Tablet PC Technology for the Enhancement of Synchronous Distributed Education

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Abstract—In this paper, we describe how Tablet PCs are being used at Georgia Tech Savannah (GTS) to improve student learning in a distributed classroom environment. The Tablet PC is an attractive technology for use in synchronous distributed learning environments because of its mobility, and its ability to not only serve as an effective note taking device but also as a high-resolution course content viewing device and a tool for interactive assessments. The research questions addressed here are: 1) "What impact does the Tablet PC have on student perceptions of their engagement in a distributed learning environment?" and 2) "Can the Tablet PC be used to improve student learning in a distributed learning environment?" In this project, the instructor and students were given a Tablet PC to use during the semester, and surveys were administered to evaluate student attitudes about the use of Tablet PC technology as a means of receiving, processing, and learning course material. The significance of this work is that it serves as a case study on the use of Tablet PCs as an effective technology for implementing established educational practices in distributed education environments.

Index Terms—Engineering education, distributed education, tablet PC, distance learning, digital ink technology, active learning.

1 Introduction

Distributed Learning (DL) environments seek to implement established pedagogies for effective student instruction in a unique classroom structure where the instructor and students may not be present in the same physical learning environment. Despite the technology that is available to deliver video and audio streams to remote classrooms, DL environments are still challenged in discovering ways to promote active learning and meaningful instructor-student and student-student interactions during a class session [1], [2]. Many synchronous DL classrooms utilize basic video-conferencing designs that allow for audio and video communication between sites but often suffer from two primary challenges in creating effective learning environments: 1) poor transmission quality of lecture material and 2) constraints on creating in-class material for participant interaction and student assessment.

Although resources designed to improve distributed education exist [3], [4], [5], physical factors that cannot be avoided often degrade the quality of the education experience. For example, the delivery of lecture content is largely dependent on the quality of equipment and protocols that are in place. The reality is that poor video resolution in delivering class material to a distant classroom can be particularly damaging to a student's ability to view and follow the lecture. Regarding instructor-student and student-student interaction, the physical separation of DL classrooms largely limits all in-class interaction and responses to purely verbal interaction. Additionally, any in-class testing, evaluation, and assessment (e.g., practice problems, exams, etc.) must be prepared enough time in advance to be sent to each remote site prior to the start of a lecture. Completed assignments must then be collected and sent to the instructor after class via mail, e-mail, or fax, which prevents instantaneous feedback. Thus, this process limits the options for instructors who frequently use in-class activities and assessments to promote active learning.

In this paper, the authors describe how Tablet PCs [6] are being used at Georgia Tech in an effort to improve student learning in a distributed classroom environment. Specifically, the motivation for this paper is to report on how Tablet PC technology and software may improve the delivery of lecture material and have an impact on student learning in a DL course. A discussion about how the Tablet PC technology and software reduce some of the constraints on the instructors and students in creating effective learning experiences is also presented. In this project, the instructor and students were given a Tablet PC to use during the semester along with the Dyknow [7] software package. Surveys were administered to evaluate student attitudes about the use of Tablet PC technology as a means of receiving, processing, and learning course material. In addition, an analysis of student performance in the pilot courses was performed and benchmarked against their academic performance in other coursework. The research questions addressed here are:

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1. What impact does the Tablet PC and Dyknow software have on student perceptions of their engagement in a distributed learning environment?
2. Can the Tablet PC and appropriate software improve student learning in a distributed learning environment?

Preliminary results from this pilot project at the Georgia Tech Savannah campus indicate that the use of Tablet PCs with appropriate interactive software can improve student satisfaction with their learning process in a synchronous DL environment. Additionally, there is evidence to suggest that student performance is positively affected in some measure over their performance in other synchronous DL environments. To fully determine the effect on student learning will require significantly more data and analysis. Thus, the significance of this work is to serve as a case study that reports on the usefulness of Tablet PCs as an effective technology for implementing established educational practices.

2 Background

The underlying foundation of conveying information in an educational environment has changed very little over the years. The process of information delivery in the classroom generally revolves around an instructor presenting written or electronic material while the students process and/or write down the information presented to them. Additionally, in order to promote learning, instructors strive to create environments that promote and facilitate the learning and understanding of concepts. Thus, deep learning is separated from surface learning [8] and encompasses the higher levels of learning in the cognitive domain as defined by [9]. This type of learning can be achieved via the use of an appropriate instructional design process [10], [11]. In the classroom, instructors may then pose questions, present problems or exercises to the class, design inquiry activities for teams to pursue, or use many other pedagogical techniques with the goal of promoting student engagement and interaction. Recent emphasis on these types of activities has created a shift from the traditional teaching paradigm to a learning paradigm [12]. Underpinning this paradigm shift is foundational educational research that has established a sound set of principles to better understand human learning [13]. Furthermore, it has been widely acknowledged that effective educational practices within this learning paradigm should provide active learning environments in which the cycle of knowledge transfer between instructor and student involves feedback to correct misconceptions and promote student learning. Several summaries of the literature in this area are available [14], [15], [16], [17].

