Sacred Heart University
DigitalCommons@SHU

Mathematics Faculty Publications | Mathematics

10-2012

Instructor Use of Tablet PCs in a College Pre-Calculus Course: Implementation & Assessment

Julianna Connelly Stockton
Sacred Heart University, stocktonj@sacredheart.edu

Peter Gregory
CUNY Bernard M Baruch College

Follow this and additional works at: https://digitalcommons.sacredheart.edu/math_fac

 Part of the Educational Assessment, Evaluation, and Research Commons, Educational Methods Commons, Scholarship of Teaching and Learning Commons, and the Science and Mathematics Education Commons

Recommended Citation

Stockton, Julianna Connelly and Gregory, Peter, "Instructor Use of Tablet PCs in a College Pre-Calculus Course: Implementation & Assessment" (2012). *Mathematics Faculty Publications*. 9.
https://digitalcommons.sacredheart.edu/math_fac/9

This Peer-Reviewed Article is brought to you for free and open access by the Mathematics at DigitalCommons@SHU. It has been accepted for inclusion in Mathematics Faculty Publications by an authorized administrator of DigitalCommons@SHU. For more information, please contact ferribyp@sacredheart.edu, lysobeyb@sacredheart.edu.

Instructor use of Tablet PCs in a College Pre-Calculus Course: Implementation & Assessment

Julianna Connelly Stockton
Sacred Heart University, USA
stocktonj@sacredheart.edu

Peter Gregory
Baruch College, CUNY, USA
peter.gregory@baruch.cuny.edu

A group of six math instructors used tablet PCs to teach their individual sections of a high enrollment gateway Pre-Calculus course in a diverse urban four-year college. Student performance in the experimental sections were compared to those in 31 other sections in terms of student retention, pass rates, and score on the department-wide standardized final exam. Student performance was higher in Tablet PC sections across all three measures, although in some cases the improvement was not substantial enough to improve students' overall course grades. Surveys of students and faculty in classes using a Tablet PC reflected overall positive impressions of the technology's use in mathematics classrooms.

Background

This study investigated whether instructor use of a tablet PC in the classroom has a positive impact on student performance. In the Spring semester of 2010, a group of six math instructors used tablet PCs to teach their individual sections of the high enrollment gateway Pre-Calculus course in a diverse urban four-year college. Instructors wrote on the tablet PC's screen (which was then projected) instead of on a white board; this allowed for incorporation of a graphing calculator emulator, images and word problems from the online homework system, and

data charts or graphs all alongside the handwritten notes. In order to see if the use of this technology improved student achievement, the final exam results of the tablet PC sections were compared with those of the 31 other sections in which instructors did not make use of a tablet PC. Surveys were also administered to the students in the six tablet PC sections to gauge their opinions and perceptions about the implementation of this relatively new teaching technology, and about the efficacy of the single-tablet classroom.

Literature Review

The literature available on the use of the tablet PC as an instructional tool details various ways in which this technology can be implemented in the classroom. The tablet PC has been in use as an instructional tool in K-12 and college classrooms since the early 2000s, and educators recognized early on that the tablet PC could prove invaluable in helping make lectures as student-centered, interactive and engaging as possible (Cox & Rodgers, 2005). Previous studies on tablet PC effectiveness mainly present survey results that show instructors' and students' opinions about using tablet PCs in the classroom. Gupta (2009) presents several modes for using tablet PCs for teaching and learning and gives advantages and disadvantages for each; each of these modes falls into two categories: the "single-tablet" classroom, in which only the instructor has use of the tablet PC (Brophy & Walker, 2005; Fister & McCarthy, 2008; Galligan, Loch, McDonald, & Taylor, 2010; Gorgievski, Stroud, Truxaw, & DeFranco, 2005; Gupta, 2009; Lim, 2011; Schwager, Anderson, & Kerns, 2005; Weitz, Wachsmuth, & Mirliss, 2006; Yost, 2007), and the "multi-tablet" classroom, in which both instructors and students use tablets (Anderson, et. al., 2004; Berque, Bonebright, & Whitesell, 2004; Carruthers, 2011; Digiorgio, 2003; Filer,

Tront, Scales, & Olsen, 2008; Galligan et al., 2010; Hawkes & Hategekimana, 2009; Lohani, Castles, Johri, Spangler, & Kibler, 2008; Reins, 2007; Romney, 2011). Of course, whatever is possible in the single-tablet setting is also possible in the multi-tablet, but not vice versa.

