AC 2008-276: ACHIEVING COMPELLING STUDENT COMPREHENSION OF COMPLEX INFORMATION STRUCTURES FOR BOTH ON-SITE AND ON-LINE COURSES

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Achieving Compelling Student Comprehension of Complex Information Structures for both On-Site and On-Line Courses

Abstract

Teaching engineering and technology subjects involves conveying understanding of abstract information structures and processes such as complex telecommunications protocols, complex mathematical concepts, and data structures. These are multidimensional and can be difficult to grasp quickly. Supported by a Hewlett-Packard (HP) Technology for Teaching grant, the School of Engineering and Technology at National University has embarked on a project to enable students to grasp these complex concepts more quickly and easily, using continuous dialog among students and instructors as the structures are first introduced and then examined from multiple perspectives through real-time interaction among students, small groups, and instructors.

HP Wireless Tablet PCs are used to discuss and experiment with diagrams and processes in real-time. This allows combining lectures and problem-solving sessions into a single class session. Our hypothesis is that: 1) an in-depth learning of theory is accomplished, and 2) student engagement is enhanced. Presentation of theory by the instructor is integrated with application while the theory is still in the student's short-term memory. Students no longer have to wait for a separate session such as a recitation session to apply the concepts. This approach often takes less time. In addition to accelerating the learning process, expert instructors find this approach more rewarding as students grasp new concepts more quickly.

Analysis of data captured from both students and instructors are presented to support our hypotheses, and our results are compared with similar research carried out by other universities.

In addition, the level of interaction enabled by the use of HP Tablets in on-line classes is discussed. The best teaching tools available in existing on-line teaching platforms are compared with the additional tools available in on-site courses when every student has a wireless Tablet PC and specific recommendations are made to on-line teaching. These tools will enable a higher level of interaction between students and instructors to enhance learning of engineering and technology subjects, even in those cases where the on-line students may be using a computer other than a tablet PC.

Introduction

In his famous essay, Eugene Wigner commented, "the miracle of appropriateness of the language of mathematics for the formulation of the laws of physics is a wonderful gift which we neither understand nor deserve."[1] But it is not always easy for engineering students to grasp this "appropriateness". And understanding the relationship between mathematics and the physical world is only the start. Engineering students must learn to grasp many complex and sometimes abstract logical structures and processes. A few examples include queues, trees and, more generally, data structures in computer science; various kinds of database designs in information systems; layered architectures and complex telecommunication protocols in data networks; digital signal processing algorithms to generate, transmit and receive multiplexed radio signals; complex mathematical equations and graphs; and a myriad of details of physical structures in civil engineering. Conveying complex concepts for easy understanding at a faster pace is one of many challenges we face in teaching engineering and technology subjects.

Using equipment received under a two-year 2007 HP Technology for Teaching – Higher Education Grant, National University has introduced the use of Tablet PCs into the hands of every student in selected courses, to enable understanding of complex concepts more quickly and easily.

Research Goals

The best way for students to learn an information structure is through collaborative, and small group experiments in which students can apply their own "touch and feel" to a concept. Presenting students with concepts on which they can experiment individually and in small groups makes it easier and quicker for them to absorb complex information structures and interact with each other and their professors to gain a deeper understanding. Questions that are difficult to verbalize are often easier to ask using Tablet PCs through which questions and discussion points can be shared visually.

In addition we are helping students retain and enhance their concentration throughout the time span of the longer classes that are typical of the accelerated learning environment at National University. National University serves a diverse population of adult learners through classes that are each three and a half hours to four and a half hours in length. Retaining the attention of students who are sometimes fatigued after a full work day, along with the concerns of family, children, and jobs is challenging. The increased interaction with students through the Tablet PCs enables professors to assess students' learning in real time, and adjust teaching strategies appropriately.

The specific goals of our research are:

Goal #1 - Demonstrate that students learn complex data structure concepts faster and more completely when Tablet PCs are used appropriately in the classroom.

Goal #2 - Demonstrate that the use of Tablet PCs enables students to remain engaged in learning during the longer classes that are typical of accelerated learning environments.

Based on the reports of Denning, Griswold and Simon[2], Koile and Singer[3] as well as others, we expect to achieve both of these goals.

