# AC 2010-171: EXCEL IN MATHEMATICS: APPLICATIONS OF CALCULUS

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# EXCEL in Mathematics: Applications of Calculus

## Abstract

Nationally only 40% of the incoming freshmen STEM majors are successful in earning a STEM degree [1]. The University of Central Florida (UCF) EXCEL program is an NSF funded STEP (Science, Technology, Engineering and Mathematics Talent Expansion Program) whose goal is to increase the number of UCF STEM graduates. One of the activities that EXCEL has identified as essential in retaining students in science and engineering disciplines is the development and teaching of special courses at the freshman level, called Applications of Calculus I and Applications of Calculus II, or Apps I and Apps II, respectively. In Apps I and II, science and engineering professors are asked to lecture twice, as guest lectures, and to demonstrate to students where calculus topics appear in upper level science and engineering classes as well as where faculty use calculus in their research programs. This paper outlines the process used in producing the educational materials for Apps I and II courses (textbook, presentations slides, in-class homework assignments, demos) and it also discusses the assessment results pertaining to this specific EXCEL activity.

## Introduction

The UCF EXCEL program is funded (2006-2010) by the National Science Foundation (NSF) under the auspices of STEP (Science Technology Engineering and Mathematics Talent Expansion Program) with the goal of increasing the number of U.S. citizens obtaining a B.S. degree in Science, Technology, Engineering, or Mathematics (STEM). In the book *Talking About Leaving, Why Undergraduates Leave the Sciences* (see [2]), a list of reasons has been provided, such as: **(1)** Discouraged/loss of confidence due to low grades in early years, **(2)** Morale undermined by competitive STEM culture, **(3)** Curriculum overload, fast pace overwhelming, **(4)** Poor teaching by STEM faculty, **(5)** Inadequate advising or help with academic programs, and **(6)** Loss of interest in STEM, i.e., "turned off by science."

The UCF EXCEL program addresses all of these reasons that affect student retention in STEM. In particular, to address reason 6 (loss of interest in science and engineering) EXCEL has developed two one-credit courses that are taught in tandem with Calculus I and II, called *Applications of Calculus I and II (Apps I and II)*. These courses were developed as a result of studies that have shown that students increase their appreciation of calculus through applications in science and engineering [3-5]. Six science and engineering faculty, in coordination with the math faculty who teach the calculus topics, team teach the *Apps I and II* courses. In *Apps I and II* faculty demonstrate to students how a particular calculus topic is used in their future science and engineering courses or how the professor uses it in their own research. For example, a chemist has hands on demonstrations with reaction rates when discussing derivatives; a civil engineer focuses on the stresses on the football stadium when students bounce to Zombie Nation and how this application relates to the anti-derivative of a function; a molecular biologist discusses how he uses integration in his cancer research. Pre and post tests on the six calculus topics that the *Apps I and II* courses address are administered to both the experimental group (EXCEL students) and the control group (a group of non EXCEL students with similar academic backgrounds as the EXCEL students). The pre and post tests are graded by EXCEL funded graduate students who are trained by the Faculty Center for Teaching and Learning at UCF. The grading follows a rubric developed by the EXCEL mathematics faculty.

This paper will discuss the process used to produce the educational materials (class notes, presentation slides, in-class assignments, demos) for the *Apps I and II* courses, and the *Apps I and II* assessment results (student questionnaire and pre and post test results). Some observations will also be made regarding the positive impact that the EXCEL program has on the retention of its students (an increased retention percentage of up to 21% has been observed for some EXCEL cohorts compared to corresponding control cohorts), as well as the perceived impact of the *Apps I and II* courses on the calculus concepts imparted on the EXCEL students (e.g., the pre and post tests show an increased math knowledge imparted on the EXCEL students who take Calculus II and *Apps II*, compared to the control students who take only Calculus II). The organization of the paper is as follows: We first provide some information about the EXCEL goal, objectives, and plans to achieve these objectives. Then, we discuss the process undertaken to produce the educational materials needed for the teaching of the Apps I and II courses. The assessment results obtained that evaluate the merit of the Apps I and II courses and the impact on the EXCEL cohorts, follows. The paper is concluded by providing retention numbers for one of the EXCEL cohorts and their corresponding control groups and by making some pointed conclusive remarks.

