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Fang Chen
University of Manitoba, fang_chen@umanitoba.ca

James Sager
California State University - Chico, jlsager@csuchico.edu

Gail Corbitt
California State University - Chico, gcorbitt@csuchico.edu

Kent Sandoe
Californai State University - Chico, ksandoe@casuchico.edu

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Fang Chen
Department of Accounting and Finance
University of Manitoba
fang_chen@umanitoba.ca

James Sager
Department of Accounting and MIS
California State University at Chico
jlsager@csuchico.edu

Gail Corbitt
Department of Accounting and MIS
California State University at Chico
gcorbitt@csuchico.edu

Kent Sandoe
Department of Accounting and MIS
California State University at Chico
ksandoe@csuchico.edu

ABSTRACT

This study compares the use of a Tablet PC in teaching with the use of an earlier generation of presentation technologies (e.g. overhead projectors, blackboards, PowerPoint™) that are an integral part of a traditional classroom learning environment. Presentation technologies are used to facilitate instruction and learning by performing three major pedagogical functions: (1) demonstrating the process of problem solving; (2) providing visual aids; and (3) keeping a record of instructional content. Among the most recently introduced presentation technologies is the Tablet PC. Tablet PC use appears to support the three functions described above to a greater extent than traditional approaches. Moreover, the Tablet PC approach appears to accommodate multiple learning styles and facilitates a higher level of interactive learning if properly used. Tips for effective use of Tablet PCs in the classroom are discussed.

Keywords

Tablet PC, computer assisted learning, presentation technology, instructional media

INTRODUCTION

Presentation technologies (e.g., blackboards, overhead projectors, PowerPoint™) are an integral part of a traditional classroom learning environment. They are used to facilitate instruction and support multiple learning styles by performing three major pedagogical functions: demonstrating the process of problem solving, providing visual aids; and keeping a record of instructional content. By writing problem solving steps on a blackboard while explaining orally, instructors demonstrate the process of problem solving. By displaying drawings, writings, pictures, maps, or slide shows, instructors provide visual aids for students to examine. By maintaining a repository of all materials used in the class (e.g., drawings, writings, pictures, maps, slides) instructors keep a record of instructional content which can be distributed to students and reused in future classes.

Over the past few decades, presentation technologies have evolved to more fully support these three pedagogical functions. A century ago, the only technology available in the classroom was the blackboard (the term blackboard is used herein to refer to both blackboards and whiteboards). Blackboards are an effective tool for demonstrating problem solving, but provide only limited visual aids and do not support record keeping. Students are forced to take detailed notes if they want to keep a record of lecture content. In the early 1900s, film projection was introduced to the classroom followed mid-century by the use of 35mm slides. While both media are effective visual aids, they provide limited opportunity for an instructor to interact with them in order to demonstrate a problem solving processes. In addition, there are both practical and legal limitations to their reproduction and distribution for study outside of the classroom.

Opaque projectors and overhead projectors were introduced into classrooms in the mid-1900s. More recently, the digital document camera has largely supplanted the opaque projector for the display of nontransparent materials such as book pages, maps and artworks. These document projection technologies are more adaptable than either blackboards, film or slides in

that they readily support all three pedagogical functions. For example, instructors can demonstrate a problem solving process by writing on overhead transparencies or on documents that are projected by a document camera. The visual aids provided by transparencies and annotated documents can be more detailed and accurate than free hand drawing or writing on a blackboard since they can be copied from textbooks or other printed materials. Overhead transparencies and annotated documents can be saved, copied for distribution to students, and reused in future classes.

In recent decades, the use of desktop computers to display digital documents, such as Microsoft PowerPoint™ (PPT) slides, has become commonplace in the classroom. PPT documents are easy to prepare and instructors can insert a variety of teaching materials into their PPT presentations: for example, a piece of music, a video clip, a graphic, or an Internet hyperlink. Through the use of multi-color and multi-media capabilities, PPT is generally a more effective visual aid than other traditional presentation technologies. Moreover, PPT slides can be posted online so that students can print the slides beforehand and bring them to the class for note taking. PPT, however, is not an effective tool to demonstrate a detailed problem solving process since it does not support real time freehand writing. Instructors who need to demonstrate a problem solving process still rely primarily on technologies such as blackboards or overhead transparencies.

Recently, the Tablet PC has emerged as a promising technology for classroom use. A Tablet PC is a laptop computer that is manipulated with a stylus pen using natural handwriting and screen touches directly on the display. All writings and drawings produced on a Tablet PC can be saved in digital files. With appropriate software, the Tablet PC appears to support all three pedagogical functions supported by traditional presentation technologies. As with blackboards and overhead transparencies, it allows an instructor to demonstrate a problem solving processes in real time using free hand writing. It provides effective visual aids by supporting display formats such as PPT slides and digital video. Finally, it allows the instructor to save all lecture materials in digital files for future use.