The Starting Point

Many National University School of Engineering and Technology on-site classrooms have been equipped with desktop computers and hard-wired Internet connectivity for several years. In on-site programming classes students are given exercises to work on their desktop computers. In other classes, students are given problems which require them to search the Internet for answers. But the majority of teaching in on-site classes involves lecturing - either writing on the whiteboard or using PowerPoint charts projected on a screen at the front of the room. Some of the PowerPoint presentations include animations to build up complex information structures on a step-by-step basis. There has been limited opportunity for students to share their work and interact with each other or discuss problems with the instructor other than gathering as many as people as possible around the display for a particular desktop computer.

Student/instructor and student/student interaction has been more limited in on-line classes. PowerPoint charts are distributed to students via the iLinc[4] system (a 2-way web based audio and video over IP commercial product used at National University) in synchronous on-line classes and via eCollege®[5] for asynchronous on-line classes. But the software for on-line courses does not support PowerPoint animations. On the other hand, on-line synchronous class sessions are recorded, making it easier for students to review the instructor's presentations at their own pace.

For on-site or synchronous on-line classes, the primary means of student/instructor and student/student interaction has been verbal discussion and text chat. For asynchronous on-line classes, threaded discussion has been the primary means of interaction.

Research Implementation - Teaching

Since receiving the grant, we have been redesigning our lectures to increase interaction between professors and students. We have used both Ubiquitous Presenter (UP)[6,7,8] from the University of California at San Diego (UCSD), and DyKnow Vision™ [9,10] to "push" charts out to students that the students can mark up and submit back to the instructor. Curricula are being extended to incorporate interactive segments in which students can take turns entering the next step(s) in structures under discussion. For example, they may enter several lines of code for a program they are writing jointly and then the whole class can view the result of those added lines. Another example involves proceeding step by step through the details of how an encryption algorithm such as the Advanced Encryption Standard (AES) operates on plaintext to produce cipher text.[11] Other examples include starting with a basic equation and observing how adding terms to the equation transforms a graph of the equation, or entering successive steps in a data network protocol and tracing the messages exchanged.

Students have the ability to correlate their notes with what is being discussed through both typing and use of digital ink[12] to handwrite notes and drawings directly on their DyKnow Vision™ copy of the lecture charts as well as through the use of Microsoft OneNote.

Problem solving/brainstorming sessions are being added to on-site classes where students are split into groups and asked to use their tablet PCs jointly to solve problems in class. DyKnow Vision™ supports the ability to set up small groups in which students can work together using their individual Tablet PCs for interaction. Each student in the group can see what the other student is writing, typing or drawing in a shared space, such as a virtual whiteboard.

Research Implementation - Technology

Each on-site instructor and student has an HP Tablet PC equipped with the Microsoft Windows XP operating system, the full Microsoft Office suite including PowerPoint, Excel, Word, and both DyKnow Vision™ and DyKnow Monitor™. Special applications software is also included as needed for particular courses. All are connected to each other and to the Internet through an IEEE 802.11g Wireless Access Point. For the first year of this research, we are making use of a DyKnow Vision™ server operated by Indianapolis-based Dynamic Knowledge Transfer, LLC (DyKnow).

The DyKnow Vision™ server software coupled with DyKnow Vision™ client software on each Tablet PC enables instructors to push charts to all students in a particular class. Class sizes typically range from 10 to 20 students. Response time, from when an instructor selects a particular chart to when that chart appears on each student's Tablet PC, is typically no more than a few seconds. Students are able to write, type, and draw on their copy of the instructor's charts and then submit their results to the instructor via the DyKnow Vision™ server. Any submission can be shared by the instructor with the whole class either anonymously or with attribution. The instructor also has the option of storing student submissions for review and grading. The same software is used by small groups of students to interact during breakout sessions when they solve exercises assigned by the instructor.

We have begun limited experiments to increase student interaction in synchronous on-line classes where we are using iLinc Learn*Linc*™.[13] We do not wish to require on-line students to buy tablet PCs to replace the PCs they are already using for on-line classes. However, instructors are using the digital ink capability on the iLinc Learn*Linc*™ whiteboard to amplify their lectures for synchronous on-line classes. iLinc Learn*Linc*™ also enables instructors to set up small student groups to work together on problems with VoIP conferencing.

