Effective use of Tablet PCs for Engineering Mathematics Education

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Abstract - **Recently, there has been a growing interest in the use of tablet PCs (TPCs) as a means for improving engineering education, primarily in technical courses such as basic physics. However, there has been little discussion on how to apply this technology to engineering mathematics courses. The purpose of this paper is to present an approach for teaching mathematics to engineering students with the TPC. The approach was implemented in a second-year differential equations and linear algebra course within the Electrical and Computer Engineering Department at the University of Toronto. The effectiveness of the approach was tested qualitatively through a survey of 89 students, and quantitatively through a comparison between the three lecture cohorts of the course, since two of the cohorts were taught with a traditional blackboard technique. The survey results were quite positive, yet the more interesting results are found from the grade comparisons. These results indicate that the TPC-based instruction had the greatest impact on the students in the bottom half of the class. In this paper, the approach will be discussed and survey and grade comparison results will be presented.**

Index Terms - Tablet PC, Engineering Education, Mathematics, Technology in the Classroom.

INTRODUCTION

In many engineering schools, the core mathematics courses are often taught by mathematicians rather than members of the engineering faculty. This has the distinct advantage of giving the students a rigorous presentation of the theoretical concepts of the course, which can allow the students to gain a broader range of understanding and reasoning capabilities. However, one of the drawbacks of this approach is that the applications which are specific to that engineering discipline are generally not discussed in great detail. This is partly due to the fact that the instructors often are not working in the engineering field. As well, there is little extra time to properly introduce these applications and make the connections with the mathematical concepts at hand. This problem is further exacerbated by the fact that most engineering mathematics textbooks offer a broad range of applications, which touch on many areas of science and engineering. Yet, they generally do not delve into the details of many of these applications. This is understandable, as these books have to be useful for a large number of courses to be commercially viable.

These issues with engineering mathematics education were identified many years ago by Strum and Kirk [1]. Their main suggestions were to "reduce the rigor and abstraction" of the engineering mathematics courses, and to "establish a cooperative working relationship between mathematics and engineering departments". They felt that much of the material that a mathematics professor may find to be critically important, is not necessarily useful to engineering students. This often means that these students are lacking the fundamental mathematical skills they need for their subsequent courses. The instructors of these courses then have to review the required background material before covering their main material. Strum and Kirk concluded that by designing the mathematics courses as a team, the engineering and mathematics departments can find the correct balance between the degree of rigor and the proficiency of the students in using the theories and techniques.

In many ways these suggestions have not yet been given their proper consideration and there still seems to be a general disconnect between the mathematical needs of upper-year engineering students, and the content and organization of the core mathematics courses. In some programs this is beginning to change, and one example of this is in the College of Engineering at Cornell University [2]. Within one of their first-year calculus courses, they have dedicated one recitation hour per week to a group problem-solving exercise. These exercises are based on suggestions from engineering professors who use this mathematical material in their upper-year courses. Although this initiative is still in the early stages, it was reported that the feedback from the students has been very positive. As well, it is known that this type of active learning environment promotes greater retention and comprehension of the key concepts at the heart of the exercise [3].

It is the purpose of this paper to present an approach for using a tablet PC (TPC) to address some of these issues of how to improve engineering mathematics education. This approach was used in the fall term of 2007 in a second-year course on differential equations and linear algebra (DE & LA) in the Electrical and Computer Engineering (ECE) Department at the University of Toronto. In the first section the details of the approach will be discussed. The effectiveness of this approach will then be assessed in the second section. This will be measured through student survey results and comments, and through a grade comparison of the three cohorts of the course.

TPC USE IN ENGINEERING MATHEMATICS EDUCATION

The technology of the TPC offers many unique advantages for teaching abstract concepts to engineering students [4]-[8]. These include:

- **The ability to incorporate complex visual aids into a standard "blackboard" lecture**: The TPC can be used as a projected "blackboard", where all text can be written as it would be on a traditional blackboard or whiteboard. However, with use of the TPC one can very easily incorporate complex figures, animations, videos, and other visual aids into a traditional lecture.
- **The ability to organize the lecture material by providing skeleton notes to the students**: By giving a brief outline of the lecture material to the students before the lecture, the instructor can organize the material into a logical presentation. As well, by working through these skeleton notes, it is not necessary to write out long theorems, statements, or formulas since these can be included in the skeleton notes. This can save a significant amount of time, which can be used in more effective ways.
- **The ability to demonstrate the use of software in class**: For mathematical courses, it can often be of great benefit to visually demonstrate a concept. For example, the plotting of an example function in 2D or 3D can be of great use when explaining many of the vector calculus techniques (gradient, divergence, curl, etc.), or in the teaching of differential equations. Through the use of the TPC, one can easily switch between a "blackboard", and Matlab, Maple, or other software to illustrate the main points.