## EXCEL Specifics

The **goal of the EXCEL project** *is to increase UCF's retention rates in STEM disciplines*, thereby increasing the number of students graduating with a STEM degree. In this process an increase in the percentages of under-represented groups (women, and minorities) graduating with STEM degrees is expected. The result will be an institutionalized program that can be implemented at other educational institutions.

The EXCEL project has **two objectives**. The **first objective** is to attract 200 students per year from the *higher attrition STEM freshmen group into the EXCEL program* (EXCEL participants). The higher attrition STEM freshmen group is defined to be the group of freshmen that are declared STEM majors and have math SAT scores belonging to 2nd and 3rd quartile of math SAT scores of all STEM students entering UCF. UCF Institutional Research data shows that this group of students typically experiences higher STEM attrition, due to their performance in mathematics. The **second objective** is to increase the number of students remaining in STEM majors by increasing UCF retention rates from the current 50% rate to the projected 75%.

To **achieve the first objective** the EXCEL Program Directors, faculty, and staff have embarked (since the inception of the project (January of 2006)) in an aggressive marketing campaign to inform UCF STEM applicants and their parents of the benefits in participating at the EXCEL program at UCF (e.g., guaranteed housing, block scheduling, exposure to the applications of Calculus from early on in their college careers, tutoring and personalized attention at the EXCEL Center). In summary, the EXCEL program receives approximately 600 applications a year for 200 slots.

To **achieve the second objective**, the EXCEL faculty have designed a set of educational activities which are focused on the cornerstone courses of Calculus I and II. In particular, one of the innovations of this EXCEL program is the introduction of the Applications of Calculus classes that are taught by science and engineering faculty who emphasize the importance of calculus topics in both STEM coursework and their own research areas. Through this sequence of Applications of Calculus classes it is expected that EXCEL students will have more concrete examples of the topics covered in their calculus classes and their time on task with calculus concepts will be increased. EXCEL students have access to the EXCEL Center, a 1200 square foot lab where they can study alone, study together, or get personalized tutoring by any of the 10 graduate EXCEL students. Finally, EXCEL students are block scheduled in Precalculus, Calculus I, and Calculus II in addition to the Apps I and Apps II courses. EXCEL graduate student mentors carefully monitor student progress on a weekly basis so that any observed deficiencies can be immediately addressed.

The EXCEL program is following a block scheduling structure for a sequence of classes offered in the first year of the EXCEL student cohort. These classes are:

- Pre-Calculus, Calculus I, and Applications of Calculus I in the Fall semester of the freshman year,
- Calculus II, and Applications of Calculus II in the Spring semester of the freshman year,

