectures per week, a 50-80 minute recitation, and an additional workshop that met once or twice a week throughout the term (Duncan & Dick, 2000). In the first year of the Math Excel program, the college algebra and pre-calculus workshops met once a week for 2 hours and in the second year of the program these workshops were 80 minutes twice a week (Duncan & Dick, 2000). Both the differential calculus and integral calculus workshops met for 2 hours twice a week each year of the program (Duncan & Dick, 2000). The Math Excel workshops were led by a graduate student, who met weekly with faculty coordinators, and one or two undergraduate student assistants who were mathematics majors or had been previous participants of the Math Excel program (Duncan & Dick, 2000). The Math Excel program was like a problem-solving workshop where students would work together on designed worksheets of problems (Duncan & Dick, 2000). The worksheets included more challenging problems than normal homework or examination questions, and often included examples of applications or extensions (Duncan & Dick, 2000).

Students were not specially selected for participation in the Math Excel program. Enrollment in the program was open to all students, and recruitment efforts included special presentations made during registration periods, either in prerequisite classes during the academic year or during new student summer orientation (Duncan & Dick, 2000). While the program was made available to all students, special efforts were made to recruit minority students (Duncan & Dick, 2000). The program was not advertised as either a remedial program aimed to help underprepared students nor as an honors program appropriate for only elite students (Duncan & Dick, 2000).

Participation in the Math Excel program at OSU contributed to significant improvements in student success, with students scoring 0.671 grade points higher on average than the students that were not in the program. Since students self selected participation in the program, it could be hypothesized that more capable students might have been attracted to it, accounting for the positive difference in performance. However, differential positive results remained after adjusting for the students' SAT Math scores (Duncan & Dick, 2000). A 95% confidence interval for the grade predicted by the SAT Math score was calculated for each term and it was discovered that Math Excel students had a higher actual mean grade than the predicted mean grade for all college algebra and integral calculus courses while all but one pre-calculus class and one differential calculus course showed a higher predicted mean grade (Duncan & Dick, 2000).

The 19 sections of Math Excel almost always showed a positive difference between actual and predicted grades and grades showed a statistically significant positive effect due to the Math Excel program (Duncan & Dick, 2000). Survey responses showed that over 90% of students in Math Excel felt that they would not have earned as high of a grade in their mathematics course without the Math Excel program and viewed cooperative groups as a highly effective way of learning mathematics (Duncan & Dick, 2000). Nearly half the students in Math Excel spent less time studying mathematics outside of class, and found the structured collaboration with peers to be extremely valuable and an effective replacement for time normally spend studying alone (Duncan & Dick, 2000).

Hake, Crow, & Dick (2003) looked at nontraditional college students' persistence in mathematics at OSU in connection to the Math Excel program. Educational Opportunities Program (EOP) at OSU provides academic and admission support for nontraditional students, including students of color, to assist them in entering and navigating the educational system and in 2000 the Math Excel program became an integral part of the mathematics instructional support strategy for EOP (Hake, Crow, & Dick, 2003). Based on past research and their own findings, Hake and colleagues (2003) suggested that the use of collaborative learning is the most effective method for improving the rates of participation and retention of students in mathematics classes, which is used in the Math Excel program.

In 2002, the OSU Department of Mathematics and EOP piloted structural changes in College Algebra and similar changes for Pre-Calculus with the hope that more minority students would continue onto the next mathematics course and also that students would see that a learning community is vital for success in the course (Hake et al., 2003). The changes to the courses included a designation of a special section of College Algebra that required concurrent enrollment in Math Excel and direct involvement of the instructor for lectures and Math Excel workshops (Hake et al., 2003). The structural changes to Math Excel for College Algebra and Pre-

Calculus made a positive difference in both participation and persistence (Hake et al., 2003). The instructor found that over time the culture of collaborative work in Math Excel workshops carried over outside the classroom, students enjoyed the more challenging problems, students appeared to build their personal math confidence over time, and felt that instructors trusted their ability so students came to trust themselves (Hake et al., 2003). Based on the positive effects on the college algebra course, Hake and colleagues (2003) suggested that similar changes be made to calculus courses.