The tablet PC is used by the instructor in both types of classrooms to deliver lecture notes and lead class discussions. Brophy & Walker (2005) studied the benefits of the tablet PC operating as a whiteboard replacement; survey results from 41 students in a fourth year mechanical engineering class showed that students preferred a lecture delivered on the tablet PC to one given on whiteboards because the notes were more clearly displayed and the instructor was able to face the class for the entire lecture. Gorgievski et al. (2005) reported similar survey results from a Calculus class of 103 students. Students perceived that the use of the tablet PC enabled them to pay closer attention during class, thereby helping them to better understand the presented material. Tablet PCs also allow the instructor to include multimedia in lectures more easily and document this inclusion in the lecture notes (Brophy & Walker, 2005). Although some studies mentioned the fact that the notes produced and displayed on the tablet PC are posted and shared online with students after (and in some cases, before) class, they did not emphasize that this ability to archive lecture notes is one of the most important features of the tablet PC and the main reason why students would feel that they are better able to pay attention during class (Gorgievski et al., 2005; Brophy & Walker, 2005). The importance of archived lecture notes was addressed by Fister & McCarthy (2006), who found that 93.1% of 682 students in tablet PC classrooms from 2004 to 2006 downloaded the archived tablet created notes at some point during their course. Student survey results from this same study indicated that students believed that use of the tablet PC "increased instructor effectiveness" and "promoted student learning" (Fister & McCarthy, 2008, p. 291).

While it has been reported that the multi-tablet approach improves student attention (Hieb & Ralston, 2010), assessment outcomes (Hawkes & Hategekimana, 2009; Hieb & Ralston, 2010), and collaboration (Carruthers, 2011; Ellington, Wilson, & Nugent, 2011; Reins, 2007), a significant problem arising when both instructor and students using tablet PCs during class is the tendency for students to be easily distracted by the availability of other programs and features of the technology. Berque et al. (2004) surveyed students in a multi-tablet setting who indicated that email, instant messaging and internet browsing distracted them during class. In a later study, Kraushaar et al. (2008) found that, on average, a student using a tablet PC during a 75 minute class opened 93 programs or windows not pertaining to the course.

The potential for this type of distraction has led several institutions to implement multi-tablet classrooms in conjunction with a program that limits student access to certain programs and/or websites. Additionally, many of the educational benefits in a multi-tablet classroom relate to the potential to synchronize the screen inputs across tablet PCs, allowing instructors to view student work in real time and to project selected inputs on the main screen (Donovan & Loch, 2012). Much of the research on the multi-tablet classroom has therefore required the introduction and discussion of two technologies: the tablet PC, and a software package that allows real-time communication during class between instructor and student tablets while limiting access for students to online distractions (Anderson et al., 2004; Hieb & Ralston , 2010). Hawkes & Hategekimana (2009) found that the use of tablets by both students and instructor in freshman-level math had a positive impact on student performance on quizzes and tests. Hieb & Ralston (2010) found that the use of tablet PCs seemed to decrease the percentage of students receiving D, F or W grades as compared to the percentage of students receiving those grades in a non-tablet classroom. In a recent longitudinal study, Romney (2011) reported a higher

percentage of students from a networked tablet PC class continuing to pursue STEM majors in subsequent semesters as compared to students who started out in the same mathematics class taught without use of tablet PCs.

Several institutions select a single-tablet model instead of the multi-tablet approach in order to avoid the issue of student distractions or for budgetary and logistical reasons. Previous research supports the idea that even a single-tablet approach can make a positive difference in teaching and learning. In the single-tablet classroom, the instructor uses the pen capabilities of the tablet PC in conjunction with a note-taking software package like Windows Journal or Microsoft OneNote to write notes on the tablet PC screen, and project the screen of the tablet via a classroom LCD projector onto a large screen at the front of the classroom. In some cases, instructors use the pen capabilities to annotate prepared Powerpoint slides during class (Galligan et al., 2010; Gupta 2009; Mock, 2004). This practice of writing on a tablet PC screen ostensibly limits the amount of space on which the instructor can write, but as long as the classroom projector infrastructure is already in place, that seems to be one of only a few drawbacks to using the tablet PC as a lecture delivery tool. Additional drawbacks from the faculty perspective in implementing a single-tablet classroom include the learning curve for faculty in making the switch from writing on a whiteboard to implementing, in a meaningful way, all the relevant features, of the tablet PC (Lim, 2011; Schwager et al., 2005; Weitz et al., 2006). That is to say, in order for the single-tablet PC approach to have any effect at all on teaching and learning it must be used in a way that makes giving a lecture using the tablet PC different in quality and content than giving notes on a whiteboard.