What is changing, at a very rapid pace, is the technology that is available to the instructor to use in the classroom for the development of new educational practices and pedagogies. Computers, the Internet, hand-held devices, and a host of other technological marvels have altered the concept of knowledge transfer, and classrooms are being reconstructed and redefined with very different modalities for teaching, assessment, and learning. This revolution in communications has created broad impacts on the 21st century classroom [18], [19]. The Classroom 2000 project [20], [21] promoted technology for authoring, capturing, and storing lecture content and class events using pen-based computer devices for the instructor and students. One of the goals of the project was to ensure that lecture events could be easily captured and integrated for future access. Work concerning *Authoring on the Fly* [22] presented tools for creating multimedia representations of lecture content that could be used in a local class session or across distance. The use of technology to create virtual environments for instructor-student interaction on pen-based and mobile computing devices has been promoted in several other projects as well, such as *Classtalk* [23], *ClassinHand* [24], and *WIL/MA* [25].

However, the use of technology in the classroom does not necessarily equate to increased learning, more effective teaching, or a more engaging learning environment. In education, the merit of technology must be judged on its ability to improve student learning [26], [27], [28], [29]. In other words, technology is only a medium or a tool through which new educational pedagogies may be developed, and the effectiveness of these new pedagogies will depend on how these technologies are deployed.

While there are a number of useful studies on the use of computer technology in the classroom, this article will focus on examples related specifically to Tablet PCs.

2.1 Tablet PCs in Education

Tablet PCs are being evaluated in many colleges and universities for their effectiveness in improving student learning, promoting student engagement, enhancing the delivery of electronic course materials, and providing an effective way to connect the instructor and student together in an integrated learning environment [30], [31], [32]. Tablet PCs function in much the same way as traditional laptops with the added functionality of providing the user digital ink to create information directly on the screen. Investigations of the impact of laptops in the classroom such as [33] have paved the way for innovative uses of tablets [34], [35]. The use of digital ink in the classroom is not unique to Tablet PCs as electronic whiteboards (e.g., smartboards [36]) and other forms of digital ink have been available for a number of years. Digital ink technology provides flexibility to instructors in creating lecture content before, during, and after class. It has also been shown that digital ink may be used to effectively create annotations on prepared lecture content as a substitute for physical gestures to highlight context and meaning during lecture [37], [38]. The use of pen-based devices in basic classroom activities and the desire for instructor-student interaction is supported by several software programs which include (but are not limited to) Classroom Presenter [39], Dyknow [7], *BIRD* [40], *Writon* [41], [42], and eFuzion [43] to list only a few. Dyknow software was adopted for use in this study.

Tablet PCs may be implemented in an instructor-only environment (i.e., where only the instructor has a Tablet PC for creating and displaying content) such as in [44], [45], [46], [47] or in an environment where the instructor and students have access to Tablet PCs (or other pen-based computers). The latter environment is of particular interest to this study. In [48], the instructor and students utilized

Tablet PCs in conjunction with Classroom Presenter to deliver lecture content and distribute/collect student exercises. While learning outcomes were not directly evaluated, the student participants showed a high degree of receptivity to the technology. Additionally, it was noted that the inclusion of prepared material that involved in-class exercises lead to a increase in the preparation time for the lecturer. Another study combining Tablet PCs and Classroom Presenter [49] divided a class of 52 students such that 19 used loaner Tablets, 20 used personal laptops, and 13 did not use either device. Regarding overall performance, it was found that the students who utilized Tablet PCs performed slightly better when considering their final grades. Work in [50] highlighted the use of Dyknow and Pen-based Wacom Tablets for the instructor and students in a computer science department for supporting collaborative note taking, classroom interaction, the ability of students to replay lecture material outside of class, and basic lecture presentation. The results suggested that the combination of Dyknow and the Pen-based input devices was helpful in creating an effective educational environment. Instructors reported a heavy usage of the digital ink input during lecture with an approximate 50/50 split in the use the pen and keyboard input outside of lecture for class preparation. Additionally, the study reported that students tended to use the pen and keyboard inputs in approximately equal parts. A similar study [51] investigated the use of digital ink versus keyboard input. In the project, groups of students were given access to laptops or Tablet PCs while the instructor would conduct class lectures and problems using software interface based on Classroom Presenter. The results of the study showed that Tablet PC users nearly always used the digital ink option for working class exercises and performing other simple input operations. However, while students tended to prefer the digital ink option for input in problem-oriented sessions, many students were able to function with either input mode depending on what was available. Work in [52] investigated a laptop initiative that would require students to own Tablet PCs. The study utilized a combination of Dyknow software and Tablet PCs for the instructors and students. Surveys on the student participants indicated that 90 percent of the students felt the most effective use of the software features was while using the digital ink input. Students identified their favorite feature to be the ability to see the instructor's notes exactly on their own Tablet and being able to annotate the notes as they wished. Additionally, the survey responses suggested that the students felt there was a positive impact on their learning while using the technology. A summary of several types of deployments of Tablet PCs in various levels of education is found in [53]. However, these studies and most of the other work that relates to wide spread deployment of Tablet PCs in the classroom have focused on nondistance learning environments. The case study presented here focuses primarily on synchronous distance learning classrooms.

2.2 Distributed Education at Georgia Tech

Distributed learning (DL) environments have become a significant part of the infrastructure at Georgia Tech, which has faculty and students distributed across campuses in Atlanta (Georgia), Savannah (Georgia), Metz (France), and Shanghai (China) [54]. Currently, Georgia Tech Savannah (GTS) provides engineering education to students who are physically located at four different universities. In this scenario, the instructor and students engage in a live classroom session via videoconferencing equipment that allows the students and professors to be at different geographical locations. Distance education programs are not intended to replace traditional face-to-face classroom instruction, but rather to expand the accessibility of knowledge to students where face-to-face instruction is not always feasible [55], [56], [57], [58].