In 2009, the University of Texas at Arlington (UTA) was awarded an NSF STEP grant for the Arlington Undergraduate Research-based Achievement for STEM (AURAS), which was a combined effort of the College of Science and College of Engineering at UTA to increase retention of STEM majors (Peterson, Epperson, Lopez, Schug, & Tiernan, 2013). The Emerging Scholars Program (ESP) model was used to develop pre-calculus, calculus 1, calculus 2, general chemistry 1, and chemistry for engineers courses offered to freshman beginning in Fall 2010 (Peterson et al., 2013). The AURAS courses at UTA focused on ways to help students master course material by providing challenging content and providing help while fostering a sense of community and engagement for those involved (Peterson et al., 2013). In addition to regular lecture and labs associated with a course students would have to attend a seminar/workshops of varying length depending on the course (Peterson et al., 2013).

There were many significant improvements in the AURAS study, including: (1) improvement in pass rates and decrease in drop rates; (2) 89.1% of ESP students completed the courses versus only 73.8% of non-ESP students; (3) in each course, ESP students received higher grades than the non-ESP students with 80% of ESP students earning an A, B or C while 65.9% of non-ESP students earned those grades; (4) no ESP student failed any mathematics course and ESP students had a higher GPA in all courses; (5) the difference in grades between the groups was statistically significant for the Math 1323 and Chemistry 1441 courses; and (6) regarding calculus ESP students' versus non-ESP students' conceptual understanding of continuity and derivatives, and it was found that there is a statistically significant result in favor of ESP students (Peterson et al., 2013).

2.3 Current State of Calculus

Twenty five years after the publication of Treisman's (1992) results, the state of calculus remains the same on many levels. Calculus continues to play an important role for STEM students as it is a "gatekeeper" to STEM degrees with at least one calculus course required for most STEM majors. Many students cannot get through calculus courses and see calculus as an obstacle to pursuing degrees that require mathematical skills (Bressoud, Mesa, & Rasmussen, 2015). Recent studies focus on gender differences, finding that women are almost twice as likely as men not to continue beyond Calculus 1 even if their major requires it (Saxe & Braddy, 2015). In the study by Ellis, Fosdick, & Rasmussen (2016) it was shown that Calculus 1 is a critical "leak" in the STEM system, especially for women. Introductory level mathematics courses, like Calculus 1, have been associated with a students' choice to leave a STEM major (Ellis et al., 2016). Calculus is not the only challenge that students in a STEM major must face but is one of the most difficult challenges one must go through in pursuing a career in STEM (Ellis et al., 2016). Student's confidence and enjoyment of mathematics all decreased after taking a Calculus 1 course with fewer students making the choice to take more mathematics courses (Bressoud et al., 2015).

Undergraduate calculus courses have attracted national interest with the National Science Foundation spending millions of dollars on programs to strengthen calculus courses since the release of the David Report on the state of undergraduate and graduate mathematics in the United States (Bonsangue & Drew, 1995). More recently, a joint statement from MAA and NCTM in 2012 on calculus "asked faculty to redesign college calculus curricula in response to the ubiquity of calculus in secondary schools" (Saxe & Braddy, 2015, p. 29). Bressoud, Mesa, and Rasmussen (2015) completed a five-year nationwide study of college level Calculus that established a base of knowledge of who takes Calculus 1, why they take Calculus 1, what their preparation was, what they experience in the classroom, and what effect does the course have on their confidence and enjoyment of mathematics. Major recommendations of this study include coordination of instruction, including the building of communities of practice, use of student-centered pedagogies, use of active learning strategies, and construction of challenging and engaging courses.

In the study by Bressoud, Mesa, and Rasmussen (2015) some instructors of Calculus 1 courses used "ambitious teaching practices" - teaching practices that move away from traditional lectures to incorporate active learning experiences and support the educational goals of promoting deep conceptual knowledge and active student engagement in mathematics. Some examples of ambitious teaching practices include small group collaboration, pressing students to explain their thinking on mathematics problems, engaging students to solve challenging problems, and conducting class discussions. These ambitious teaching practices have had critical benefits for student's conceptual understanding without hampering their procedural understanding (Bressoud et al., 2015). In addition ambitious teaching practices were associated with lower switching rates in particular when there was high levels of good teaching and ambitious teaching only 7% of students switched (Bressoud et al., 2015).

In a study by Ellis, Kelton, & Rasmussen (2014) it was shown that the increased odds of switching out of calclus were associated with students reporting that the instructor infrequently showed students how to work specific problems, prepared extra material to help students understand calculus concepts of procedures, held whole class discussions, and required students to explain their thinking on exams. In non-STEM intending students in particular, explaining thinking during class was significantly related to the end of term calculus persistance in which the student would continue to calculus 2 (Ellis et al., 2014). An implication of the study by Ellis, Kelton, & Rasmussen (2014) was that instructors should be more uniform in engaging students during class discussions.