Initial Findings

By the end of 2007, the Tablet PCs were used by four instructors in a total of seven courses with approximately 75 students. Every student used a tablet PC in three on-site graduate courses in National University's Master of Science in Wireless Communications program: WCM 604 – Coding and Modulation for Wireless Communication course and WCM 605 – Information Privacy and Security in Wireless Systems (two different groups of students) courses with approximately 10 students in each class. One on-site student was so pleased with the capabilities of the tablet PC that he bought himself one for his personal use. In addition, Tablet PCs were used by full time faculty to teach four synchronous on-line courses: CSC 208 – Calculus for Computer Science, ENE 603 – Unit Processes of Environmental Engineering, CSC 310 – Linear Algebra and Matrix Computation, and CSC 220 – Applied Probability and Statistics.

Impact of the Digital Ink Capability

There have been a number of reports on the power of digital ink for teaching. Of particular interest is the work of Kowalski, Kowalski and Hoover.[14] Students and instructors in National University classes being taught with Tablet PCs report increased empowerment and efficiency which they credit to the use of the digital ink capability of the system.

From the teaching perspective, instructors find the added capability to highlight and handwrite clarifying notes onto existing slides and the ability to insert additional slides on-the-fly to be highly useful. These capabilities enable instructors to deliver and customize their lectures better. Instructors are finding that using a stylus on a Tablet PC is more powerful than writing on a physical whiteboard in an on-site class. The ability to emphasize points on a chart by circling the points at the time the instructor is talking about them helps students to follow the lecture better. And, this is a very efficient substitute for the time-consuming process of animating Microsoft PowerPoint charts. Digital Ink makes it easy for instructors to amplify points on PowerPoint charts by writing equations or drawing diagrams directly on the charts.

PowerPoint includes the ability to save the ink annotations made by the instructor during the class. These charts with digital ink annotations are then uploaded by the instructors to a National University server at the end of each class so that students can download the annotated charts for additional study. When instructors are using DyKnow, the ink annotations made by the instructor are automatically saved for students by DyKnow.

Students are taking advantage of the digital ink pen-based system to add their own notes to the instructor's lecture. And with DyKnow they can replay the instructor's ink edits stroke by stroke.

Instructors are responding very positively to the digital ink capability of the Tablet PCs for teaching. One instructor, who readily admits to being computer-challenged stated, "If I can learn how to teach with a tablet, anybody can!" Another instructor statement said, "The tablet gave me the power to teach." This latter comment is a very significant statement as it was made by a professor who was selected from approximately 200 faculty members as National University's Outstanding Teacher of the Year in 2002. After teaching an on-line course with a Tablet PC, an adjunct professor declared that he would not teach another on-line course unless the university always provided him a Tablet PC to use while he taught.

On-line students are particularly enthusiastic about the use of digital ink on the shared iLinc™ whiteboard by instructors. They state that it is a "tremendous improvement" that helps them learn faster and achieve deeper understanding. In principle, on-line instructors could draw on the iLinc™ whiteboard with a mouse on a laptop or desktop PC. However, most instructors have not developed the fine motor control that is required to control the mouse this way.

The Impact of Tablet-Based In-Class Exercises

In the WCM 604 - Coding and Modulation class interactive sessions were integrated with the lecture; students were given "real-time" problems to work on either individually or collaboratively in small groups., Each student was responsible to write up the solution on their Tablet PC in her/his own way and submit it back to the instructor. The instructor shared student responses with the rest of the class. This allowed an opportunity for students to engage in discussions and problem solving. In theory, it would be possible to carry out a similar exercise without using tablets by having every student use the whiteboard in the front of the room. However the logistics of having every student come to the front of the room and stand and work in their small space would not only be daunting, but also not conducive to student learning.

One component of WCM 605 – Information Privacy and Security in Wireless Systems teaches students how to generate "strong" passwords for user authentication. Students are taught seven principles of generating strong passwords as shown in Table 1 below.

They are then taught a mechanism for generating strong passwords by thinking up a phrase that is relatively easy for them to remember and then extracting a password from that phrase by taking the first letter of some words and turning other words into numbers or special characters. For example, a password generation phrase might be "My three favorite months are March (3), June (6) and December (12)." The extracted password could be "M3fmrM3J6&D12". This thirteen character password would be difficult to break. It complies with Rules 1-4. Because the phrase is easy to remember, it is easy for a user to comply with rules 6 and 7: "Don't write it down" and "Don't tell anyone." And, users are more willing to comply with Rule 5 – "Change the password regularly," when they can generate good passwords using this approach. Research has shown that passwords generated from mnemonic phrases are at least as strong as passwords long random passwords that are computer-generated, but that is beyond the scope of this paper.[19] This mechanism for generating passwords was taught to WCM 605 classes in January and July 2007 by simply presenting the concept in class and leaving it up to students to experiment with it on their own. In the October 2007 WCM 605 classes, students were required to generate a passphrase on their Tablet PC in class, then extract a password from it and submit both the passphrase and the password to the instructor in class. Of the ten submissions by students in the October 2007 course, only two demonstrated a good understanding of the concept. To help those who got it wrong, we discussed several of the submitted passphrases and passwords during the class, without making any reference to who had submitted what.