While, conceptually, DL environments expand the accessibility of education to a wider group of students, the design of DL classrooms have typically suffered from several challenges that create significant barriers to effective student learning and teacher instruction including:

1. poor transmission quality of live lecture content,
2. limitations on basic classroom interaction among the instructor and students,
3. challenges in class administration of basic assessment activities, such as in-class examples and exams, and
4. difficulty in students receiving help when not in lecture.

These challenges have caused students and instructors to have serious reservations about how effective a DL environment can be for education. This paper presents how many of these challenges were addressed with the use of Tablet PC technology and software.

3 Tablet PC Implementation

With support from HP, Microsoft, and GTS, Tablet PCs equipped with Dyknow software were installed in two remote classrooms spanning two academic years from 2006-2008. The courses targeted for this project were distributed across two campuses that were separated by 50 miles, and the faculty teaching the course would often rotate between the two campus sites so that each student would have an opportunity for live instruction. Over the 2006-2008 academic years, a total of five GTS faculty members across six engineering courses and over 120 students were involved in the project. An example of a traditional DL environment between two classrooms is shown in Fig. 1a with an instructor having the option of creating lecture content on a computer, elmo [59], or whiteboard that is displayed locally and transmitted for projection at a remote class site. While video and audio are exchanged openly via microphone and camera equipment, the exchange of any electronic data created in class is primarily only from the instructor to the student. Additionally, any feedback the instructor may receive from the students is limited to verbal interaction. While this modality does allow for the basic functionality of a class session, instructors and students have generally not found this to be an ideal model for facilitating an active learning environment. Fig. 1b shows the model for the DL environment that was implemented for this paper which integrates Tablet PC technology and Dyknow software. Within this environment, the instructor

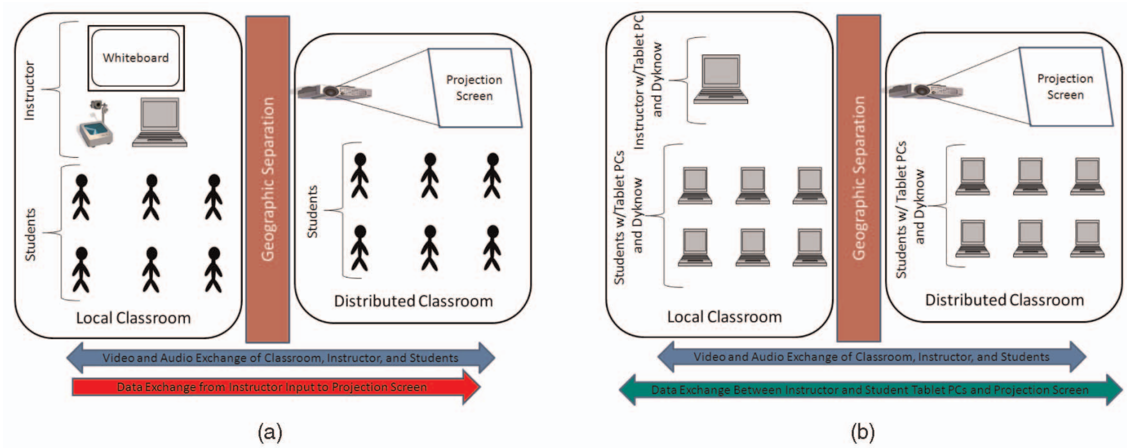


Fig. 1. Distributed Learning (DL) setup. (a) Traditional/common DL environment. (b) Tablet PC/Dyknow software integration.

uses a Tablet PC to present lecture material to students and students are able to view the lecture on their own Tablet PCs and have the ability to independently scroll back over previous slides, in real time, as the instructor lectures. Additionally, the instructor is able to create an active work space so that students, local and remote, may freely exchange electronic data among themselves and with the instructor. The digital ink input modality of a Tablet PC allows the instructor to freely annotate prepared material, create on-the-fly examples and problems, and easily write complex equations and simple diagrams. For the students, the digital ink input allows them to take take private notes, make personal annotations on the lecture, send written examples of questions to the instructor, and solve in-class assessment activities (i.e., exams, exercises, etc.) directly on their Tablet PC screen. As mentioned earlier, there are several examples of interactive software that allow for digital ink input in the creation of lecture content and student assessment activities. However, we will present a few examples on the use of the Tablet PC technology and Dyknow software which was utilized in this case study.

The use of prepared lecture material (e.g., Powerpoint) is common in many engineering courses. However, some instructors prefer or feel more comfortable with the more traditional approach of delivering a lecture by writing on a whiteboard. The combination of Dyknow and Tablet PC technology allows for a ”hybrid” approach to lecturing. In this case, an instructor can prepare as many or as few slides as desired for lecture in Dyknow. During lecture, slides can be annotated, highlighted, or created completely in real-time. An example of this concept is presented in Fig. 2. The figure shows a slide that was prepared with some electronic text. However, the instructor then uses the remaining parts of the slide to annotate, demonstrate, and highlight key points being made during the lecture. The key aspect of this feature from an instructor’s standpoint is to provide freedom in exercising the method of instruction they prefer (i.e., prepared slides versus real-time content creation). From a student perspective, the lecture is presented directly on their Tablet PC screen and they are free to make private annotations or personal notes to supplement those of the instructor. Despite this opportunity, initial findings suggest that many students tended to take notes less frequently in their Tablet PC courses. This will be addressed further in the Results section.