Successful traits of successful calculus programs include building communities of practice, construction of challenging and engaging courses and the use of student centered pedagogies and active learning strategies (Bressoud & Rasmussen, 2015). It was found that universities and colleges that had a successful calculus program had instructors that were in regular coordination with other instructors (Bressoud & Rasmussen, 2015). In regards to students success in college Kuh said, "Challenging intellectual and creative work is central to student learning and collegiate quality" (as cited in Bressoud & Rasmussen, 2015, p. 145) which was also found to be the case in calculus courses. In talking about an effective educational practice Suh said, "Students learn more when they are intensely involved in their education and have opportunities to think about and apply what they are leaning in different settings" (as cited in Bressoud & Rasmussen, 2015, p. 145). In calculus classes active learning strategies forced students to engage mathematical ideas and when class sizes made active learning difficult, recitation courses strongly encouraged and supported it (Bressoud & Rasmussen, 2015).

2.4 The Context of the Study

About twenty years ago the Math Excel program was established at a University in the Pacific Northwest (UPNW) for mathematics courses including differential calculus, integral calculus, and vector calculus. This Math Excel program is based on Uri Treisman's workshop model and is intended to give any student an opportunity to get a better understanding of course material and gain confidence in mathematics through active learning. Students in an Excel differential calculus (EDC), integral calculus (EIC), or vector calculus (EVC) class attend a normal lectures three times a week for 50 minutes but are also required to attend two workshops per week, with each workshop being 2 hours versus a normal recitation once a week for 80 minutes. The lecture section has approximately 100 Math Excel students separate from normal sections, but consists of similar homework and tests. The workshop section consists of about 25 students each.

Students work together in small group to solve challenging mathematics problems and are expected to actively discuss, share ideas, and support each other.

Students ask each other questions, explain concepts, and discuss their strategies for solving a problem. The focus of the program is students helping other students to learn mathematics with the idea that we learn best when we teach others. The workshops are taught by a seasoned instructor, who guides students and provide clues but does not tell students how to solve the problem. Overall, students take responsibility for their own learning and helping their peers.

Three years ago the structure of the Math Excel program was changed to support a specific section of calculus each term. During the 2013-2014 academic year the calculus sequence EDC, EIC, and EVC was implemented on a yearly basis. A section of EDC is available in the fall quarter, a section of EIC is offered in the winter quarter, and a section of EVC is offered in the spring quarter. These courses are designed to address the major needs of first year calculus courses which are building of communities of practice, use of student-centered pedagogies, use of active learning strategies, and construction of challenging and engaging courses.

2.5 Purpose of the Study

The purpose of this thesis is to determine how the Math Excel calculus courses affect student success in the Math Excel courses and other mathematics courses they take in the future. Based on the research addressed above and the context of the study my research questions are:

RQ1: Are pass rates higher in Math Excel courses versus traditional versions of the class?

RQ2: Are grades higher in Math Excel courses versus traditional versions of the class?

> RQ3: Do students that take the Math Excel course do better in the next traditional mathematics course than students that took a traditional section?

In the next chapter, I will describe the data and the statistical methods I used to answer these research questions.

Chapter 3: Data and Methods

In this chapter I will describe the data that was obtained from UPNW's database, which included information collected on students. While discussing each research question, I will describe the statistical methods used and the rationale behind them. I will also describe how and why data was manipulated in order to proceed with the analysis.

3.1 Data

Data was obtained from UPNW's database and included students in traditional and Math Excel versions of differential calculus, integral calculus, and vector calculus courses from fall 2010 through spring 2016. These courses are labeled in the following ways:

- Excel Differential Calculus (EDC) and Traditional Differential Calculus (TDC)
- Excel Integral Calculus (EIC) and Traditional Integral Calculus (TIC)
- Excel Vector Calculus (EVC) and Traditional Vector Calculus (TVC)

There were separate data sets for the three calculus courses- differential calculus (DC), integral calculus (IC), and vector calculus (VC). These courses are generally taken as a three-course sequence. The information that was gathered on each student included:

- Academic period taking the course (term and year)
- Course (Differential, Integral or Vector Calculus)
- Section
- De-identified student ID number

- The college students were enrolled in
- Students' major
- De-identified instructor ID
- Students' final grade and the grade point earned
- Math Excel or traditional version of the course.