1. Use characters other than just A-Z
2. Choose long passwords
3. Avoid names or words in any dictionary
4. Choose an unlikely password
5. Change the password regularly
6. Don't write it down
7. Don't tell anyone else

Table 1 – Principles of Strong Passwords

We then assessed the impact of these real-time, in-class exercises on certain mid-term exam questions. One of the questions on the mid-term exam for all WCM 605 classes required students to generate a passphrase, extract a password from it, and then discuss how it satisfied the requirements for strong passwords. Mid-term exam scores on this question for the October 2007 class were considerably higher than the same scores for the January 2007 and July 2007 classes, improving from approximately 50% correct answers for the combined January and July 2007 classes to approximately 90% correct answers for the October 2007 class.

This approach was extended in the January 2008 WCM 605 class to five final examination questions concerned with complex information structures. Table 2 shows that on the average, the number of students answering the questions correctly improved from an average of 18% correct answers to these five questions in July 2007 exams to an average of 73% correct answers on the January 2008 exams, when the students were first given real-time, in-class exercises to help them learn the concept. In addition, the overall grade on the January 2008 final exam improved by nearly 7% from 77.2% to 84.1%.

Comparison With Results Of Other Universities

We find our results to be good initial evidence for the benefit of introducing student/instructor interaction to enhance the learning of complex information structures. We have also been able to begin a comparison of our results with the work of others.

In mid-February 2008 two of the authors met for two days with colleagues from approximately 100 other universities who are also carrying out research on the impact of using Tablet PCs in the classroom to improve student learning. Many were using Tablets PCs to teach computer science, electrical engineering and other engineering subjects.

A variety of different software was used to introduce interactive segments in which students were given exercises to work on their Tablet PCs and then submit their results wirelessly to the instructor in real-time. All results were positive; there were no negative results. But, the results had not yet been quantified in most cases.

	% of Students Answering Correctly	% of Students Answering Correctly	
Description of Question	**Jul-07**	**Jan-08**	**Change**
Eselbrücke	22%	88%	65%
Use Vigenére Tableau	11%	81%	70%
Polynomial Representation	33%	75%	42%
Encrypt Short Message	11%	69%	58%
Cipher Block Chaining	11%	50%	39%
Average	18%	73%	55%
Number of Students	9	16	
Avg Grade overall	77.18%	84.10%	6.92%

Table 2

We worked closely with six other universities during the two-day meeting to compare our approaches to data collection, analysis and evaluation. Our colleagues confirmed that our approach is sound, but that some minor changes would be appropriate. As a result of that collaboration, we are extending our data collection and analysis as discussed in the next section. And we will continue to follow the research of others, and compare our findings with theirs, as their results and our results become better quantified.

Next Steps

Instructors are learning how to redesign courses to incorporate interactive segments, focusing on those information structures that have been the most difficult for students to learn. We are implementing DyKnow Vision™ and incorporating interactive segments of instruction to significantly increase "hands on" learning for students in on-site classes.

We are also developing questionnaires to measure the extent to which the increased interactivity contributes to student perception of the contribution of the Tablet PCs to their learning of complex information structures and to their engagement over four-hour long classes. Table 3 below lists the draft questions we propose to ask. Questionnaires will be initiated following approval from the National University Institutional Review Board.

The questions listed in Table 3 are intended to measure student perception of the extent to which students learn complex information structure concepts faster and more completely when tablet PCs are used appropriately in the classroom. We will also continue to instrument specific questions on major examinations for which we have data from pre-Tablet PC classes and Tablet