A significant challenge in traditional DL environments is the difficulty in allowing for classroom interactions between the instructor and students and among students themselves. Creating an active learning environment requires a constant cycle of instructor-student and student-student feedback and interaction on class concepts and material. However, informal feedback from students and instructors has noted a feeling of being “disconnected” from the class participants. Instructors who use eye contact and various other forms of physical analysis to gauge their class involvement level find it much more difficult for the students who are only seen on a monitor at the back of the room. The Dyknow software interface grants class participants several options for interaction. One option is a simple color-coded bar on the software interface side for each student which can be changed in color to reflect a student’s level of understanding. The instructor interface (which contains some information that is seen only on the instructor Tablet PC) displays the color-coded feedback from each student at all times and can be used to determine when students seem to be following the lecture or when they are confused without the need to openly identify a

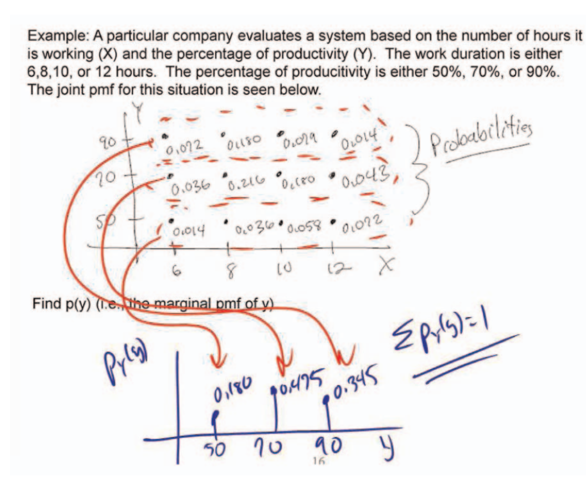


Fig. 2. Example hybrid slide created in Dyknow.

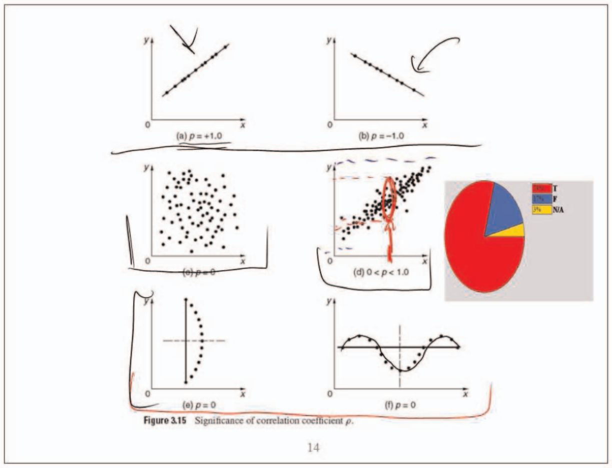


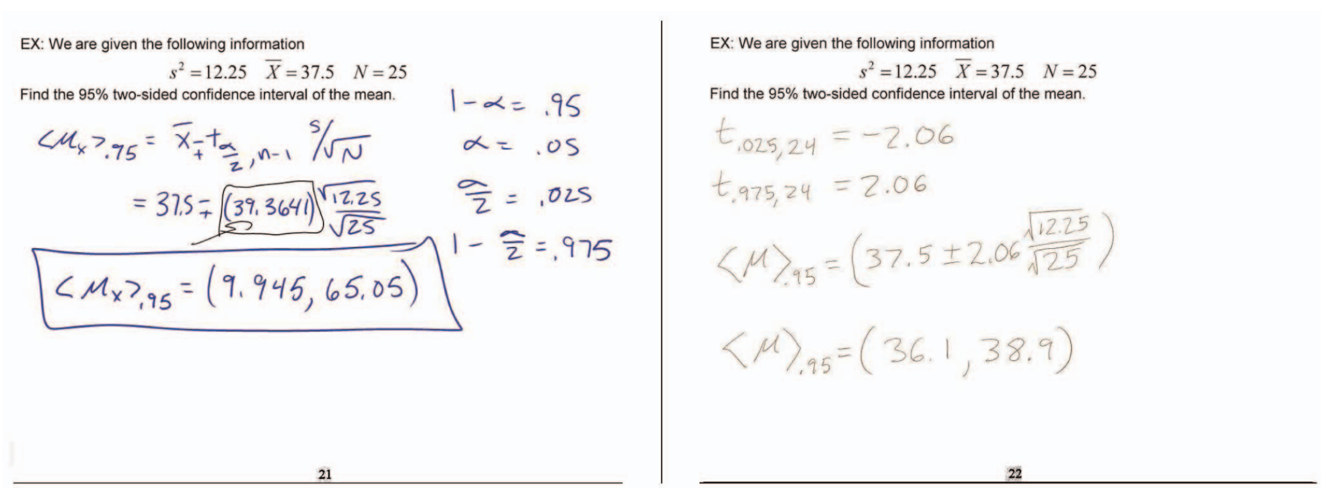
Fig. 3. Example class poll during a lecture.

specific student. Another feature involves the ability for the instructor to poll the class on a topic and display the results on every student's Tablet PC for the benefit of the entire class. Fig. 3 shows a pie chart that is the result of a class poll for a question relating to the slide. The students' responses are anonymous and do not require raising hands or verbal responses (things that are difficult enough to solicit in a traditional classroom and even more difficult in a distributed classroom). Additionally, each student can see where their thoughts and views fit within the rest of the class. The impact of this interactivity is an attempt to alleviate some of the perception of being "disconnected" from the instructor or other students who are not in the same physical space.