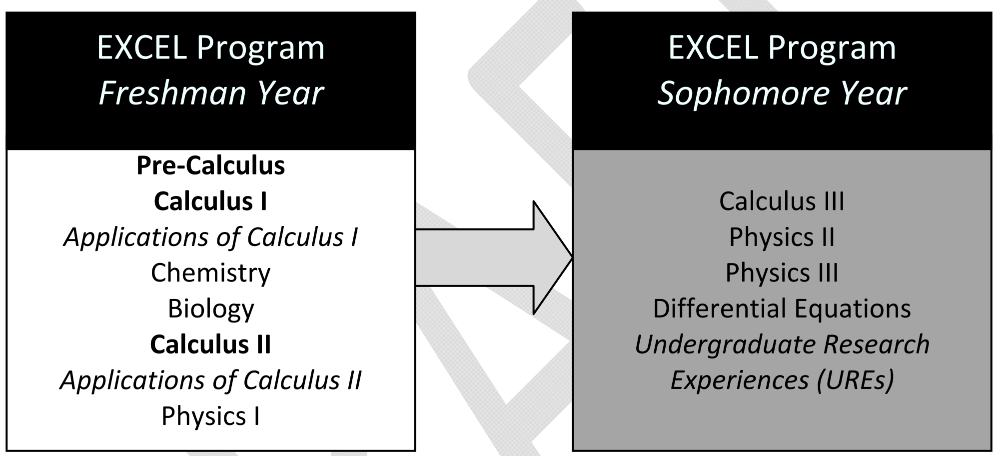



**Figure 1:** A pictorial illustration of the sequence of the common EXCEL courses taken by an EXCEL cohort. Calculus classes that are bold-faced are classes blocked for EXCEL students and taught by EXCEL faculty. Courses that are italicized are new courses that have been introduced by the EXCEL program and taught/supervised by EXCEL faculty

A pictorial that shows the sequence of EXCEL classes planned for an EXCEL cohort (starting in the fall of an academic year) is shown above, in Figure 1. The bold-faced mathematics courses are EXCEL only sections. Note that the EXCEL cohort is divided in two groups. The group that is not Calculus ready and is placed in the Pre-Calculus Class for Fall, and the group that is Calculus ready is placed in the Calculus I class for Fall. A math placement test is required of all EXCEL applicants and this test determines the appropriate math placement of the incoming cohort (Pre-Calculus ready or Calculus I ready). The Applications of Calculus classes are new classes that were introduced into the undergraduate curriculum in order to facilitate the appreciation of calculus topics, and they are co-taught by a number of science and engineering faculty. The Undergraduate Research Experiences give EXCEL students the opportunity to experience, first hand, the research that STEM faculty are conducting at UCF.

Since our primary interest is to report the impact of the Apps I and II courses on the EXCEL cohorts, and these courses are geared towards increasing the EXCEL STEM retention rates, it is worth revisiting, in more detail, the EXCEL plan to increase these rates. As a reminder, the second objective of the EXCEL program is to increase (at the level of 75%) the rate of EXCEL students who graduate with a STEM degree. To achieve this objective EXCEL has focused on a number of academic, advising and social activities that help in the creation of an EXCEL learning community consisting of faculty, staff, graduate students and cohorts (06-09 EXCEL students). The goal of the EXCEL learning community is to increase the success of the EXCEL cohort in the first two years in college, thus attributing to the increase in retention rate of the EXCEL cohort within STEM. The academic, advising and social activities planned by EXCEL cohorts are as follows:

1. Group on-campus housing block.
2. An EXCEL specific orientation.
3. Welcoming parties at which faculty, staff and graduate students introduced UCF to the EXCEL cohort
4. EXCEL Only Sections of Calculus classes (Pre-Calculus, Calculus I and II)
5. Applications of Calculus I and II classes designed and taught by a number of science and engineering faculty to the EXCEL cohort.
6. Advising offered on a regular basis (at the EXCEL Center) by the First Year EXCEL academic advisor and other college advisors.
7. Mathematics and science tutoring offered (at least 60 hours per week) by graduate students at the EXCEL Center
8. Recitation sessions, offered at the EXCEL Center, by the math professors who are instructors of the Pre-Calculus, Calculus I and Calculus II courses
9. Peer tutoring sessions organized at the NIKE Housing community (where EXCEL students reside) on Sunday through Thursday evenings.
10. Undergraduate research experiences offered by UCF faculty to interested EXCEL sophomore students.

The remainder of this paper is devoted to Activity # 5 (development and teaching of the Apps I and II courses) and its impact on the EXCEL cohorts.

**Development of Applications of Calculus I and II**

The Applications of Calculus I and II courses are one-credit courses that meet one night a week for an hour. Students simultaneously are enrolled in the traditional Calculus I or II course respectively. The Apps I and II courses are led by a STEM Professor (Instructor of Record) who coordinates the other faculty (six STEM faculty are slated to co-teach each of the Apps I and Apps II courses) for their presentations. The six science and engineering professors each teach two consecutive weeks. Each professor who co-teaches in the Apps I and II courses produces a chapter in a book (called Apps I or Apps II textbook) and PowerPoint slides for his/her presentation. In this section we will discuss how the book chapters and PowerPoint presentations are developed and delivered.