1. What are your strongest learning styles based on the learning style inventory at http://www.howtolearn.com/lsinventory_student.html (or similar other web site)
    a. Answers to Questions 2-10 will be correlated with student assessment of their strongest learning styles
2. Use of the Tablet PC helps me learn because it supports my learning style better than learning without the tablet.
    a. Possible answers: Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree
3. Classes taught with a Tablet PC keep me more engaged in learning than classes taught without student computers
    a. Possible answers: Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree
    b. Please comment on how the Tablet PC helps you to stay more engaged.
4. Classes taught with a Tablet PC keep me more engaged in learning than classes taught with desktop or laptop computers for students
    a. Possible answers: Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree
    b. Please comment on how the Tablet PC helps you to stay more engaged than classes taught with desktops/laptops.
5. The Tablet PC is a particularly effective tool for small groups working together on case studies
    a. Possible answers: Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree
6. I used the feature of DyKnow Vision to review recorded classes
    a. Possible answers: Almost every class, Frequently, Sometimes, Occasionally, Not at all,
7. The ability to correlate my personal notes with a specific place in a recorded lecture helped me learn better.
    a. Possible answers: Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree
8. Use of the Tablet PC enabled me to learn new concepts better/faster because I was able to understand the way other students reasoned about a problem
    a. Possible answers: Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree
9. The ability to make submissions in class through my Tablet PC enabled me to ask questions that would have been hard to put into words.
    a. Possible answers: Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree
10. The ability to ask questions and/or interact anonymously in class through my Tablet PC enabled me to overcome or circumvent my inhibitions about asking questions in front of my classmates.
    a. Possible answers: Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree

Table 3 – Questionnaire for Students

PC classes. By combining the results from multiple classes, we expect to obtain statistically-significant evidence of the benefit (or detriment) of this approach to teaching. Based on analysis of the questionnaires, specific measurements of improvements on specific exam questions, and through experience in the classroom, a set of "Best Practices" for teaching engineering and technology classes will be developed and made available to instructors.

Six faculty members were trained during November 2007 in use of DyKnow Vision™. Three have incorporated in-class exercises into additional on-site including one additional graduate course - WCM 610 – Next Generation Wireless Infrastructure and Standards, and two undergraduate courses - CIS 301 – Management Information Systems, and CSC 331 – Data Structures and Algorithms. We also plan to measure the impact of the availability of DyKnow Vision™ recordings of on-site lecture presentations for playback and by review by students after class.

Students will be taught how to link notes in their Tablet PC to particular segments of the recorded lecture so that they can jump to the particular segment of the recording that was being made while they were entering their note.

Future plans include extending the research to classes outside the School of Engineering and Technology courses by involving other faculty members who want to use tablet PCs in teaching and who will commit to learn how to use them effectively.

We plan to measure whether student engagement increases with time, remains constant, or decreases in classes taught with the HP Tablet by developing software to automatically log times when students interact with the instructor and other students. Some measurements of student participation against time in class have been reported by Anderson et al[20] but their measurements are for 60 minute classes rather than for our 240 minute long classes. The logs will be analyzed to determine the time distribution of student engagement in on-site computer science courses, information systems courses, and wireless communication courses. We recognize that this distribution will depend on when instructors ask for interaction from students.

Finally, we will compare the distribution of student interaction with average GPA by class as a possible indicator of whether the technology is more suitable for some types of engineering and technology courses than for others. Data from the few courses taught to date with Tablet PCs versus the same courses taught without Tablet PCs is inconclusive, and we do not yet have measurements of the distribution of student interactions. Ongoing updates to our research can be found at our project website: http://www.nu-engineering.net/tabletpc/tpc.html.

Extending the Benefits to On-Line Courses

Thomas and Carswell have observed[21] that collaborative learning is a powerful tool for distributed environments. Their work focuses on asynchronous on-line classes. To the best of the authors' knowledge, the level of interaction enabled by the use of HP Tablets in classrooms has not been extended to on-line synchronous classes. As reported by Uhlig, Viswanathan, Watson and Evans, [22] National University uses the iLinc System Learn*Linc*™ suite of software for on-line synchronous classes. The iLinc web site for Learn*Linc*™ *lists* the powerful tools shown in Table 4 for on-line teaching. It should be noted that a similar set of tools is available in a number of other synchronous on-line teaching software systems, for example Horizon Wimba.[23]

DyKnow Vision™ has the features shown in Table 5. Many of the features of Learn*Linc*™ and DyKnow Vision™ are quite similar, as would be expected for software designed for teaching "live" courses. For example, both systems support polling of on-line students. Both systems support a shared whiteboard space, and both systems support display of PowerPoint charts on student screens (without animation). One of the major differences is that LearnLinc™

iLinc Learn*Linc*™ Features

- Participation Meter
- Application, Desktop, and Region Sharing
- Polling, Surveys, and Q&A
- Chat (with Emoticons)
- Viewable Class Lists
- Breakout Groups
- Glimpse Student Screens
- Multimedia Courseware
- Streaming Video
- Synchronized Web Browsing
- Electronic Hand Raising
- Audio Options — Teleconference or VoIP