Another type of interaction of particular interest in STEM (Science, Technology, Engineering, and Mathematics) courses is the ability to create practice problems, shared diagrams, and other types of technical content during a class lecture [60]. This type of activity is largely dependent on the type of course and the instructor's style, but it is an important option to have available to accommodate a variety of lecture formats. It is this type of interaction in particular that is most challenging in a synchronous distributed learning environment as the most basic setup for DL course accounts only for the transmission of lecture content from the instructor to the student. Any in-class activity requires prior planning so it can be sent to the remote sites, collected, and then returned to the instructor for evaluation. The Dyknow software handles this type activity by allowing the instructor to create panels (or slides) which contain exercises that each student must solve and submit to the instructor for assessment. The instructor may view what is being written on any one of the student Tablet PCs as a problem is being worked, and the instructor may view the solutions submitted by each student to determine which students are having trouble with the problem. Fig. 4 shows an example of an instructor interacting with the class on a practice problem. In this example, a problem was presented to the class and each student was required to work the problem on their Tablet PC. In Fig. 4a, the student has answered the problem incorrectly. The instructor can then show the class this incorrect response without revealing the identity of the student who submitted it. The figure shows how the instructor indicates where the error has occurred, and this then becomes a point of discussion in the class. After the discussion, the instructor chooses a correct response to show the class, as shown in Fig. 4b. The impact of this activity is to give students an opportunity to practice their knowledge in class and receive immediate instructor feedback that can potentially correct and prevent errors that may occur in out-of-class assessment activities such as homework or projects.

4 Methodology

One of the dangers in evaluating attitudes regarding new technology is that it is difficult to assess if the subjects really find value in the use of the technology or are just struck by the apparent *novelty* of something they have not experienced before. In order to evaluate the effectiveness of the Tablet PC integration into the DL courses in this case study,



(a) (b)

Fig. 4. Student panel submission example. (a) Incorrect student response. (b) Correct student response.

TABLE 1
Student Composition by Discipline

CEE	EE	CmpE	ME
26%	47%	10%	19%

three surveys were administered over the 17-week semester as follows:

- *Presurvey*: Administered within the first two weeks of the semester. The purpose of this survey was to establish the baseline demographics of the students participating in the project. Information was gathered on student majors, the number of DL courses they had participated in, and their overall comfort with learning new computer applications.
- *Midsurvey*: Administered between week 8 and week 12 of the semester. The purpose of this survey was to get an initial evaluation from the students on how they felt that the use of the Tablet PC and software was impacting their learning experience in the DL classroom. Information was also collected on the opinions of students regarding the use of Tablet PCs in DL courses (Fig. 1b) compared to their other DL courses, which were set up to only transmit video and audio (Fig. 1a).
- *Final Survey*: Administered during the final week of the semester. This survey was structured almost identically to the midsurvey. Having responses to the same questions from two different points in the semester allowed for tracking of the consistency in student attitudes as they became more accustomed to the technology.

In addition to the subjective analysis of the surveys, a collection of cumulative student Grade Point Averages (GPAs) was collected along with the recorded grades for each student in the Tablet PC DL courses. The purpose of this analysis was to provide a general understanding of how well students performed relative to their cumulative performance in all of their other synchronous DL courses.

5 Results

Over the 2006-2008 academic years, five faculty in six different engineering courses and over 120 students were involved in this project. The survey response rate was approximately 75 percent for the presurvey, 78 percent for the midsurvey, and 92 percent for the final survey. The differences in student response rate can be attributed to several factors. In one course, students ignored the presurvey completely, which lowered the overall number of responses. Additionally, the midsurvey was approximately 60 questions long, which discouraged many students from taking the time to complete it. The relatively high response rate for the final survey is likely related to instructors making greater efforts to encourage students to participate and providing other class-related incentives for completing the survey. Table 1 shows the student breakdown by major: CEE (Civil and Environmental Engineering), EE (Electrical Engineering), CmpE (Computer Engineering), and ME (Mechanical Engineering). Over 90 percent of the students were enrolled as full-time students.

Since, for most students, this was the first time that they had used Tablet PCs in the classroom with the Dyknow software, it was desired that the students would be able to quickly learn how to use the Dyknow interface on their Tablet PC. Therefore, all students were asked about their confidence and abilities in learning how to use new computer applications and their general skill in using computers. The responses indicated that the majority of students in the project felt they had slight or moderate confidence and skill in learning and using computer applications. Responses to other survey questions administered throughout the semester revealed that students did not have trouble acclimating to the use of Dyknow in the classroom. The importance of these results was that it helped to ensure that student responses to survey questions focused more on the educational aspects of the Tablet PC technology in the classroom rather than on their difficulties in learning how to use new software. It was also important to note that nearly all of the students participating in this project had either previously been enrolled or were currently enrolled in a traditional DL course, i.e., one that did not use Tablet PCs.

Evaluating the effectiveness of a new technology in education can be challenging, and a relatively large pool of students is necessary to make general conclusions. Ideally, any assessment strategy would focus on measuring the effect of technology on student learning. However, even with carefully designed assessment strategies, it is extremely difficult to assess student learning and determine the primary factors that contributed to any changes in learning. Ultimately, each student is responsible for making the effort to learn the material that is presented to them. Therefore, three primary areas are reported in this article, including 1) the potential impact of the Tablet PC on student participation, 2) student attitudes on the Tablet PC integration, and 3) a general summary of student performance.