The development of the Applications of Calculus book is lead by Apps I and Apps II science and engineering faculty coordinators. They start with a list of core topics for Calculus I and Calculus II which are provided by mathematics faculty. Then, the Apps I and Apps II faculty coordinators share these topics with the six STEM faculty that are slated to co-teach the courses; each one of these faculty select one of these core Calculus I and II topics that they feel comfortable with and can illustrate its usefulness both in higher level courses taught in their disciplines, as well as in the research that they conduct.

The STEM faculty work with EXCEL math faculty to ensure consistency of notation for the book chapter and power point presentations that they produce. Additionally a master schedule is developed by the math faculty to ensure that the calculus topic has been covered in the calculus course *prior* to it being covered in the Apps course. An example of an application topic covered in the *Apps I* course that focuses on cooling fins in personal computers, while illustrating the mathematical concept of limits is provided below and referred to as an Apps I module. The goal of this module is to illustrate the importance of limits in engineering analysis and to help students develop physical intuition (through discovery learning) as to why fins are useful, why they are manufactured utilizing aluminum or copper, and why they are effective in heat removal.

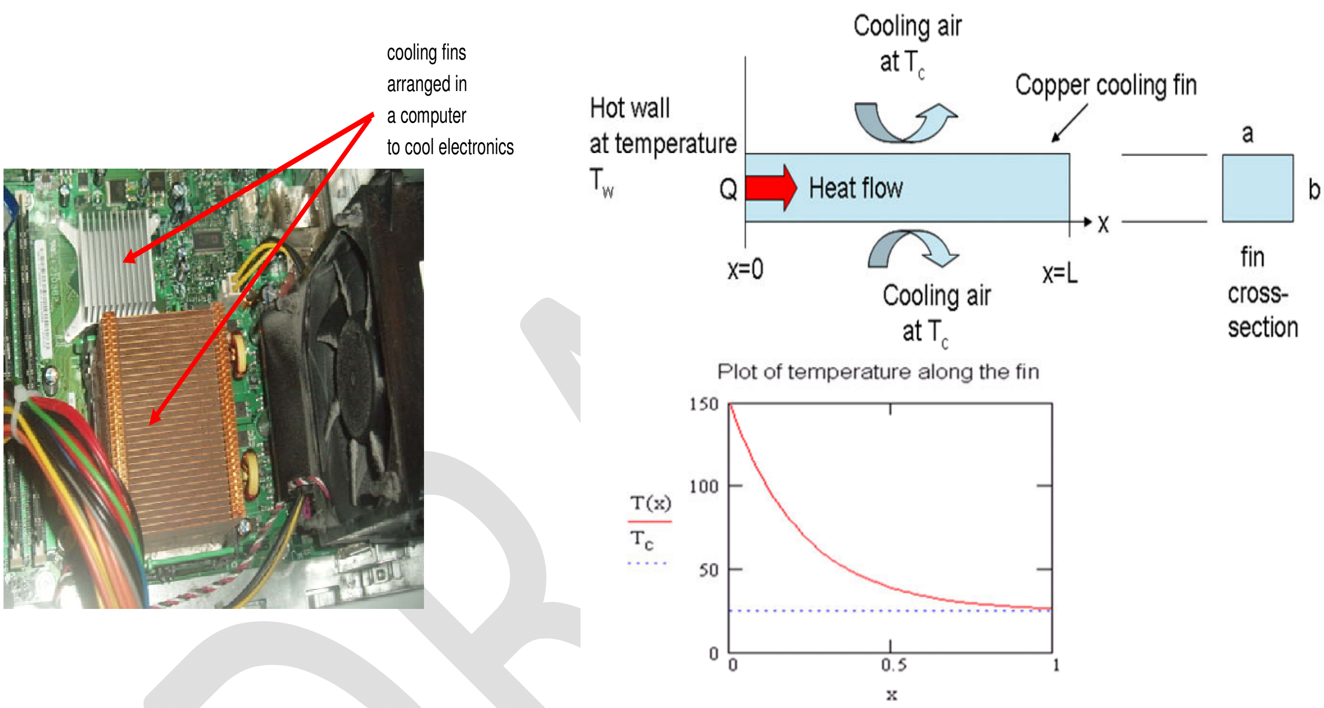



**Figure 2:** A pictorial illustration of the cooling fan in a computer and how it cools is used by Dr. Alain Kassab in the Applications of Calculus I course.