Most of the studies concerning single-tablet classrooms to date have focused on either student or instructor perceptions of the efficacy of using the tablet PC as a lecture delivery tool,

with surveys finding that both faculty and students tend to view use of the tablet PC favorably. Gupta (2009) also suggested that use of the tablet PC resulted in improved student attendance. Nonetheless, the present study is the first involving the single-tablet PC classroom to evaluate how the use of the tablet PC affects student performance on standardized departmental assessments.

Methodology

Participant Selection: Instructors

As part of a larger joint experiment between the mathematics and psychology departments, twelve instructors were selected from those who responded to a call for volunteers from the department chair. Of those who volunteered, six were chosen to work with Tablet PCs. The other six volunteers were involved in the psychology portion or as part of a control group. The six Tablet PC instructors were a mix of adjunct (n=2) and full-time (n=4) faculty, with a variety of years of experience teaching and representing a mix of genders, race, age, and seniority at the institution. For the purposes of the mathematics experimental portion (the focus of this study), the experimental group is considered the six instructors working with Tablet PCs during that semester and this experimental group will be compared to the rest of the mathematics instructors, adjunct and full-time, as none of the other instructors were actively using Tablet PCs in their classes that semester. Each of the six instructors selected for participation in the experiment taught only one section of the Pre-Calculus course.

Participant Selection: Students

The course identified for the project was MTH2003: "Pre-Calculus with Elements of Calculus". All six instructors had taught the course before. The Pre-Calculus course was identified as a course in which critical concepts and skills were developed that would be necessary for students' future academic success, particularly in the business major. It is also commonly seen as a "gatekeeper" course that students may need to take multiple times before passing and so the issues of student performance (pass rates) and student persistence (retention rates) are clear concerns for the institution regarding this course. Each section of Pre-Calculus was capped at 30 students, and enrollment in the experimental sections took place as part of the college's standard enrollment and registration processes – so students did not know in advance that they had enrolled in an experimental section. A total of 828 students enrolled in MTH2003 at the beginning of the Spring 2010 semester (640 students across 29 day sections, 188 from 8 evening sections), of whom 154 were enrolled in one of the six experimental sections, for a total of 129 day and 25 evening students. Exam performance data is regularly collected by the mathematics department each semester for teaching assessment purposes and so was available, in aggregate, for comparison purposes between the six Tablet PC sections and the remaining sections of the course during the Spring 2010 semester.

Preparation: Faculty Development

Participating instructors were selected early in the Fall 2009 semester and spent the next few months preparing to teach the experimental Pre-Calculus sections in the Spring 2010 semester. Over a period of four 2-3 hour faculty development sessions, the six instructors were introduced to the Tablet PC and worked together to develop materials for implementation in the

following semester. A general introduction to the technology and software options was provided by a member of the college's information technology staff. Only one of the six instructors had prior experience using a Tablet PC in teaching mathematics courses – he led one of the faculty development sessions and served as a general technical resource for the rest of the teaching team. The remaining five instructors had varying levels of technical proficiency and comfort levels with the new technology. Additional faculty development focused on incorporation of graphing calculator technology for visualization of Pre-Calculus concepts and troubleshooting specific software questions. Use of both Microsoft OneNote and Windows Journal were explored, and the instructors ultimately made their own software selection based on individual preferences. Each computer was also equipped with a Virtual Texas Instrument emulator for the TI-89 (the department standard required calculator for MTH2003), Adobe Acrobat for PDF editing, and the standard Microsoft Office suite.

Implementation

All six instructors used Tablet PCs in teaching their Pre-Calculus section. Individual techniques for incorporating the Tablet PC varied slightly between instructors but in general included the following activities:

- Writing on the Tablet PC screen instead of on the white board, which was then projected on a large screen in the front of the classroom (in most rooms the screen covered the white boards, so the Tablet PC served as a direct replacement, rather than supplement, to board writing). This included both typing and hand-writing text, writing mathematical symbols and expressions, writing in multiple colors, and drawing sketches of graphs or other mathematical images.

- Demonstration of homework problems from the online homework system WeBWorK, including "live" problem testing and solution entry.
- Incorporation of pre-typed word problems from PDF files (e.g. homework, sample exams)
- Demonstration of graphing techniques via TI-89 emulator
- Incorporation of graphs generated on TI-89 emulator as images embedded within class notes
- Incorporation of graphs or other numerical data representations from programs such as Microsoft Excel

Several of the instructors had previous experience projecting the TI-89 emulators, WebWork online homework system, and Excel charts in class from a standard laptop. They found the impact of these programs was enhanced by the additional functionality a tablet PC provided. For example, once material from these outside sources was incorporated into the class notes file, it could be written over with a pen tool – instructors used this feature to label key points on a graph, underline or highlight portions of a sentence in a word problem, or add additional comments to previously prepared material.