Students were assigned a value of Y if the student was in the Math Excel version of the course while N was given to a student that was in the traditional version of the course. The sample sizes for TDC, TIC, and TVC were 11526, 8806, and 7745 respectively. The sample sizes for EDC, EIC, and EVC were 149, 152, and 134 respectively. An example of the data that was obtained in this study is found in the table below.

Table 1: Data Example

Academic Period	**Term**	**Year**
201101	Fall	2010
201101	Fall	2010
201101	Fall	2010
Course	**Section**	**Math Excel**
MTH251	10	N
MTH251	10	N
MTH251	10	N
ID	**Student College**	**Major**
12148864777	04 - Pre-Engineering Program	030 - Pre-Elect & Computer Engineer
12148979647	04 - Pre-Engineering Program	351 - Pre-Mechanical Engineering
12148816491	04 - Pre-Engineering Program	333 - Pre-Chemical Engineering
Instructor	**Final Grade**	**Grade point**
643	C	2
643	C	2
643	D	1

The data also included sections of the courses that were for international students only. These students were removed from the data sets since classes for those students are run differently from a traditional section or Math Excel section. Final grades ranged from A, A-, B+, B, B-, C+, C, C-, D+, D, D-, F, S, U, W, and Aud where S, U, W, and Aud were Satisfactory, Unsatisfactory, Withdraw, and Audit, respectively. Students that audited the course were removed from the data sets since their success in the course could not be measured. Finally, a pass column was added with a value of T given to students who passed the course while a value F was given to students who did not pass the course where T and F were Boolean values of True and False respectively. Passing grades included A, A-, B+, B, B-, C+, C, C-, and S. Although different majors have different requirements, grades of C- and above were chosen as passing grades because at lease a C- is required to continue to the next course. The data sets were imported into the statistical software program R, where the data analysis was conducted. Each data set that was used in the analysis of the following research questions had between 57 and 11,675 students. Several t-tests were used to answer my research questions and all were Welch two sample t-tests (Welch, 1947).

3.2 Analysis for Research Question 1

Research Question 1: Are pass rates higher in Math Excel courses versus traditional versions of the class?

To answer this question, two logistic regression models were made and a t-test was used for each type of calculus course. A logistic regression model was chosen in the analysis of this question because it is a standard choice for modeling binary outcomes (pass or not pass) to assess first-order effects of the included predictor variables. Reasonably large sample sizes allow for valid inferences for these first order trends. The data sets that were used for the logistic regression models were the three data sets noted above. For the t-test, each calculus course was separated into two separate data sets with one containing students in the Math Excel version of the course and the other containing students in the traditional version of the course. For example, for DC there was a data set for EDC and TDC. Based on the research question stated above, I tested the hypotheses below:

- Null Hypothesis 1: After controlling for student's major college and instructor, there is no difference between pass rates of students in a Math Excel course and students in a traditional course.
- Alternative Hypothesis 1: After controlling for student's major college and instructor, there is a difference between pass rates of students in a Math Excel course and students in a traditional course.

The first logistic model had passing the course as the response variable and enrollment in the Math Excel version of the course, students' major college, and instructor as predictor variables. For the students' major college, a substring of just the numerical value corresponding to the major college was used in the model. The enrollment in Math Excel was the variable of interest in this model. The model used to answer this research question is given by the following equation

$$\ln\left(\frac{p}{1-p}\middle|\, \text{Excel, Major College, Instructor}\right) = \mu_0 + \alpha_E + \gamma_{MC} + \delta_I \quad \text{(eq. 1)}$$

Table 2: Coefficients of Eq. 1

Coefficient	**Description**
μ_0	Intercept term, which contains the baseline group.
α_E	Excel coefficient
γ_{MC}	Major college coefficient that is different depending on a student's major college.
δ_I	Instructor coefficient that is different depending on a student's instructor.

The second logistic model had the same response variable but the instructor was removed from the predictor variables. This was done to see how the results would change and because of the possibility of an instructor only teaching the course once. The model is the same as eq.1 without the instructor variable, and the coefficients have the same description as table 2 without δ_I. The interpretation of this model would be the log odds of a student passing the course based on the coefficient values. An example of R code used can be found below.