For the DE & LA course that is the basis of this paper, the design and presentation of the lectures made use of these advantages. As well, as was discussed in the introduction, the lecture content was less focused on mathematical rigor than traditionally has been the case for this course. Instead, the concepts were always motivated by examples of how the material would be useful to these ECE students in the coming years. Therefore, the general lecturing approach can be summarized by the following key points:

- The lectures were prepared in PowerPoint, and presented using the basic animations built into PowerPoint. These animations enabled the material to be presented logically and in a controlled fashion.
- In these slides, the most important points were typed in ahead of time, and theorems and complex figures were also included in the slides. These slides were edited slightly to create the skeleton notes, which were provided to the students before the lectures.
- During the lectures, annotations were made over the slides as the concepts were discussed. All the example problems were written out by hand in class, so that they could be worked out interactively with the students. Approximately 50% of the lecture text was written out by hand in the lectures.
- Where appropriate Matlab was used for a variety of purposes. These included the plotting of functions, and matrix calculations.
- In an effort to properly motivate key concepts within the course, a number of ECE applications were discussed in the lectures. A few of the applications that were used and their associated topics are summarized in Table I. The use of the skeleton notes provided some extra time to discuss these applications in reasonable detail. As well, the TPC allowed some excellent figures and animations to be used to enhance these presentations. This was particularly useful in discussing computer graphics as well as Fourier Series in communications systems.

TABLE I
ELECTRICAL AND COMPUTER APPLICATIONS USED TO ILLUSTRATE MATHEMATICAL CONCEPTS IN DIFFERENTIAL EQUATIONS AND LINEAR ALGEBRA

Application	Mathematical Concept(s)	Presentation Details
Electric Circuit Analysis (Resistive Circuits)	Gaussian Elimination Reduced-Row Echelon Matrices Inverse Matrices	• Used a three loop electric circuit with multiple sources as an example of linear system solutions using inverse matrices
Simulation of Electromagnetic Systems (Finite Element Method)	Linear System Solutions Inverse Matrices	• Introduced the finite element method as a way to approximate the solutions to Maxwell's equations for electromagnetic problems using matrix equations. • Discussed how the solution to the problem is based on finding the inverse of a matrix. • Showed a resulting field pattern solution of a cellphone radiating in a car.
Electric Circuit Analysis (*RL* Circuits)	First-Order Ordinary Differential Equations	• Solved an example switched *RL* circuit problem using the integrating factors method.
Computer Graphics	Vector Spaces Matrix Transformations	• Discussed the basic transformation matrices in three-dimensional space • Presented applications of these transformations to create different lighting scenarios, and moving a "camera" around in a virtual world.
Fourier Series in Communication Systems	Bases Linear Combinations	• Demonstrated how a digital signal can be approximated by a Fourier series of increasing number of sine functions.

ASSESSING THE EFFECTIVENESS OF THE TPC APPROACH

The purpose of the approach described above was to leverage the technology of the TPC to improve the teaching of the DE & LA course to future engineers. In order to measure its effectiveness, three items have been considered. First, a survey of the students was taken in class about two-thirds through the term. There were 89 responses to this survey. Second, student comments were collected in this survey. Third, a comparison was made between the academic performance of the three lecture cohorts for this course.

Student Survey Results

The student survey included a number of questions dealing with how the TPC was received and how the lectures were presented. The detailed results for these questions, as well as how students of different learning styles responded to the use of the TPC can be found in [9]. One of these questions, asked the students to respond to the statement, "*The technology of the tablet,…*", and Figure 1 shows the results and the possible answers that were given. It can be seen that about two-thirds of the class found the use of the TPC very beneficial. Since such a large percentage of the students (17%) selected "Other", it is useful to consider some of their comments:

"*It really depends on the professor.*"
"*Moderately improves my learning experience.*"
"*Less frustrating and easy to concentrate.*"
"*Improves my learning experience a little.*"
"*It just makes the lectures 'cleaner and smoother'.*"

These comments indicate how the TPC can be used to provide a more organized lecture, and that the use of skeleton notes allows for a greater degree of concentration of the student. However, the success of the TPC-based lectures highly depends on the instructor's ability to use the technology appropriately.