5.1 Student Participation

The ability to effectively engage students in lecture remains a challenging task in any learning environment. In a DL classroom, engaging students and creating an active learning environment are even more challenging since students at remote sites typically feel disengaged from the class since the instructor is not physically present to answer and ask questions, and eye-to-eye contact between the student and instructor is not possible. Students in this project were asked to evaluate the frequency with which they ask questions, volunteer to answer questions, and take written notes in class. The scores for their responses from the survey were tabulated based on a scale of 1 (Never) to 6 (Very Frequently). For simplicity, Table 2 shows the average response of all participants from the pre, mid, and final surveys. Additionally, a Kruskal-Wallis test for statistical significance was conducted on the survey responses from all the students. While the mid and final survey averaged responses would seem to suggest a slight improvement in regard to the frequency of asking the instructor questions and volunteering to answer questions, these differences were not statistically significant. At this

TABLE 2
Example Hybrid Slide Created in Dyknow

How Frequently Do You:	Pre (N=90)	Mid (N=94)	Final (N=110)
Ask the instructor questions during class	3.42	3.69	3.67
Volunteer to answer a question during class	3.51	3.70	3.75
Take written notes during class	5.36	4.04	3.87
1. Never, 2. Very Rarely, 3. Rarely, 4. Occasionally, 5. Frequently, 6. Very Frequently			

point, the conclusion would seem to be that the use of the Tablet PC in the DL classroom did not improve the inclination of the student to ask or volunteer to answer questions during the class. This result is not entirely surprising. Even though the Tablet PC classroom may provide the instructor more opportunities to engage students in class activities, this does not necessarily translate to a student's inclination in willingly asking or answering a question of their own volition. Of particular interest from this set of questions was the response to taking written notes. The Kruskal-Wallis test revealed that the differences in the student responses for the pre/mid and pre/final pairwise comparisons were statistically significant ($p << 0.01$). A Kruskal-Wallis statistical significance test between the mid and final survey responses revealed that their was no significant difference. All of the students for this project received lecture content live during the class period. In one course, the instructor provided lecture slides online prior to class for students to access. Additionally, 4 of the 5 instructors posted the in-class lecture presentations online after each class for student access. (Generally, posting lecture content after class was for students who had missed lecture since all students who were present could save the lecture to there own personal data drive and access it on their own.) Prior to attending the class, the students indicated a very strong history of note-taking whereas in the Tablet PC equipped classroom, there was a clear indication that this was not the case despite the specific features in the Dyknow interface to allow students to make private annotations and notes. While the students were not formally asked to explain the reason for taking notes less frequently in the Tablet PC equipped classrooms, informal discussions with students and instructors have led to several viable explanations for this drop in in-class note-taking in the Tablet PC equipped classrooms:

- The lecture notes being presented directly on the student Tablet PCs left many students feeling that taking notes was not necessary.
- Online posting of all the notes and annotations made by the instructor during the lecture for access outside of class allowed some students to sufficiently capture the in-class material without taking private notes. Additionally, the students could save the lecture to their own personal data drive for their own personal access.
- One course instructor posted lectures prior to class which may have impacted the students in that particular course from feeling the need to take notes.

Informal discussions with students suggested that there was always a subset of students who would take private notes regardless of whether the lecture was posted online, although this has not been formally examined in this article. While it is clear that the ability to create, store, and post lecture content electronically had an impact on the frequency of student note-taking, what is unclear at this point is whether this practice benefited or hindered student learning experiences overall.

5.2 Student Attitudes on Tablet PCs for DL

One of the most important evaluations for this project, given the often-negative attitude towards DL classes, was to determine whether or not students felt that their experiences in DL courses improved with the use of the Tablet PC and interactive software compared to their experiences with traditional DL courses that used only videoconferencing solutions based solely on video and audio transmission. On the Mid and Final Surveys, students were asked to evaluate several aspects of DL classrooms including lecture delivery, student-instructor interaction, and the ability to follow lectures and clearly view the lecture material for traditional and Tablet PC equipped DL classrooms. The scores were recorded on a scale of 1 (Poor) to 5 (Excellent). The distribution of scores is shown in Fig. 5 which displays the median values of the responses as dotted circles and the interquartile range (dispersion between the 25th and 75th percentile) as a bold line. A Kruskal-Wallis test for statistical significance was conducted making pairwise comparisons of the following:

- (Mid Survey) Traditional (TDL)/ Tablet PC DL (TPCDL) pairwise comparisons
- (Final Survey) Traditional (TDL) / Tablet PC DL (TPCDL) pairwise comparisons
- (Traditional DL) Mid/Final survey pairwise comparisons
- (Tablet PC DL) Mid/Final survey pairwise comparisons

Statistically significant differences ($p < 0.01$) were found for all Traditional/Tablet PC DL pairwise comparisons. However, there was no statistical difference between the mid and final survey pairwise comparisons. This suggests the students responses were fairly consistent throughout the semester with no significant changes in attitude from the mid to the final weeks of the course. One of the important conclusions that can be drawn from the results given in Fig. 5 is that students clearly do not have a very good impression of the traditional DL classroom environment built only around video and audio transmission. Student responses ranged largely between "Fair" and "Good" for every question related to the traditional DL classroom. With respect to the Tablet PC DL classroom, student responses were significantly more positive. The most notable improvements were for questions concerned with the lecture delivery and student viewing of lecture material that was presented during class. In the traditional DL classroom, the average student response was between "Fair" and "Good" whereas with the use of the Tablet PC, the average response was between "Very Good" and "Excellent." This improvement is clearly due to the means by which the Dyknow software delivers and displays the content of the instructor's Tablet PC on the Tablet PC of each student. Another factor is likely due to the fact that