Using MATHCAD and having students "guess" and compute values, we follow through a progression of integration of key mathematical concepts taking the student from the abstract idea of a limit to calculation and interpretation within a visual environment, effectively analyzing a particular engineering problem.

A student's inquiry-based-learning involvement in this module includes: (1) taking the limit of the average rate of change to arrive at the instantaneous rate of change, (2) using a limit to define, *e*, the natural base of logarithms, the exponential function and its derivative, (3) illustrating the difference between dependent and independent variables in the equation for the temperature, $T(x)=T_c+(T_w-T_c)\ e^{-\lambda x}$, while enforcing concepts of units associated with variables, (4) applying the concept of the limit of the equation for the temperature as *x* tends to zero (the temperature at the base of the fin) and to infinity (the tip of a very long fin), (5) introducing a physical relation, Fourier's law of heat conduction, relating the rate of cooling to the instantaneous rate of change of the temperature with respect to space, (6) dthat the derivative of the exponential function is an exponential function (important rule in calculus), (7) introducing a variety of fin candidate materials and having students select materials based on resulting temperature profiles and fin effectiveness, and (8) trying to take a limit $\Delta x \rightarrow 0$ numerically and realizing the inherent limitations due to round-off and machine precision, therefore enforcing the importance of analytical methods in a world pervaded by computation.

$$m_T(x) = \lim_{h\to 0}\left[\frac{[(T_c + C_1 e^{-\lambda(x+h)}) - (T_c + C_1 e^{-\lambda x})]}{h}\right]$$
$$= C_1\left\{\lim_{h\to 0}\left[\frac{e^{-\lambda(x+h)} - e^{-\lambda x}}{h}\right]\right\}$$
$$= C_1\left\{e^{-\lambda x}\underbrace{\lim_{h\to 0}\left[\frac{e^{-\lambda h} - 1}{h}\right]}_{\text{what is this term?}}\right\}$$

Computing the limit numerically:

$$\text{Function}(h) := \frac{\left(e^{-\lambda\cdot h} - 1\right)}{h}$$

| $h_i$ = | $\text{Function}(h_i)$ = |
|---|---|
| 0.1 | -3.568 |
| 0.01 | -4.318 |
| $1\cdot 10^{-3}$ | -4.404 |
| $1\cdot 10^{-4}$ | -4.413 |
| $1\cdot 10^{-5}$ | -4.414 |
| $1\cdot 10^{-6}$ | -4.414 |
| $1\cdot 10^{-7}$ | -4.414 |
| $1\cdot 10^{-8}$ | -4.414 |
| $1\cdot 10^{-9}$ | -4.414 |
| $1\cdot 10^{-10}$ | -4.414 |

$f(x) = e^{-\lambda x}$

$$m_f(x) = \lim_{h\to 0}\left[\frac{e^{-\lambda(x+h)} - e^{-\lambda x}}{h}\right] = -\lambda e^{-\lambda x}$$

The entire grade for the course is based on clicker questions that students answer in class. An example of a clicker question (and the correct answer) is provided to the right.

**i>clicker answer: with $\lambda$=4.414 [m$^{-1}$], $k$=385 [W/mK], $T_w$=150°C, $T_c$=25°C, and the area of the fin $A$=2x10$^{-4}$ [m$^2$], what is the heat flow rate at the base of the fin, i.e. at x=0?**

from last cliker question: $C_1 = T_w - T_c$

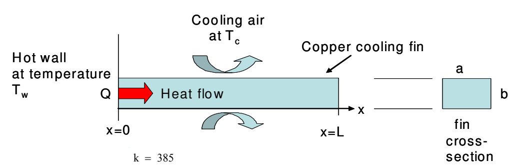
$$Q(x) = +kA\lambda C_1 e^{-\lambda x}$$