The students were also asked to respond to the statement, "*The discussion of the use of the mathematical concepts in electrical and computer engineering applications is:*". Figure 2 shows the possible answers and the results of the students' responses. This shows there was not an overwhelmingly positive response to the discussion of ECE applications, with an equal number of students finding them "extremely helpful" and "not very useful". Part of the reason for this response could be that this was the author's first time teaching this course, and these discussions were not as polished as they could have been.

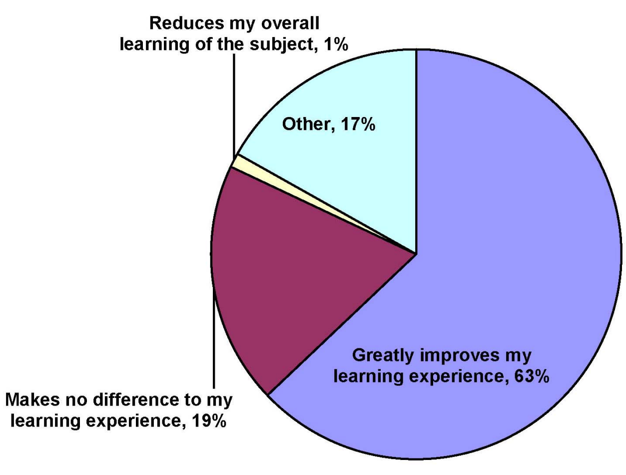

FIGURE 1
HOW THE STUDENTS RATED THE USE OF THE TABLET TECHNOLOGY

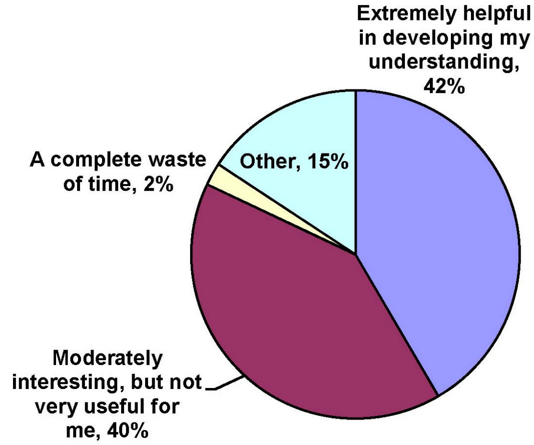

FIGURE 2
HOW THE STUDENTS RATED THE USE OF ECE APPLICATIONS

Student Comments

As is shown in Figure 2, 15% of the 89 respondents selected "Other" for the question about the presentation of applications in the lectures. A representative sample of the comments that students wrote in for "Other" are:

"*Useful for other courses.*"
"*Interesting, shows way to use lecture material.*"
"*Provides clarity on some concepts.*"
"*Don't see the connections much yet.*"
"*Like examples from circuits.*"
"*Somewhere between moderately interesting and extremely helpful.*"
"*Interesting, but sometimes just want to take notes and learn applications some other time.*"
"*Very interesting, you should keep it up. But I don't think it improves my understanding of the topic dramatically.*"
"*Motivation to learn more about this course.*"
"*Somewhat useful (depending).*"
"*Let's just say it's 'enjoyable'.*"

Overall, these comments are quite positive, and they show that perhaps the results of the question were a bit skewed due to the wording "extremely helpful".

These results and comments indicate that this approach to teaching mathematics to engineering students generally has a positive effect on their learning experience. It appears that it would be worth pursuing a continued effort to improve this approach.

Cohort Comparison

About 310 students took this course, and thus they were split into three lecture cohorts. Cohort #1, was taught by the author with the method described above. Cohorts #2 and #3 were taught by experienced instructors using the traditional blackboard approach.

In the comparison that follows, it is important to keep in mind that it is not possible to completely isolate the effect of the use of the TPC from the effectiveness of the instructor as a teacher. However, it is the opinion of the author that the positive results which are presented below are primarily due to the introduction of the TPC into the lectures. This opinion is based upon the author's previous experiences in teaching one section of a multi-sectioned course in the ECE Department at the University of Toronto. These past experiences have demonstrated that, within this department, multiple cohorts of students generally end up with final averages within ±1% of each other if the same method of teaching is used in all the cohorts. Therefore, since only one of these cohorts made use of the TPC, a measure of the effectiveness of the TPC-based lecturing approach can be assessed by comparing the academic performance of these three cohorts.