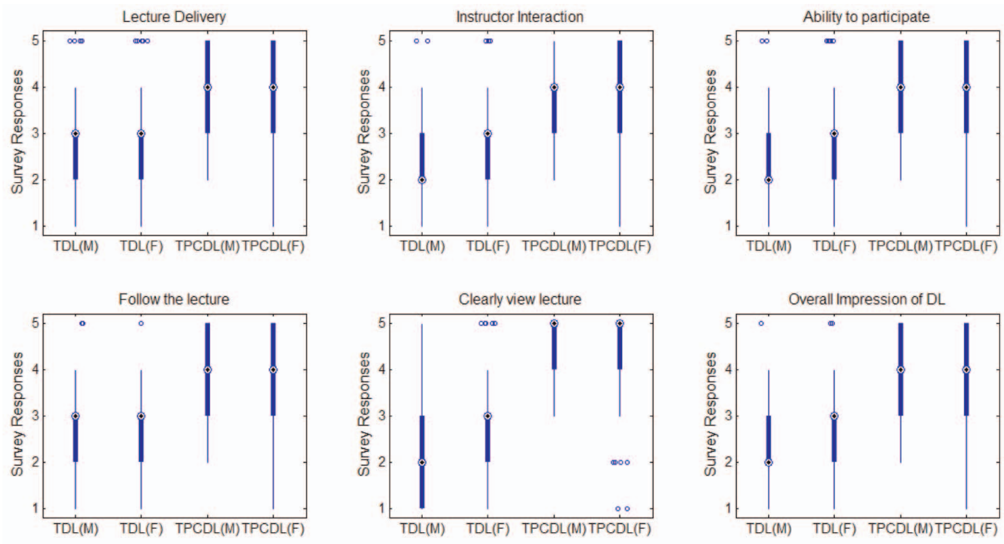


Fig. 5. Student attitude on distributed learning classrooms: TDL - Responses regarding traditional DL classrooms; TPCDL - Responses regarding tablet PC DL classrooms; (M = Mid Survey, F = Final Survey, Dotted Circles = Median, Empty circles = Outliers).

Dyknow allows each student to scroll back to previous slides whenever desired so they have some control in reviewing some material they may have missed even if the instructor has moved on in the lecture.

Fig. 5 also shows several outliers that would seem to go against the interpretation that the Tablet PC environment was always better. For all of the questions, there are instances where several students rated traditional environments as being ”Excellent” despite the majority of responses being ”Good” or lower. While there is no definitive answer for these outliers, it is likely that they can be attributed to some of the faculty who conducted the lectures in their previous DL courses. Since the primary mode of instruction at GTS is through synchronous distributed learning, many of the faculty members have adjusted their teaching styles to alleviate some of the challenges mentioned earlier. In these instances, it is possible that some students were then satisfied with their DL experience. Additionally, as the study was conducted over a period of two years, it is possible that several students related their previous DL experiences to another course in which they had used Tablet PCs despite the question being worded in such a way as to encourage students to only consider their courses for which Tablet PCs were *not* used. The plots also suggest that there are responses that rate even the Tablet-PC-equipped rooms as having only “Fair” or “Poor” ratings. A possible explanation for this could be related to some of the technical problems that could occur during the semester. Occasionally, the network would fail or the server would not allow students to log on or the software interface would “crash” during the lecture. This may have produced a negative attitude in students regarding the Tablet PC implementation, such as in response to the question about “Clearly view lecture.” Additionally, informal discussion with students suggested that, even with the Tablet PCs, distance learning environments are not favorable to non-DL environments which would cause the ratings to skew low for some students regardless of the implementation.

Students were also asked questions about how their experience with the Tablet PC DL classroom affected their attitude about DL courses. Table 3 shows student responses to this line of questions with average scores using a scale from 1 (Strongly Disagree) to 5 (Strongly Agree). No statistically meaningful difference between the mid and final surveys is apparent, indicating the responses are consistent across the semester. The results in Table 3 show that the use of the Tablet PC can improve student attitudes about taking distance learning courses. In addition, students were in general agreement that they felt more involved in lecture in the Tablet PC DL classroom and expressed a strong desire to see other DL courses use Tablet PC technology. When asked to compare their feelings about their level of involvement in a Tablet-PC-enabled DL course to a traditional non-DL course, the result shows that students would prefer to take non-DL courses. This, however, is not surprising as instructors and students tend to prefer the more personal interaction that can be achieved through non-DL courses.