**A) – 23.8 [W]**

**B) +23.8 [W]**

★ **C) +42.48 [W]**

**D) - 42.48 [W]**




$k = 385$
$\text{Area} = 2\times 10^{-4}$
$T_W = 150$
$T_c = 25$
$C_1 = 125$
$\lambda = 4.414$

$Q(x) := k\cdot \text{Area}\cdot C_1\cdot \lambda\cdot e^{-\lambda\cdot x}$

$Q(0) = 42.48$

**Assessment of Applications of Calculus I and II**

The Apps I and II courses are assessed in two main ways: (1) pre and post tests on Calculus I and Calculus II topics given to both experimental (EXCEL) and control groups (2) and the EXCEL group is provided with an Apps I and II questionnaire through which students give feedback to the assessment team about the Apps I and II courses. This assessment was applied to all of the Calculus I and II courses taught to EXCEL students since the inception of the EXCEL program (2006). Data has been collected for the years 2006-2009. We have chosen to provide analysis for the EXCEL 2006 cohort who took these classes in the Fall 2006 and Spring 2007 as this class is currently graduating with STEM degrees.

The pre and post tests are administered to an experimental group (EXCEL students) and a control group (students identified with similar majors and math SAT scores as the EXCEL students). The pre and post tests are identical and consist of six questions that are on the six calculus topics which are reinforced through the Apps classes. Mathematics faculty write the six questions similar to what they would put on a final exam. These six questions are given in all Calculus classes on the first day of class as the "Pre" test. Students do not get these returned. These same six questions are embedded in the Calculus final exams.

The rubric that serves as a guide for grading the pre and post tests is developed by the math faculty and the Faculty Center for Teaching and Learning (FCTL) director at UCF. Once the rubric is satisfactory, the two EXCEL graduate students are trained by the FCTL and math faculty to grade the pre and post tests according to the rubric. Double blind grading is performed to eliminate drift. Scores are tallied and statistics are based on the two sets of grades (any discrepancies between grades by the two graduate students are averaged).

It should be noted that the pre and post tests are logistically challenging to execute as they require consensus of math faculty on questions, flexibility of math faculty to incorporate these questions into their final exams, the manual labor of identifying the control group participants among the non EXCEL sections, photocopying those final exams immediately after conclusion of the exam (prior to faculty grading) and training of graduate students to grade according to rubrics.

An independent sample t-test conducted to compare pre-test scores for both groups (2006 EXCEL group and 2006 control group) indicated that the pre-test scores were essentially the same for both the control and EXCEL groups [$t(265)=.35$, $p=.73$]. The means and standard deviation statistics are shown in Table 1 below. The magnitude of the differences in the means was negligible (eta squared = .0005). The same result was obtained for the post-test scores [$t(265)=.35$, $p=.73$]. The magnitude of the differences in the means was negligible (eta squared = .0005).

| Calculus I Group | N | Pre-test Mean | Pre-Test SD | Post-test Mean | Post-Test SD |
|---|---|---|---|---|---|
| *Control* | 110 | 4.01 | 1.92 | 11.01 | 4.04 |
| *EXCEL* | 157 | 3.94 | 1.71 | 10.81 | 4.83 |

**Table 1:** The table shows the mean and standard deviation (SD) for each group (Control or EXCEL) for the Pre and the Post Test for Calculus I in Fall 2006.

A paired sample t-test that was conducted for both groups indicates that there was a significant increase test scores from the pretest to post-test for both the control and the EXCEL groups. The results for each group, Pre-test to Post-Test are below:

- Control Group: $t(109)=-18.01$, $p<.0005$. The eta squared statistic (.75) indicates a very large effect size.
- EXCEL Group: $t(156)=-18.58$, $p<.0005$. The eta squared statistic (.69) indicates a very large effect size.