Figure 1: Logistic Regression Model R code

```
glm(formula = Math251W0$Pass ~ as.factor(Math251W0$Excel) +
as.factor(substr(Math251W0$STUDENT_COLLEGE_DESC,
   1, 2)) + as.factor(Math251W0$PRIMARY_INSTRUCTOR_LAST_NAME),
   family = binomial())
```

The t-test compared pass rates in Math Excel versions of a course to pass rate in the regular versions of the course where R turns the Boolean T, F into 1, 0 values respectively. The t-test was a two-sided and unpaired test. A two-sided test was chosen based on the alternative hypothesis being a two-sided question. An unpaired test was chosen because there was no natural pairing used and the numbers of students in each group were unequal. The output of the test in R included the t-value, degrees of freedom (df), p-value, 95% confidence interval, and the sample means. An example of R code used can be found below.

Figure 2: Pass Rate t-test R Code

```
t.test(Excel251$Pass,Reg251$Pass,paired = FALSE, conf.level =0.95 )
```

3.3 Analysis for Research Question 2

Research Question 2: Are grades higher in Math Excel courses versus traditional versions of the class?

To answer this question two linear models were developed and a t-test was used for each type of calculus course. Linear models for GPA were used to assess the first order effects of class-type, after accounting for major college and instructor. Similar to the logistic models, reasonably large sample sizes ensure approximately valid inference for these effects. For the linear model the data sets discussed in 3.1 were used but students receiving a grade of S were removed. The reason why students receiving an S were removed was because there is no quantitative data from that grade, as a grade point could not be given to a student that received an S. For the t-test each calculus course was separated into two separate data sets with one containing students in the Math Excel version of the course and the other containing students in the traditional version of the course like in the previous section. In order to answer this research question I tested the following hypotheses:

- Null Hypothesis 2: There is no difference between grades of students in a Math Excel course and students in a traditional course.
- Alternative Hypothesis 2: There is a difference between grades of students in a Math Excel course and students in a traditional course.

The first linear model had grade point as the response variable and enrollment in the Math Excel version of the course, students' major college, and instructor as predictor variables. For the students' major college a substring of just the numerical value corresponding to the major college was used in the model. The enrollment in Math Excel was the variable of interest in this model. The model used to answer this research question is given by the following equation with the coefficients having the same description as table 2.

$$y = \mu_0 + \alpha_E + \gamma_{MC} + \delta_I \qquad \text{(eq. 2)}$$

The second linear model had the same response variable but the instructor was removed from the predictor variables for the same reasons as stated in section 3.2. The model is the same as eq. 2 without the instructor variable, and the coefficients have the same description as table 2 without δ_I. An example of R code used can be found below. The interpretation of this model would be the predicted GPA (y), based on the coefficient values.

Figure 3: Linear Regression Model R Code

```
lm(formula = Math251W0$GRADE_POINT~ as.factor(Math251W0$Excel) +
as.factor(substr(Math251W0$STUDENT_COLLEGE_DESC,
   1, 2)) + as.factor(Math251W0$PRIMARY_INSTRUCTOR_LAST_NAME))
```

The t-test compared grade points in Math Excel versions of a course to grade points in the traditional versions of the course. The t-test was a two-sided and unpaired test for the same reasons stated in section 3.2. The output of the test in R included the t-value, degrees of freedom (df), p-value, 95% confidence interval, and the sample means. An example of R code used can be found below.

Figure 4: Grade Points t-test R Code

```
t.test(Excel.2$GRADE_POINT,Reg.2$GRADE_POINT,paired = FALSE, conf.level
=0.95 )
```

3.4 Analysis for Research Question 3

Research Questions 3: Do students that take the Math Excel course do better in the next traditional mathematics course than students that took a traditional section?

To answer this question, I had to track students across courses. I used the match function in R using students' de-identified ID numbers to extract students that moved from a Math Excel course to the next traditional course in the sequence. In particular, I first selected students in EDC that went on to take TIC or a student in EIC that went on to take TVC. Then, the students that were in EDC were removed from the TIC data set and students that were in EIC were removed from the TVC data set. Also, when the data was collected from UPNW's database, there were students whose ID numbers were 0. These students were removed from the data sets as it would be impossible to track them through their ID numbers. Students in courses with fewer than eight students had an ID number of 0. Then two t-tests were used for the analysis. I tested the following hypotheses:

- Null Hypothesis 3: There is no difference between pass rates of students in a traditional mathematics course who took a Math Excel course for the previous course in the sequence and students who did not.
- Alternative Hypothesis 3: There is a difference between pass rates of students in a traditional mathematics course who took a Math Excel course for the previous course in the sequence and students who did not.