TABLE 3
Student Attitude on Technology Implementation

Regarding the Tablet PC and software technology implementation for DL courses	*Mid(N=94)*	*Final(N=110)*
My overall perception of distance learning has improved.	4.16	4.16
I feel more involved in the lecture than in other distributed learning courses.	4.09	4.03
I feel more involved in the lecture than in other traditional courses (i.e., non-distance learning courses).	3.83	3.80
I would like to see more DL courses use this implementation.	4.35	4.35
1. Strongly Disagree, 2. Disagree, 3. Undecided, 4. Agree, 5. Strongly Agree		

TABLE 4
Student Attitude on Performance in Tablet PC Courses

	Mid(N=94)	Final(N=110)
Indicate how the Tablet PC implementation has impacted your overall performance in this class	4.08	4.19
1. Strongly Negative, 2. Slightly Negative, 3. No Impact, 4. Slightly Positive 5. Strongly Positive		

5.3 Student Performance Summary

Another critical part of the assessment of this project was to determine the impact on student performance in the classroom. It is always desirable to implement technology in a way that helps students to learn and perform better in their classes. On the mid and final surveys, students were asked how they felt the use of the Tablet PCs in the classroom had impacted their performance with options ranging from 1 (Strongly Negative) to 3 (No Impact) to 5 (Strongly Positive). Table 4 shows that, overall, the students felt that the use of the Tablet PC in their DL courses had a slightly positive impact on their performance in the class. While this is an admittedly subjective look at student performance, it is important to know to what extent the students felt the use of the Tablet PCs helped, hindered, or had no impact on their ability to perform to their expected standards.

In an effort to better quantify this result, the cumulative GPAs of each student in their other DL courses up to the point of their participation in the project were collected and analyzed based on the grade each student received. Table 5 shows the distribution of cumulative GPAs and assigned letter grades for the students in the project over the 2006-2008 academic years. The students are grouped by cumulative GPA across the top row and by assigned letter grades down the columns. With the exception of one student who received an "F" despite having a cumulative GPA between 3.5 and 4.0, the table seems to support the students impressions indicated in Table 4. Generally, students who had high cumulative GPAs (> 3.0) tended to also perform well in the Tablet PC class with only 4 out of 38 students failing to make an "A" or "B." Students in the 2.5-2.99 range seemed to show some slight improvement as nearly 1/3 of these students received an "A" in their classes. Students with cumulative GPAs below 2.0 generally did not fare any better than their cumulative GPA suggested with only 1 out of 23 students managing a 'B' in a course. While Table 5 provides a nice objective look at student performance over the course of this Tablet PC project, more data over time will need to be collected to truly analyze the impact the Tablet PCs and interactive software are having on student learning.

6 Conclusion

The Tablet PC is an attractive technology for use in synchronous distributed learning (DL) environments because of its mobility and its ability to not only serve as an effective note taking device but also as a high-resolution course content viewing device. The implementation of Tablet PCs into the DL classrooms at Georgia Tech Savannah provided a general solution for improving the delivery of lecture content and providing alternative methods of in-class interactions between the instructors and students for facilitating active learning. The primary advantage of a Tablet PC over a laptop is the digital ink input modality. The use of the digital ink by the students in the class was largely dependent on the teaching style. Discussion with the faculty in this project revealed that at least one faculty member never made use of the panel submission feature of the interactive software, whereas another faculty member frequently required students to work problems in class on the Tablet PC and submit their responses. Therefore, there were some courses where it would seem that a normal laptop would have sufficed since the instructor primarily used the PC for content viewing and simple input requirements. One the other hand, for the instructors who made heavy use of the panel submission feature for doing in-class assessments, the digital ink modality was an essential feature. It was the goal of this project to provide a device that could provide instructors and students with the freedom to choose their type of interaction for which the Tablet PC was a general solution.

While it is clear that the students and instructors would largely prefer to participate in non-DL courses if given the option, the opportunity to participate in educational delivery at remote sites is still highly valued. Some of the significant conclusions presented in this article include:

- Provision of electronic notes (posted online before and/or after lecture) via the Tablet PC and Dyknow greatly reduced the frequency of in-class note-taking by students who had previously indicated a high-frequency for taking notes. Currently there is no clear indication on how this may have affected a

TABLE 5
Student Performance in Tablet PC Courses by Cumulative GPA

	Cumulative GPA Range						
Course Grades	3.5-4.0	3.0-3.49	2.5-2.99	2.0-2.54	1.5-1.99	<1.5	No. of Students by Course Grade
A	10	10	11	0	0	0	31
B	5	9	12	4	1	0	31
C	0	3	6	15	2	4	30
D	0	0	3	6	3	2	14
F	1	0	0	3	4	7	15
No. of Students by Cum GPA	16	22	32	28	10	13	121

student's performance in the class and will be investigated more fully in the future.

- Use of the Tablet-PC-equipped classrooms for conducting the synchronous DL courses in this project helped to improve the overall attitude of students regarding their participation in DL. The most clearly seen improvement from the use the Tablet PCs was in the student's ability to more easily view the lecture notes being provided by the instructor since there was a direct transmission of lecture content from the instructor to the students Tablet PC.
- There was a general feeling from the students that the use of the Tablet PCs during the semester had provided a slightly positive impact on their class performance. An objective look at the cumulative GPAs of the students, as well as the grades they received in the DL courses they participated in for this project, provided some evidence for this assertion. A more detailed analysis will be designed to assess the relationship between a student's historical performance in DL courses and their performance in Tablet-PC-equipped DL classrooms as the project continues to expand.

Overall, the use of Tablet-PC-equipped DL classrooms has been a great success at the Georgia Tech Savannah campus. Future work will continue to monitor the impact on student learning and the pedagogy used by instructors by including an analysis of student responses on a course-by-course basis rather than the aggregate responses shown in this case study. The course-by-course analysis will allow student responses and performance to be assessed in light of course content, teaching style, and how instructors decided to use the unique capabilities afforded by the Tablet PCs and interactive software in their DL courses. Additionally, the assessment tools used in the project will be updated to gather more specific information on the frequency of use of the unique Tablet PC features as well as to modify questions related to students prior experiences in DL courses as more students are exposed to the Tablet PC technology at the campus.

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