Another important feature of the tablet PC notes system was the ability to combine all of the handwritten notes, WebWork example problems, graphing calculator images, and other programs into a single file representing the entire day's material. After each class, instructors would save the resulting notes as PDF files and post the notes on the class's Blackboard site. Some instructors also used the Tablet PC to write up answer keys for homework, quizzes, and/or in-class exams and posted those on Blackboard as well. One proposed use of the Tablet PCs during the semester development meetings was for instructors to be able to respond to student questions via email more easily (writing out a response and attaching as a PDF instead of trying

to type mathematical notation in the body of an email), but the participating instructors reported making use of this feature only rarely, if at all, throughout the semester.

In addition to the faculty development sessions held in preparation for the experimental semester, the six instructors also met every two weeks for the duration of the semester to discuss their progress and troubleshoot issues as they arose. Some faculty members experienced technical difficulties with their hardware or the equipment in their classroom, but ultimately each instructor was able to use the Tablet PC in class for the majority of the class meetings that semester.

Data Collection

Assessment

The department uses a standardized final exam across all sections of the introductory-level mathematics courses. The exam consists of 35 multiple choice questions, 25 of which are to be done without a calculator and then 10 more questions for which a TI-89 calculator may be used. The exam is written by a full-time faculty member selected on a rotating basis each semester. After drafting, the exam is checked for accuracy and difficulty level by a few other faculty members and may be revised repeatedly. Once the exam is finalized, multiple versions are generated (through rearrangement of question order and answer choice order per question) to minimize the possibility of cheating. Also, all sections of the same course take the common final exam at the same time.

The exam is scored by Scantron machine. Each question is worth 3 points (so there is a built in bonus – 35 or 34 questions correct are both scored as 100%. 33 questions correct is a final score of 99%, and so on). The mathematics department requires that students pass the final

exam with a 50% or better (at least 17 questions correct) in order to pass the course, regardless of performance and grades from the rest of the semester. Because of this requirement, and due to the inherent variability in individual instructors' grading policies, experimental sections were compared to the control group on the basis of student performance as measured by the pass rate on the final exam. This data was also available (in summary form) for the MTH2003 course for the previous 10 semesters, allowing for a longitudinal comparison as well.

Another area of interest identified by the department was that of student persistence and retention in mathematics courses. The department collects data each semester on withdrawal rates and so retention of students in the six experimental sections could be compared to retention in the remaining 36 sections.

Survey

In addition to the exam scores, researchers also surveyed students in the six experimental sections about the implementation of Tablet PCs in their class and the students' use of various Tablet PC-generated materials. The survey included both a frequency-of-use assessment and room for free response comments from students regarding their perceptions of possible advantages or disadvantages of using Tablet PCs in teaching mathematics. Student survey responses were collected from all six experimental sections. Frequency of use reports were not significantly different across the six sections and so are reported in aggregate. Free-response portions of the survey were analyzed for common themes as well as strongly positive or strongly negative views. These responses helped identify areas of use that mattered most to students, which were occasionally different from those predicted by the participating instructors.

Results & Discussion

Exam Results

A number of indicators were tracked to determine impact of instructor use of Tablet PCs on student performance. These included withdrawal rates (as a measure of retention), pass rates on the department's standardized final exam, and scores on the standardized final exam. Course grades and overall course passing rates were deemed subject to too much variability per instructor and so were not included in the analysis.

Evening sections of this course historically feature a different student population from the day sections, consisting of more part-time students and students working full-time jobs. Regardless of Tablet PC use, students in the evening sections were found to have significantly lower scores on the common final compared to students in day sections (evening average: 18.57 vs. day average: 20.80, $p = .000$). Additionally, only one of the Tablet PC experimental sections was a night section, making it impossible to differentiate effects of the Tablet PC from that of the particular instructor. Therefore, the data sample for comparison was restricted to the 639 students in day sections ($n = 128$ from the 5 sections with a Tablet PC and $n = 511$ from 22 sections without a Tablet PC). Table 1 shows the difference in withdrawal rates for these two groups. Retention appeared higher in classes where a Tablet PC was used, but the difference was not found to be statistically significant ($p = .061$ in a one-sided Fisher's Exact test).