- Null Hypothesis 4: There is no difference between grades of students in a traditional mathematics course who took a Math Excel course for the previous course in the sequence and students who did not.
- Alternative Hypothesis 4: There is a difference between grades of students in a traditional mathematics course who took a Math Excel course for the previous course in the sequence and students who did not.

The first t-test compared pass rates for students in a traditional mathematics course who took a Math Excel course for the previous course in the sequence and students who did not. The t-test was a two-sided and unpaired test. The output of the test in R included the t-value, degrees of freedom (df), p-value, 95% confidence interval, and the sample means. An example of R code used can be found below.

Figure 5: Math Excel to Traditional Pass Rates t-test R Code

```
t.test(E251toR252$Pass,Reg252NE251$Pass,paired = FALSE, conf.level =0.95)
```

The second t-test compared grades for students in a traditional mathematics course who took a Math Excel course for the previous course in the sequence and students who did not. The t-test was a two-sided and unpaired test. The output of the test in R included the t value, degrees of freedom (df), p-value, 95% confidence interval, and the sample means. An example of R code used can be found below.

Figure 6: Math Excel to Traditional Grade Points t-test R Code

```
t.test(E251toR252$GRADE_POINT,Reg252NE251$GRADE_POINT,paired =
FALSE, conf.level =0.95 )
```

In the next chapter I will present the result from these analyses and interpretations of the results.

Chapter 4: Results

In this chapter I will present the results of the statistical analysis that was used for my research questions.

4.1 Research Question 1 Results

Research Question 1: Are pass rates higher in Math Excel courses versus traditional versions of the class?

None of the logistic models showed a statistically significant effect of the Math Excel course on pass rates. All of the p-values for testing the null hypothesis that the coefficient for the Math Excel predictor variable is zero were very high. The p-value for IC without the instructor predictor variable was lower but was still not statistically significant. The p-values for testing the null hypothesis that the coefficient for the Math Excel predictor variable is zero can be found below. For all models with the instructor predictor variable there were several instructors that had a significant p-value. However, nothing can be concluded from this because there is not enough data known about instructors. There were several instructors who taught very few sections of these classes, so we have very little precision in estimating the instructor effect. For example, an instructor that taught one class with high pass rates may have a significant p-value, but there is not enough data to make a conclusion about the effect of the instructor. In addition there were significant p-values for major college 24, College of Earth, Ocean, and Atmospheric Sciences, in both models for IC. Also major college 23, Public Health and Human Science, had a significant p-value for VC with instructor as one of the predictor variables. This means that based on the results of the models, those majors may have an effect on pass rates. Although this was an interesting result, similar to instructors several major colleges had few students taking calculus courses so we have little precision on estimating the effect of a student's major college.

Table 3: Logistic Regression Model Results

Class	**Instructor Predictor Variable Included in Model**	**Estimated Value**	**p-value for Math Excel Effect**
Differential Calculus	Yes	0.005926	0.979435
Differential Calculus	No	-1.033e-02	0.952
Integral Calculus	Yes	0.10491	0.690242
Integral Calculus	No	-0.22258	0.19670
Vector Calculus	Yes	0.15335	0.619009
Vector Calculus	No	-0.11474	0.55707

Based on the results of the t-test, we fail to reject the null hypothesis that after controlling for students' major college and instructor there is no difference between pass rates of students in a Math Excel course and students in a traditional course for all courses. The p-values were very high for all courses and can be found in the table below. The value of 0, indicating no difference, is in the 95% confidence interval for each course. An interesting result is that the estimates are all in the wrong direction when the instructors are not in the model. This means that without controlling for instructor Math Excel lowers the logs odd of passing the course. A deeper look into the instructor variable would be needed to make any conclusions about this observation.

Table 4: Welch Two Sample t-test for Pass Rates Results

Class	**95% Confidence Interval**	**p-value**
Differential Calculus	[-0.07558804, 0.08154843]	0.9404
Integral Calculus	[-0.12037691, 0.03405645]	0.2713
Vector Calculus	[-0.09610111, 0.05846556]	0.6309

4.2 Research Question 2 Results

Research Question 2: Are grades higher in Math Excel courses versus traditional versions of the class?