The easiest way to compare them academically is to consider the average of the final grades for each cohort. These results are presented in Table II. The TPC taught cohort achieved an average grade that was 3% higher than the other two cohorts. This is not an extremely significant increase, but it must be remembered that this was the first time the author has used the TPC and the first time that he had taught this course. As well, each cohort had over 100 students, so it is quite a large sample, and therefore, based on the author's experience the 3% is still noteworthy.

TABLE II
COMPARISON OF FINAL GRADE AVERAGES FOR EACH LECTURE COHORT

Cohort	Final Average, DE & LA Course	Final Average, Calculus III Course
Cohort #1	72%	69%
Cohort #2	69%	69%
Cohort #3	69%	68%

This comparison can also be viewed in another way. Figure 3 shows the number of students in each cohort that fell into each letter grade, with the grades defined as: F (0% - 49%), D (50% - 59%), C (60% - 69%), B (70% - 79%), A (80% - 89%), and A+ (90% - 100%). It can be seen from this figure that the TPC taught cohort has a significant increase in the number of students with a B average. As well, 52% of cohort #1 had a B average or higher, while this percentage was 47% for cohort #2 and 51% for cohort #3. Again, these are relatively small improvements, but they do indicate that the use of the TPC can be beneficial to the students.

In this cohort comparison, there is a concern that one cohort may just be better than the other, and this could be the primary reason for the improvement in the overall performance of this cohort. For such large classes, it would be expected that the three cohorts would have approximately the same academic abilities. However, in an attempt to isolate the effect of the TPC-based instruction, the grades for the three cohorts from another course were also considered. This is similar to the technique that was used in [10] to assess the effectiveness of the TPC-based instruction.

The comparison course for the present work was another math course, titled Calculus III, which is the last course in calculus that these ECE students will take. It was taken in the same fall term of 2007, and the student make-up of the cohorts for the Calculus course was identical to that of the DE & LA course. The final grades for this course are also shown in Table II. These grades indicate that the three cohorts have about the same academic capacity.

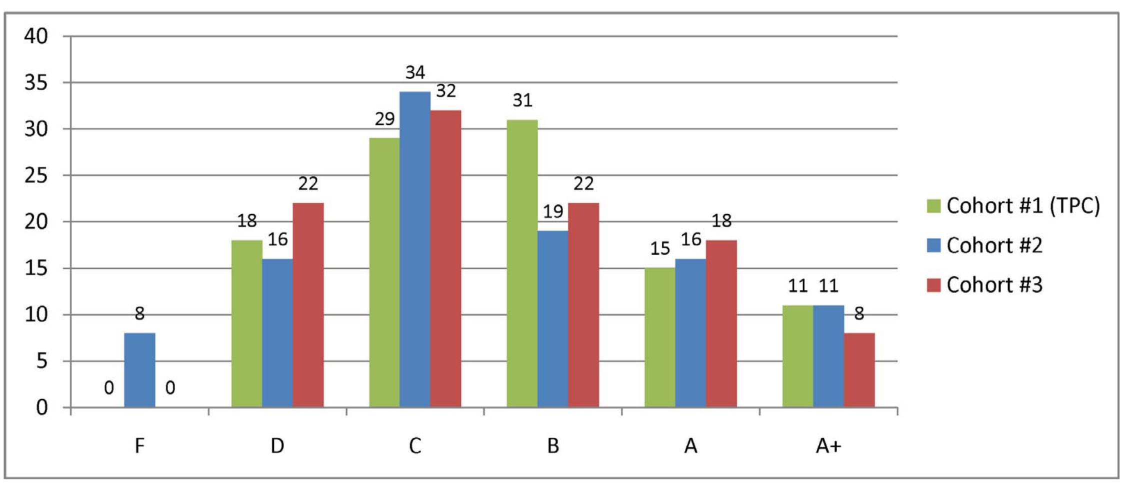

FIGURE 3
COHORT COMPARISON OF THE NUMBER OF STUDENTS WITH EACH LETTER GRADE IN THE DIFFERENTIAL EQUATIONS & LINEAR ALGEBRA COURSE