Table 1: Retention Rates

	Students Taking Final Exam	Students Enrolled At Beginning of Semester	Retention Rate
Tablet Classes	105	128	82%
Non Tablet Classes	384	511	75%

Pass rates on the department final exam were determined as the number of students who passed the exam (defined as scoring 50% or better) out of the total number of students who took the exam (so students who withdrew are not counted in this statistic). The pass rate for students in day sections using a Tablet PC was significantly higher ($p = 0.032$) than that of students in day sections without a Tablet PC, according to a Pearson Chi-Square test.

Table 2: Pass Rates

	Students Passing Final Exam	Students Taking Final Exam	Pass Rate
Tablet Classes	91	105	87%
Non Tablet Classes	296	384	77%

In a Levene Test for Equality of Variance between the two groups, equal variance was rejected ($p = .013$), confirming higher variance in the non-tablet group (Standard deviation 5.615) than the tablet group (standard deviation 4.776). Because equal variance could not be assumed, a Welch's (unpaired) *t*-test was used to compare the equality of means of the exam scores from each sample group.

Table 3: Final Exam Scores

	Mean Final Exam Score (Raw)	Mean Final Exam Score (Percentage)
Tablet Classes	21.93	65.79%
Non Tablet Classes	20.49	61.47%

The difference in mean scores was statistically significant ($p = .009$, 2-tailed *t*-test), with the tablet group scoring higher (on average) than the students in a non-tablet section. Note that both

of these averages are above the 17 required to pass the exam, and that the mean scores are within 2 questions of each other – so the mean final exam score percentages both fall in the "D" grade range (60-66%). Therefore it remains to be seen whether the differences between experimental and control groups, while statistically significant, are significant in terms of overall student performance in this or future classes.

Finally, a longitudinal comparison was made between instructors using a Tablet PC in the Spring 2010 semester and those same instructors class results from the previous year (n=4)[1]. This allowed for comparison of an individual instructor's impact on student achievement with and without a Tablet PC and helped isolate the Tablet variable. A Spring-to-Spring comparison was deemed more valid than comparing within the same academic year, because the population of students taking Pre-Calculus varies significantly between Fall and Spring (more repeaters and students who had started their college career in a lower-level math course are enrolled in the Spring sections).

Results of the longitudinal comparison varied greatly by instructor – some instructors experienced higher retention rates but lower exam scores, others slightly (but not significantly) higher exam scores, etc. The wide disparity is difficult to interpret due to the very small sample size and could have been impacted by a number of factors, such as individuals' technology adoption learning curve, variability in groups of students, etc. It is worth noting that the 2010 exam was deemed substantially more difficult than the one given in 2009. That is, in cases where there was general improvement in the mean final exam score once instructors started using

[1] Only 4 of the instructors from the 6 research study participants taught the same course in the Spring for both years.

a Tablet PC, that improvement was in the face of an overall decrease[2] in the average exam score between the two years.

Survey Results

Additional data was collected via a survey given to all students in a class using a Tablet PC (n = 125). These self-reported responses include an indication of the frequency and method students used for accessing Tablet PC-generated materials for the course.