None of the linear models showed a statistically significant effect between grade points and taking a Math Excel course. The resulting p-values were all high and similar to the results of the logistic regression model in 4.1. In addition, many instructors had significant p-values but nothing can be concluded as noted in the previous section. Also, the same major colleges had significant p-values, but just like with instructors, nothing can be concluded as noted in the previous section.

Table 5: Linear Regression Model Results

Class	**Instructor Predictor Variable Included in Model**	**Estimated Value**	**p-value for Math Excel Effect**
Differential Calculus	Yes	-0.0203811	0.911085
Differential Calculus	No	2.944e-02	0.7967
Integral Calculus	Yes	0.111196	0.532247
Integral Calculus	No	-0.10098	0.37714
Vector Calculus	Yes	0.1301322	0.417054
Vector Calculus	No	-0.1407	0.218449

Based on the results of the t-test we fail to reject the null hypothesis that there is no difference between grades of students in a Math Excel course and students in a traditional course. The p-values were high, with VC being lower but still not significant. The value of 0, indicating no difference, is in the 95% confidence interval for all courses. Similar to the logistic regression model, without the instructor the estimates are in the wrong direction for IC and VC however, DC has estimates that are in the wrong direction with the instructor variable. This means that without controlling for instructor, grades, on average, would go down in those Math Excel courses. A deeper look into the instructor variable would be needed to make any conclusions about this observation.

Table 6: Welch Two Sample t-test for GPA Results

Class	**95% Confidence Interval**	**p-value**
Differential Calculus	[-0.1750397, 0.3062768]	0.5908
Integral Calculus	[-0.3248731, 0.1354838]	0.4177
Vector Calculus	[-0.34776072, 0.06666587]	0.1821

Upon further investigation into the class grade point averages (GPA), EDC students had a higher GPA than TDC students. However, EIC and EVC students had lower GPAs than TIC and TVC students respectively. The GPAs can be found in the table below.

Table 7: GPA of Students in Math Excel and Traditional Courses

Class	**Math Excel GPA**	**Traditional GPA**
Differential Calculus	1.98	1.92
Integral Calculus	2.06	2.15
Vector Calculus	2.14	2.28

4.3 Research Question 3 Results

Research Question 3: Do students that take the Math Excel course do better in the next traditional mathematics course than students that took a traditional section?

Based on the results of the t-test we fail to reject the null hypothesis that there is no difference between pass rates of students in a traditional mathematics course who took a Math Excel course for the previous course in the sequence and students who did not. The p-values can be found in the table below. The value of 0, indicating no difference, is in the 95% confidence interval.

Table 8: Welch Two Sample t-test for Math Excel to Traditional Pass Rates Results

Class	95% Confidence Interval	p-value
Integral Calculus	[-0.03503007, 0.15310110]	0.2155
Vector Calculus	[-0.14423789, 0.09709034]	0.6971

Based on the results of the t-test we fail to reject the null hypothesis that there is no difference between grades of students in a traditional mathematics course who took a Math Excel course for the previous course in the sequence and students who did not. The p-values can be found in the table below. The value of 0, indicating no difference, is in the 95% confidence interval.

Table 9: Welch Two Sample t-test for Math Excel to Traditional GPA Results

Class	95% Confidence Interval	p-value
Integral Calculus	[-0.1793274, 0.3665346]	0.4972
Vector Calculus	[-0.57364438, 0.08438746]	0.142

When looking at GPAs students that went from EDC to TIC had a higher GPA than students that went from TDC to TIC. However, students that went from EIC to TVC had lower GPAs than students that went from TIC to TVC.

Table 10: GPA of students moving from Math Excel to Traditional and Traditional to Traditional Courses

Class	Math Excel to Traditional GPA	Traditional to Traditional GPA
Integral Calculus	2.24	2.14
Vector Calculus	2.04	2.28

In the next chapter I will summarize these results, connect them to the research literature and point to future research.

Chapter 5: Conclusion

In this chapter I will state my conclusion based on the results found in chapter 4 and suggestions for future research.