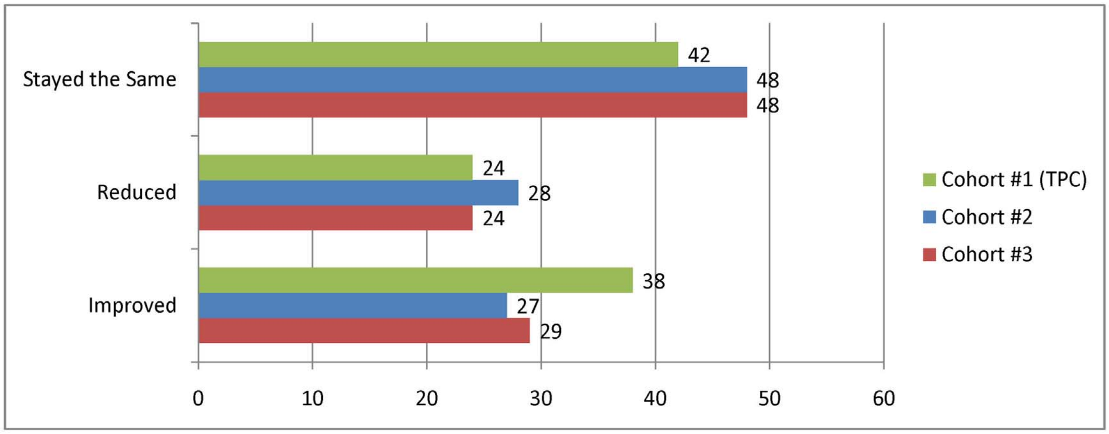

FIGURE 4
COMPARISON OF HOW MANY STUDENTS' LETTER GRADE CHANGED FROM CALCULUS III COURSE TO THE DE & LA COURSE

Another way to compare the cohorts is to see how the students improved or reduced their grade in the DE & LA course as compared to the Calculus III course. Figure 4 shows this comparison for the three cohorts. For all three cohorts there was approximately the same number of students who received the same letter grade in both courses (42, 48, and 48, for the three cohorts, respectively). As well, there were about the same number of students whose mark went down by at least one letter grade (24, 28, and 24, for the three cohorts, respectively). The most interesting result is that 37% of the TPC taught class improved their mark by at least one letter grade, while for cohorts #2 and #3 these percentages were 29% and 26%, respectively.

The comparison of the change in the letter grade, obscures some of the detail of the cohort's performance, since a small change in the grade percentage can cause an entire letter grade change. Therefore, one can also look at the average improvement in the student's grade from one course to the other for those students who increased their mark by at least one letter grade. This data is shown in Figure 5 for the three cohorts, and it should be emphasized that this figure only includes those students who improved their grades. The most striking result of this data is that it indicates that the TPC-based instruction had the greatest impact on students at the lower to middle end of the class, i.e., those students who received a D or C in Calculus III. For these two groups in cohort #1, the average improvement was 11% and 12% respectively.

The final comparison is to consider the entire group of students and the percentage by which their mark changed from Calculus III to the DE & LA course. This data is shown in Figure 6 and the students are separated into groups according to the letter grade that they received in Calculus III. Again, these results indicate that the TPC-based approach has the greatest benefit on those students at the lower end of the Calculus III course. As well, the TPC taught cohort shows larger percentage improvements for these three groups (F, D, and C) than for the other two cohorts.

The results from Figures 5 and 6 conflict with those that were presented in [10]. In that paper, the authors concluded that the TPC-based instruction had the greatest benefit for students in the upper end of the class (those that received an A or B letter grade in the comparison course). Here, it