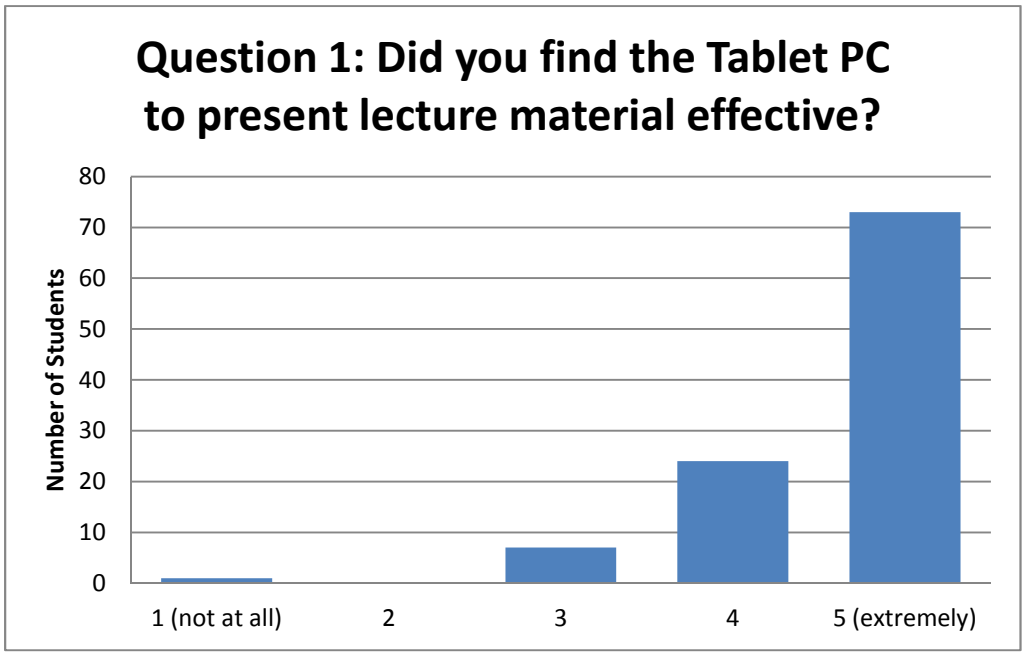

Figure 1: Responses from students in Tablet PC classes to survey question #1

Common themes that emerged from student responses when asked to discuss what they liked or disliked about the use of the Tablet PC in class included the fact that no material is ever lost the way a board gets erased, professors were able to incorporate additional technology into the

[2] Spring 2009 mean score = 21.85, Spring 2010 mean score = 20.08. Welch's t-test for equality of means yielded a p-level of .000.

lecture & notes (e.g. calculator emulator), and that knowing the materials would be posted after class allowed students to focus more on the discussion at hand without worrying as much about keeping up with taking notes. For many students, this process meant increased engagement with the material during class time but some admitted that they paid less attention since they weren't taking their own notes. Dissatisfaction with Tablet PC use in class largely centered around frustration with technological difficulties; a few students also mentioned discomfort with any new classroom system in general and expressed a preference for more traditional board-writing approach.

Selected student responses to the open-ended survey questions are presented below:

> "I liked the fact that it frees you up from writing much notes. In class you can spend more time on listening to what the professor says instead of writing notes and possibly not hearing vital lecture parts. However, in the beginning it gave me, personally, a false pretense that I did not have to take notes and certain times I was not able to follow the steps taken by the professor to reach a certain solution. The tablet notes in combination with side notes you take on your own proved effective in the end."

> "I like the fact that I did not have to focus my time writing my own notes. I also like that the tablet allowed professors to face and talk directly towards the students as opposed to facing and talking to the board. The tablet also allows for the centralized point of attention as well as larger text that is easier to see. Only disliked times when professor would have problems getting the tablet to cooperate."

> "I also liked the ability to copy and paste problems and etc., it saves a lot of time and is very clear and organized."

> "I didn't like using the Tablet PC because the professor is concentrated on technology too much rather than the actual explanation."

The student responses largely matched faculty reports on the benefits and drawbacks. Several students with reservations did suggest that Tablet PC use in classes continue as long as faculty received more training and the "kinks" of the new technology were worked out moving forward.

Students were also asked about their use of materials generated from a Tablet PC:

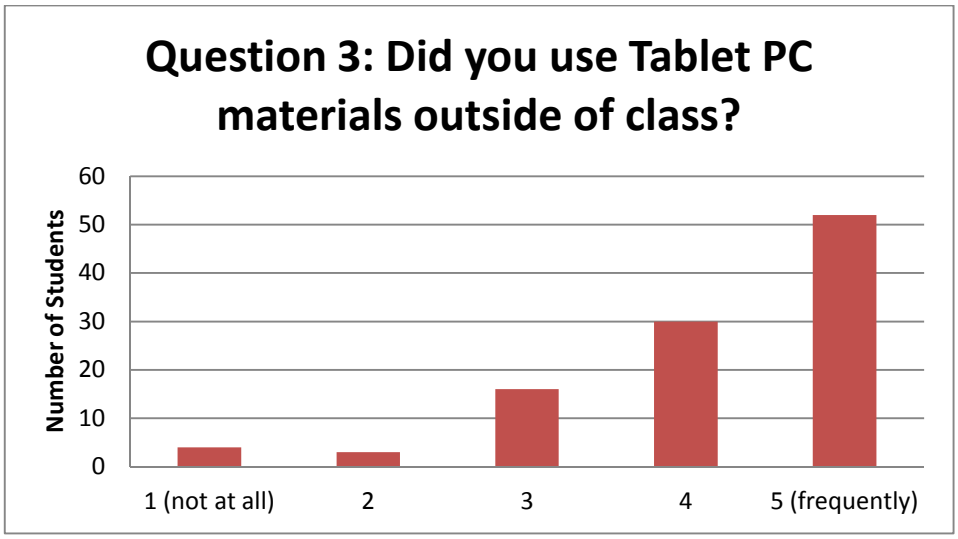

Figure 2: Responses from students in Tablet PC classes to survey question #3

Several students reported printing the class notes to use in their own studying, keeping them alongside their own notes as a supplemental resource or reference from a missed class.

> "Because of my sloppy handwriting it was a great resource to use in comparing any ambiguity in my personal notes with the accurate ones posted on Blackboard."