To compare how the two groups improved from Pre-Test to Post-Test we conducted a 2X2 mixed between-within-subjects analysis of variance. This analysis indicated that there was no significant difference in change of knowledge test scores, over time for the control and EXCEL groups. This is shown by the interaction effect in the multivariate test, which was not statistically significant [Wilks' Lambda = 1, $F(1, 265) = .047$, $p = .829$].

For the Calculus II data (Spring 2007), we conducted the same analysis as in Calculus I. The test score means and standard deviations for each group (EXCEL and control groups who took Calculus II in the Spring 2007) are given in Table 2 below.

| Calculus II Group | N | Pre-test Mean | Pre-Test SD | Post-test Mean | Post-Test SD |
|---|---|---|---|---|---|
| *Control* | 23 | .59 | .848 | 19.28 | 8.16 |
| *EXCEL* | 61 | .73 | 1.06 | 24.02 | 7.72 |

**Table 2:** The table shows the mean and standard deviation for each group (Control or EXCEL) for the Pre and the Post Test for Calculus II in Spring 2007.

The pre-test student scores were essentially the same for both the control and EXCEL groups [$t(82) = -.579$, $p = .564$]. The magnitude of the differences in the means was very small (eta squared = .004). The post-test scores for the EXCEL students were significantly higher than the post-test scores for the students in the control group. [$t(82) = -2.47$, $p = .015$]. The magnitude of the differences in the means was moderate (eta squared = .069).

The results indicate that there was a significant increase in the knowledge test scores from the pretest to post-test for both the control and EXCEL groups. The results for Pre-test to Post-test are for each group, and they are presented below:

- Control Group: $t(22) = -11.29$, $p < .0005$. The eta squared statistic (.85) indicates a very large effect size.
- EXCEL Group: $t(60) = -23.70$, $p < .0005$. The eta squared statistic (.90) indicates a very large effect size.

Finally, there was a significant difference in change of knowledge test scores over time for the control and EXCEL groups. More specifically, **the improvement in scores (from pre-test to post-test) is much larger for the EXCEL group than the control group.** This was shown by the interaction effect in the multivariate test which was statistically significant [Wilks' Lambda=.93, $F(1,82) = 5.89$, $p < .05$, multivariate partial eta squared=.07].

The Assessment Team also distributed a questionnaire to 187 EXCEL students that took the Apps I and II courses in Fall 2006 and Spring 2007 semesters. Some of the student feedback obtained from this questionnaire is provided below.

1. "Through the Applications classes I know more about science and engineering disciplines" (89% said yes).
2. "Applications classes helped me feel that I am a member of an EXCEL learning community" (68% said yes).

In spite of the fact that results were only provided above for the pre and post tests of Calculus I in Fall 2006 and Calculus II in Spring 2007, both of which pertain to the EXCEL 2006 cohort, the feedback from the analysis of the pre and post tests applied to other EXCEL cohorts (2007, 2008, and 2009) is very similar. That is, the pre and post tests applied to Calculus II concepts for these cohorts showed that increased math knowledge was demonstrated by the EXCEL cohorts compared to the control groups of students. The pre and post tests comparing the math knowledge of the EXCEL and control groups in Calculus I are inconclusive (sometimes the

EXCEL group did better, sometimes worse and sometimes the groups did as well). The Apps I and II questionnaire administered to EXCEL 2007-2009 groups also yielded very positive responses to questions 1 and 2, mentioned above for the EXCEL 2006 cohort.

**Impact of EXCEL Program on Retention Rates**

The EXCEL program has many activities: cohort for math courses, graduate student mentors, tutoring in the EXCEL center, Apps I and II courses, group housing block, recitation sections, EXCEL advisors, social activities, sophomore undergraduate research experiences, etc. All of these contribute to the overall goal of retaining more STEM majors. The following chart illustrates retention of STEM majors going into students' fourth year for the EXCEL 2006 and control 2006 cohorts; the retention rates shown in chart 1 were produced at the beginning of Fall 2009, three years after the EXCEL 2006 cohort was admitted to UCF.