5.1 Conclusion

The results from chapter 4 showed that there is not significant evidence that the Math Excel program at UPNW has a greater effect on student pass rates, grades, or future grades in calculus courses than traditional versions of the calculus courses. However, because of how recent this program was implemented consistently there was a limited amount of Math Excel calculus course data. Although the number of students was high, the number of Math Excel courses was limited to two per course. With this in mind it is possible that more data would yield a better result. Also, this study was in-between a purely observational study and randomized experiment which means confounding variables exist.

The results of this study are surprising when compared with previous studies. At the University of Kentucky a study of their MathExcel calculus program found that students in the MathExcel program earned one grade point better than traditional students in six of seven semesters and that failure rates were comparatively negligible (Freeman, 1997). At Oregon State University a student participating in the Math Excel program scored 0.671 grade points higher on average than students in a traditional mathematics course including calculus (Duncan & Dick, 2000). More recently at the University of Texas at Arlington, students that were in the AURAS program for pre-calculus, calculus 1, calculus 2 had a higher GPA than students in traditional courses and there was a statistically significant difference in grades for their Math 1323 (Pre-Calculus) course (Peterson et al., 2013). However, the study by Rasmussen and Kwon (2007) was similar to the results of this study. They found that there was not a significant difference on routine tests between students in inquiry and non-inquiry differential calculus. They looked deeper to find that students did better on conceptual problems but this study did not look deeper qualitatively.

One feature that is different from UPNW and other universities is that certain groups were targeted at other universities while anyone could take the course at UPNW. For example, at the University of Kentucky "MathExcel students are also volunteers who have responded to an aggressive recruitment program that reaches all Kentucky high schools and entails a personal interview with the Director" (Freeman, 1997, p. 4). Another example is at California State Polytechnic University, Pomona where their Academic Excellence Workshop "targets Native American, African American, and Latino/Latina students… with the ultimate goal of persistence and completion of an engineering or science degree" (Bonsangue & Drew, 1995, p. 24). Although students' previous mathematics knowledge was not significantly different in these studies, there could be an intrinsic difference between the students targeted and those that were not. A student may have seen the program as an additional burden in their course load than a beneficial opportunity. UPNW's Math Excel program being open to all students could be a reason for the results that were found in this study.

Another possible reason for these results could be the execution of the Math Excel program. Several instructors were found to have a significant effect on student pass rates and grades in the logistic regression model and linear regression model respectively as seen in chapter 4. A difference between some of the previous studies is that there were no dedicated faculty like the MathExcel program at the University of Kentucky (Freeman, 1997). This could lead to a significant instructor effect that has a larger effect than the Math Excel program but that cannot be concluded from this study alone.

Other possible reasons for these results could be factors that are out of our control. For example, students in the Math Excel program spend more time in the classroom and may not use outside resources like tutoring as much as those in traditional courses. Also, the demographic of students at UPNW could be significantly different than those at other universities. For example, students that attend a university in California may be significantly different than students at UPNW and may be better suited for a mathematics workshop model type course. Also, STEM degree programs might have different course loads at different universities.

These explanations are speculative due to the limitation of this study but inspire further research.

5.2 Future Research

As more data comes in, a similar analysis can be done to see if the results change. With more data the models are more robust and we can say more about the results. In addition, a similar study could be done with more demographic data from students and explore different factors for the models. Since the difference between a Math Excel course and a traditional course are the workshops, a model could be developed with a teaching assistant effect but the same issue with instructors in this study could be a problem. A teaching assistant might not teach a recitation section for a calculus course more than once. This makes it difficult to make conclusions about an effect they have, but if there are dedicated teaching assistants for particular courses this may be possible.

An in-depth analysis of students' demographics and activities outside the classroom could be an area of future research. The only demographic information used in this study was major college. Looking at a student's race as a factor in the models may show a certain race is benefitting from the Math Excel course more than others. Also tracking students' activities outside the classroom may open up new results. Since they spend more time in the classroom, students in a Math Excel course might not use resources such as one on one tutoring or attending office hours as much as students in a traditional course as I said in section 5.1.

I believe the biggest area of future research is looking at the instructor effect and execution in the classroom. The instructor effect may be more powerful than the Math Excel program effect, and lead to higher grades and pass rates. Active learning has been shown to be effective as seen in chapter 2, but it must still be executed correctly in the classroom. In addition, there was no commonality across sections such as common exams, homework, quizzes, and grading rubrics. Because of this, a comparison between sections is not conclusive and a better study would be one where common exams are given. A deeper look into what goes on in the classroom could lead to discoveries of possible changes that need to be implemented in Math Excel courses.

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