Students also mentioned checking the notes online if they were stuck on a homework problem and wanted to look back at that day's examples. One particularly surprising response (repeated by several students) was the ability to work on homework from anywhere at any time, without needing to have a textbook or notebook with them – since students have their laptops or cell

phones almost all the time, they mentioned the particular benefit of having tablet notes to go along with the pre-existing online homework system.

> "I print out the lecture, go to work and when I have down time I go over it a few times. I also use it when doing homework. I love it that all lectures are saved. If I want to look at the lecture from class 1 I can do it or if I want to see the one from class 3 it is there. The tablet PC is the beginning of how math should be taught. The student can listen without having to write at the same time."

Conclusions & Future Research

In this study of 6 sections of Pre-Calculus courses following a "single-tablet" model, instructor use of a Tablet PC to present material in class was found to improve student retention, pass rates, and average scores on the department standardized final exam. Student and faculty survey responses suggest that increased performance on these assessments may have been partially due to the availability of a PDF record of class notes online; students reported feeling able to pay closer attention during class sessions since they knew notes would be available afterward. It is also possible that having the additional resource of Tablet PC-generated notes available increased the amount of time students spent reviewing or studying course material outside of class, as compared with students in the non-tablet sections. Students and faculty in the study expressed generally positive perceptions of the single-tablet implementation.

The results used for data analysis were restricted to spring semester day sections of a Pre-Calculus course. Typically the spring sections of Pre-Calculus perform somewhat lower than the fall sections, since students taking Pre-Calculus in the spring either failed it in the fall and are repeating the course or started the fall semester in a College Algebra course, indicating a weaker high school mathematics background than those students who enroll in Pre-Calculus in the fall semester. Additionally, analysis of performance over the past five years suggests that students in

evening sections tend to exhibit both higher withdrawal rates and lower pass rates than students in day sections. This may be attributable to several factors such as differences in mathematical background between returning and traditional college students, workload and other responsibilities for students attending school in the evening, etc. In the future, it would be interesting to compare fall semester performance, or to more fully explore the different impact of technology adoption on different student groups (e.g. in day vs. evening sections) in a larger study. An additional topic for study is whether there is any link between the benefits students gain from Tablet PC use and the implementation of an online homework system or other technological tools. Anecdotally, it seems that students appear to appreciate the use of a Tablet PC more when other portions of a course are already happening in an online environment.

A further limitation on the generalization of our results relates to instructor selection. The participants in this study were chosen on a volunteer basis and so present a naturally self-selecting group of engaged teachers interested in improving their teaching. However, volunteers were not initially told about the Tablet PC incorporation in the experiment and so did not specifically self-select on the basis of technological proficiency. As with any new teaching approach or technology adoption, there is a learning curve for each individual faculty member in mastering the new approach and incorporating it fluidly in their classroom practice. Based on difficulties that some instructors experienced in adapting to the Tablet PC technology, it is recommended that any further roll-out of such technology be on a voluntary basis rather than mandated department-wide. While students responded quite positively to the use of Tablet PCs in class and to the ability to view the notes online afterwards, when the instructor had a hard time getting the technology to work or felt awkward using it, that difficulty was reflected in student survey responses about the Tablet PC's usefulness.

Given the improvements in student performance identified in what was most instructors' first semester using a Tablet PC, it would be interesting to continue the study over a longer period of time to see if increased instructor familiarity with the new technology helps mitigate some of the downsides and enhance student understanding and achievement. Areas of exploration include refining some of the software implementation difficulties and exploring incorporation of more advanced technologies, especially those for visualization (math applets, wolfram alpha demonstrations, use of excel for statistical analysis, etc) or for increased student participation.

References

Anderson, R., Anderson, R., Simon, B., Wolfman, S.A., VanDeGrift, T., & Yasuhara, K. (2004). Experiences with a tablet PC based lecture presentation system in computer science course, *Proceedings of the 35th SIGCSE Technical Symposium on Computer Science Education*, 56-60.

Berque, D., Bonebright, T., & Whitesell, M. (2004). Using pen-based computers across the computer science curriculum*, Proceedings of the 35th SIGCSE Technology Symposium on Computer Science Education*, 61-65.

Brophy, S. & Walker, G. (2005). Case study of the pedagogical impact of tablet PCs as a presentation medium in large-scale engineering classrooms, *Proceedings of the ASEE.*

Carruthers, C. (2011). A collaborative pen-based PC workspace for teaching and learning mathematics, *Proceedings of the Second North American GeoGebra Conference, GeoGebra-NA2011.* June 17-18, 2011, Toronto, Ontario: University of Toronto, 41-45.