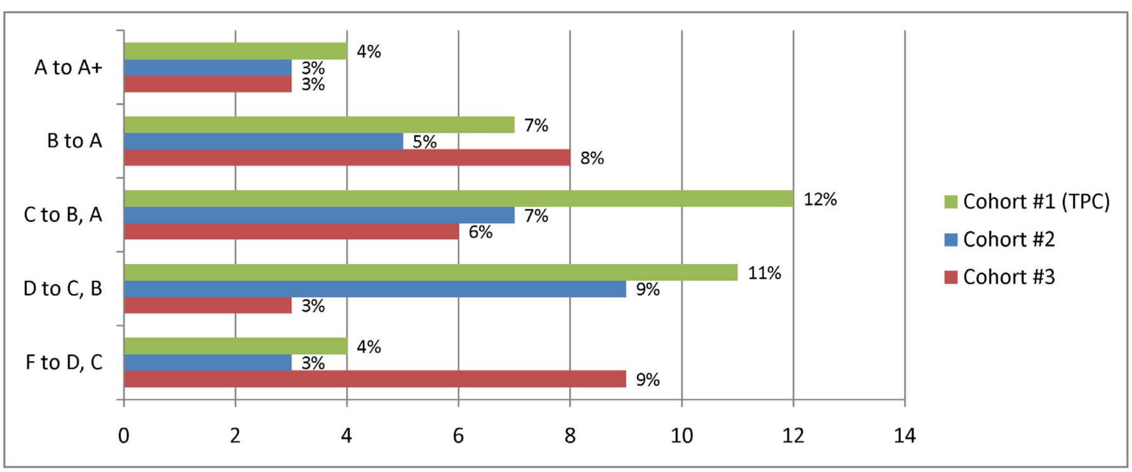

FIGURE 5
COMPARISON OF THE PERCENTAGE BY WHICH THE STUDENTS' LETTER GRADE IMPROVED FROM THE CALCULUS III COURSE TO THE DIFFERENTIAL EQUATIONS AND LINEAR ALGEBRA COURSE (ONLY THOSE STUDENTS WHOSE GRADE IMPROVED)

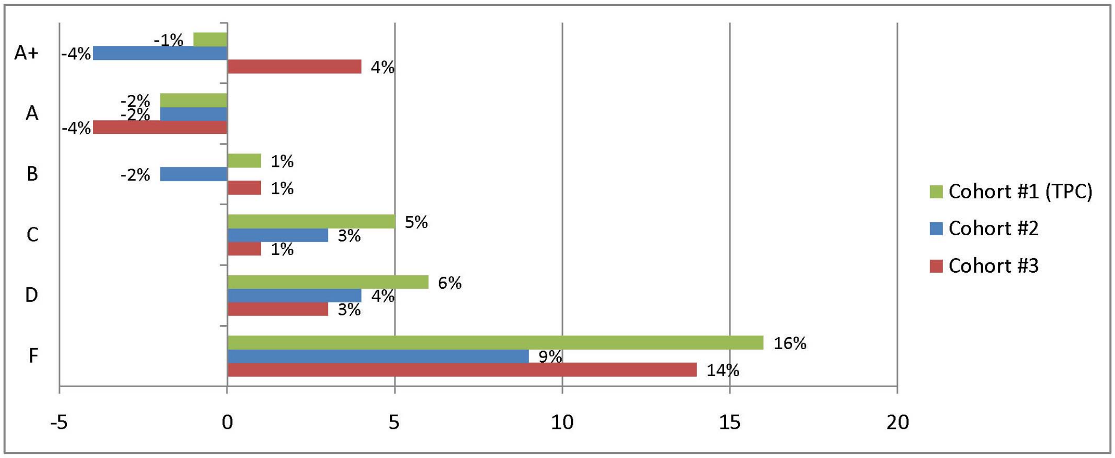

FIGURE 6
COMPARISON OF THE PERCENTAGE BY WHICH THE STUDENTS' LETTER GRADE CHANGED FROM CALCULUS III COURSE TO THE DIFFERENTIAL EQUATIONS AND LINEAR ALGEBRA COURSE (ALL STUDENTS)

appears to be the opposite. One of the differences in the two studies is that the one presented in [10] had a smaller sample size of 32 students, while the data presented here is for a much larger sample size of 310 students.

CONCLUSIONS

It is evident that the teaching of mathematics to engineers is a difficult task, as there needs to be a fine balance between mathematical rigor and ensuring the students' proficiency in applying the material to engineering problems. The TPC is a relatively new technology which can be used to help find this balance. The ability to use skeleton notes can provide the instructor with some extra time to present the important details of the background mathematics. As well, since multimedia items can be so easily incorporated into a TPC-based lecture, discipline specific applications of the material can be vividly and effectively woven into the lecture design. The use of the TPC in the second year DE & LA course that is the focus of this paper was well received by the majority of the students. As well, a good percentage of the students appreciated the use of ECE specific applications in the lectures. Since this was the first time this approach has been used, it is expected that further improvements would result in a larger approval by the students. Lastly, the comparison of the three lecture cohorts for this course indicates that the TPC-based instruction improved the academic performance of the students within that cohort. The comparison of the results for the DE & LA course with those from a simultaneous Calculus course supports this conclusion. As well, this comparison indicated that the use of the TPC as a lecturing tool had the greatest benefit for those students in the lower to middle range of the class.

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