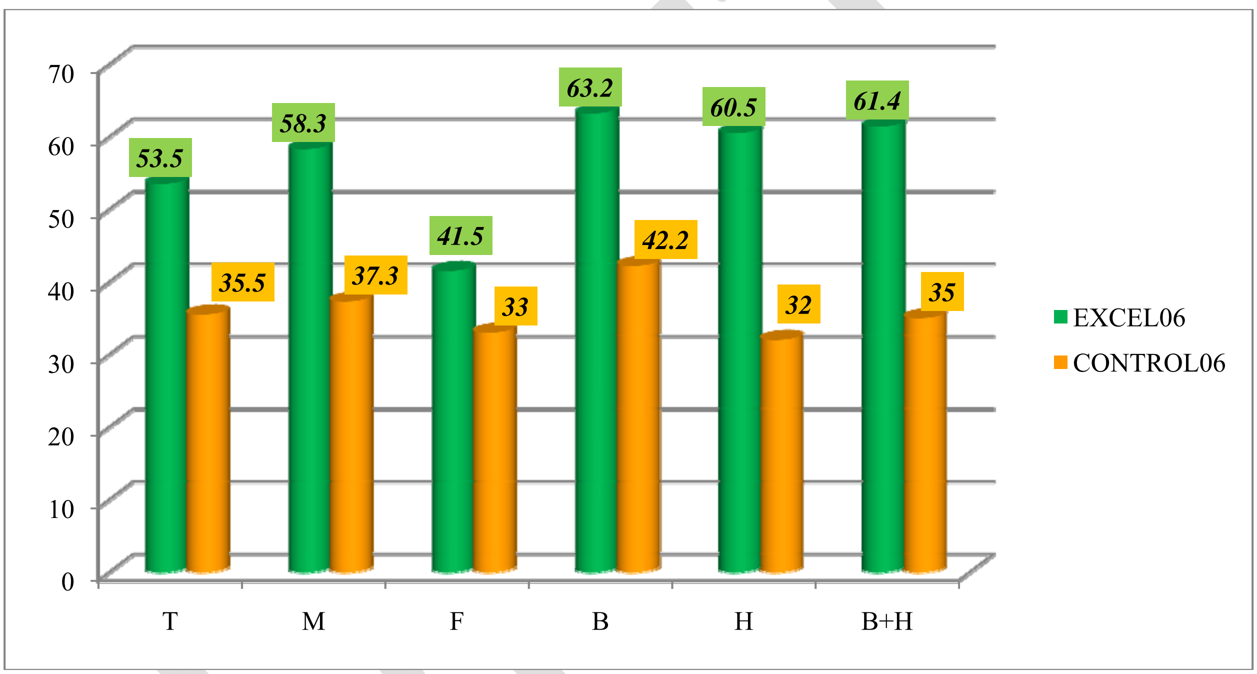



**Chart 1**: The chart shows the percentage of students who declared STEM majors as freshmen in Fall 2006 and are still STEM majors in Fall 2009. The EXCEL program demonstrates a higher retention in general and in specific underrepresented groups in STEM.

Although we cannot determine which of the many EXCEL activities and how much each one of these activities are contributing to the increased student STEM retention rates, we believe that the sense of a learning community that the Apps I and II courses reinforce plays a very significant role in the improved retention rates observed for the EXCEL cohorts.

## Conclusions

The UCF EXCEL program is increasing retention rates of undergraduates pursuing STEM degrees. The Applications of Calculus courses are key components of the program. The Pre and Post test data suggest that Apps I does not significantly improve student learning in Calculus I but Apps II does significantly improve student learning in Calculus II. Some possible reasons for only experiencing impact in Apps II are (1) students are significantly more mature in their second semester (as opposed to their first semester) of their freshman year, (2) Biology and Premedical majors only take Calculus I so they are not in Calculus II, (3) the EXCEL program offers two tracks and only the advanced students take Apps II (the other students take pre-calculus in the fall with Calculus I and Apps I in the spring). The Apps I is currently being redeveloped with more inquiry-based modules in hopes of having more of an impact on student learning in Calculus I as well. One positive outcome independent of improved student learning is that the Apps courses do significantly improve students' appreciation of science and engineering's dependence on calculus.

### References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