Cox, J. R. & Rogers, J. W. (2005). Tablet PC's: Are they the next technopedagogical fad?, *Journal of College Science Teaching*, *34*, 7.

DiGiorgio, A. (2003). Florida school participates in the tablet PC pilot program, *Transforming Education Through Technology Journal*, *31*, 10.

Donovan, D. & Loch, B. (2012). Closing the feedback loop: engaging students in large first-year mathematics test revision sessions using pen-enabled screens. *International Journal of Mathematical Education in Science and Technology, 43*(1)*,* 1-13.

Ellington, A. J., Wilson, J. H., & Nugent, J. S. (2011). Use of tablet PCs to enhance instruction and promote group collaboration in a course to prepare future mathematics specialists. *Mathematics and Computer Education*, *45*(2), 91-105.

Filer, K., Tront, J., Scales, G., & Olsen, D. (2008). The Tablet PC as a catalyst for pedagogical innovation and improvement in higher education, *Conference Proceeding at Asia-Pacific Educational Research Association Conference,* Singapore, November 26-28, 2008.

Fister, K. R. & McCarthy, M. L. (2008). Mathematics instruction and the tablet PC, *International Journal of Mathematical Education in Science and Technology*, *39*(3), 285-292.

Galligan, L., Loch, B., McDonald, C., & Taylor, J. (2010). The use of the tablet and related technologies in mathematics teaching, *Australian Senior Mathematics Journal*, *24*(1), 38-51.

Gorgievski, N., Stroud, R., Truxaw, M., & DeFranco, T. (2005). Tablet PC: A preliminary report on a tool for teaching calculus, *International Journal for Technology in Mathematics Education*, *12*(3), 95 – 102.

Gupta, M. L. (2009). Using emerging technologies to promote student engagement and learning in agricultural mathematics, *The International Journal of Learning*, *16*(10), 497-507.

Hawkes, M. & Hategekimana, C. (2009). Impacts of the mobile computing on student learning in the university: A comparison of course assessment data, *Journal of Educational Technology Systems*, *38*(1), 63-74.

Hieb, J. & Ralston, P. (2010). Tablet PCs in engineering mathematics courses at the J.B. Speed School of Engineering, *International Journal of Mathematics Education in Science and Technology*, *41*(4), 487-500.

Kraushaar, J. M., Cittenden, T., & Novak, D. (2008). A descriptive study of perceived and actual PC use by undergraduate students in a traditional lecture-based graphical modeling class in R. Reed & D. Berque, & J. Prey (Eds.), *The Impact of Tablet PCs and Pen-based Technology on Education* (81-88). West Lafayette, Indiana: Purdue University Press.

Lim, K.Y. (2011). What does the tablet PC mean to you? A phenomenological research. *Innovations in Education and Teaching International, 48*(3), 323-333.

Lohani, V., Castles, R., Johri, A., Spangler, D., & Kibler, D. (2008). Analysis of Tablet PC based learning experiences in freshman to junior level engineering courses, *Proceedings of the ASEE National Conference*. June 22-25, 2008, Pittsburgh, Pennsylvania. 1-18.

Mock, K. (2004). Teaching with tablet PCs, *The Sixth Northwest Consortium for Computing Sciences in Colleges*. Salem, Oregon.

Reins, K. (2007). Digital tablet PCs as new technologies of writing and learning: a survey of perceptions of digital ink technology. *Contemporary Issues in Technology and Teacher Education, 7*(3), 158-177.

Romney, C. (2011). Tablet PC use in freshman mathematics classes promotes STEM retention. *Proceedings of the Frontiers in Education Conference,* F1J.1-F1J.7.

Schwager, P. H., Anderson, J. E., & Kerns, R. L. (2005). Faculty perceptions of tablet PCs for teaching, research, and service: a college of business perspective. *Proceedings of the 2005 Southern Association of Information Systems Conference.*

Weitz, R. R., Wachsmuth, B. & Mirliss, D. (2006). The tablet PC for faculty: a pilot project, *Educational Technology and Society*, *9*(2), 68-83.

Yost, S. (2007). Using a tablet PC to enhance instruction and productivity. *Proceedings of the ASEE-North Central Section.*

Funding & Acknowledgements: Faculty development and participation in this study was supported by a CUNY Innovative Programs Grant, and the Lenovo Tablet PC equipment for each instructor was provided by National Grid. The authors would like to thank Sarah Harney and the other members of the Tablet PC experimental team for their support and participation in the study, and Dr. Jennifer Gosselin for her help conducting the statistical analyses.