Table 4 – iLinc Learn*Linc*™ Features

has powerful voice conferencing features designed for real-time verbal interaction between students and the instructor. This is not currently available in DyKnow Vision™ because it was designed for on-site courses. However, DyKnow Vision™ allows

DyKnow Vision™ Features

- Transmit content to student computers
- Annotate notes
- Replay content
- Use pen-based hardware
- Leverage Web content
- Insert images from other sources
- Import PowerPoint slides
- Broadcast screens
- Collaborate on a shared whiteboard
- Poll the class
- Collect student work
- Grade and return student work
- Teach extemporaneously
- Access archived notes

Table 5 – DyKnow Vision Features

students to draw write and type directly on the charts displayed by the instructor, and then submit them back to the instructor for discussion and/or grading. This feature is not available in Learn*Linc*™. This feature represents a powerful additional interactive capability between instructor and students.

Learn*Linc*™ was developed to teach on-line classes, while DyKnow Vision™ was developed with on-site classes in mind. However, based on our extensive experience with iLinc and our limited experience to date with DyKnow, we believe that combining the features of the two systems would make learning in synchronous on-line courses and on-site courses nearly equivalent. The combination would enable a higher level of interaction between students and instructors to enhance learning of complex information structures in engineering and technology subjects, even in those cases where the on-line students may be using a computer other than a tablet PC.

To begin confirmation of this hypothesis we began use of the tablet PC by one of the authors in teaching an online calculus class. Only the instructor was equipped with a tablet PC. Use of the tablet PC impacted both the instructor and the students in a very positive way. The instructor used the iLinc Application Sharing feature along with its VoIP capabilities to deliver lectures using DyKnow as the shared application. The DyKnow application on the instructor's tablet PC was shared by all the online students in real time. The impact of this combination on teaching was very powerful by comparison with old fashioned text based or even audio enhanced online chats.

The pen based system allowed the instructor to deliver his lecture as if he were in a physical classroom without having to be concerned about writing and rewriting complex mathematical equations. This freedom is essential for proper instruction of science and engineering topics. Students also benefited from the ability of the instructor to write on the tablet PC. This increased the instructor's efficiency and allowed him to provide better coverage of the materials, be more responsive to student questions and tailor lecture notes to be more specific to student needs.

At this time we do not require on-line students to buy tablet PCs to replace the PCs they are already using for on-line classes. However, as discussed above, a few of our instructors are already using the digital ink capability on the HP tablets to amplify their lectures for both synchronous and asynchronous on-line classes. Digital pens are available that could allow students with desktop or laptop PCs to write or draw on charts presented to them on their PC by their instructor. In recent training sessions for instructors, we used iLinc for the voice component of the training and DyKnow for the interactive component, and found that the combination works well. One of our areas of future research is to assess such a combination with on-line students.

Conclusions

While our research is continuing, a number of important conclusions can be drawn from our results to date.

The "digital ink" capability has proved to be a significant improvement to the ability of an instructor to deliver quality instruction. Both students and instructors have responded enthusiastically to the digital ink capability.

Use of Tablet PCs has enabled introduction of real-time exercises on which all students work simultaneously during class. Student submission of responses back to the instructor enables the instructor to immediately identify areas where understanding is incomplete. The instructor can then resolve the misunderstanding immediately with individuals, small groups and the whole class.

Our measurements of student comprehension of complex information structures show significant improvement for classes where Tablet PCs were used in our Master of Science in Wireless Communications program and our Bachelor of Science in Computer Science program. We are extending our investigation to other programs, to determine whether this improvement can be observed more widely.

Our results are consistent with the findings of research at approximately 100 other universities into the impact of introducing interactive teaching segments through the use of Tablet PCs with a wireless network in the classroom.

While we have many positive comments from students, we are planning to quantify student assessment of the extent to which use of Tablet PCs in the classroom enhances their learning experience. A questionnaire has been drafted and is currently being evaluated by the National University Institutional Review Board

Initial experiences of our instructors who have used Tablet PCs to teach on-line courses has also been very positive, but, we have only begun to tap the potential of these tools for on-line teaching. An important component of our on-going research will focus on understanding and quantifying the benefit of this tool for on-line teaching and learning.

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