Perhaps due to its versatility in providing built-in support for multiple functions, the Tablet PC is increasingly being adopted by instructors in North American universities. Is this new technology just a fad, or does it truly represent the future of the classroom presentation technology? How does this new presentation technology support learning from a theoretical point of view and how does it affect teaching and the learning process when actually used in the classroom?

This study is intended to provide insight into pedagogical principles that may be fundamental to any computer-assisted teaching practice and suggestions to help instructors make more effective use of the Tablet PC or adopt the Tablet PC with less difficulty. The study first reviews the theoretical background for technology supported learning then presents a case study in which we examine teaching and learning experiences drawn from the use of Tablet PCs in the classroom.

The paper is organized as follows: Section 2 discusses the use of Tablet PCs in typical classroom environments and presents prior research on Tablet PCs; Section 3 describes the theoretical framework for the study; Section 4 introduces the research methodology; Section 5 presents the findings of the study; and Section 6 discusses these findings, their limitations, and directions for future research.

USING THE TABLET PC: BACKGROUND AND PRIOR RESEARCH

There are two primary ways that Tablet PCs are used in the classroom; (1) an interactive mode, and (2) a non-interactive mode. In interactive mode, the instructor and each student are equipped with individual Tablet PCs which are connected to a wireless local area network (WLAN) which supports real-time interaction and communication between instructor and students. Whatever is written on the instructor's Tablet PC can be displayed on all students' screens simultaneously, thereby allowing students to annotate the instructors' notes, pose written questions, solve problems and submit answers, all in real-time. In non-interactive mode, only the instructor is equipped with a Tablet PC. In this scenario, the Tablet PC operates as a sophisticated presentation technology that supports the three pedagogical functions previously described but without real-time, network-supported interactivity. Because the interactive mode requires a much higher investment in technology and due to the complex issues surrounding networked interaction of the Tablet PCs, non-interactive use is far more prevalent in today's classroom. Therefore, this is the modality that we have chosen to investigate.

For non-interactive use, the instructor may prepare PPT slides or a Microsoft Word™ document for the lecture. During lecture, the instructor opens the prepared document and projects it onto a large screen in front of the classroom. The instructor may explain problems orally, use a stylus pen to work out a problem, or manipulate the thickness and color of the pen to highlight key information. Mistakes made on the Tablet PC in digital ink are easily erased. If the instructor needs to display a formula, diagram, or table from another digital document such as a Microsoft Excel™ workbook or an Internet webpage, he opens the document, uses the stylus pen to circle the section of interest and then copies and pastes the selection directly into the original document prepared for the lecture. By doing this, all information related to solving a problem or

pertaining to a particular topic is maintained in a single document. All drawings, scripts, and imported content can then be saved by using an application such as Microsoft's Journal™.

Another software package called Classroom Presenter™ allows for writing over or highlighting PPT slides then saving the document with the annotations. Other applications such as Silicon Chalk™ record the process of drawing and writing on the screen while simultaneously capturing the instructor's voice. When Silicon Chalk™ is used, two files are produced at the end of the class: the class notes in PDF document format and a digital video recording in MPEG format. These files can be posted online after the class for review, self-directed study, and exam preparation. Figure 1 shows a convertible Tablet PC which allows the instructor to write directly on the display in the same manner that an overhead might be used. Figure 2 shows an example of handwritten notes recorded during a lecture.

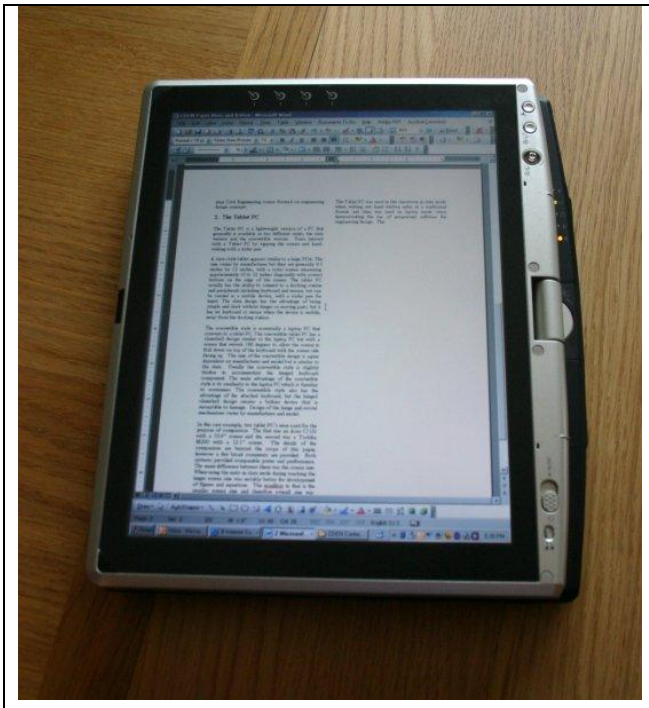

Figure 1
Tablet PC used in Tablet Mode

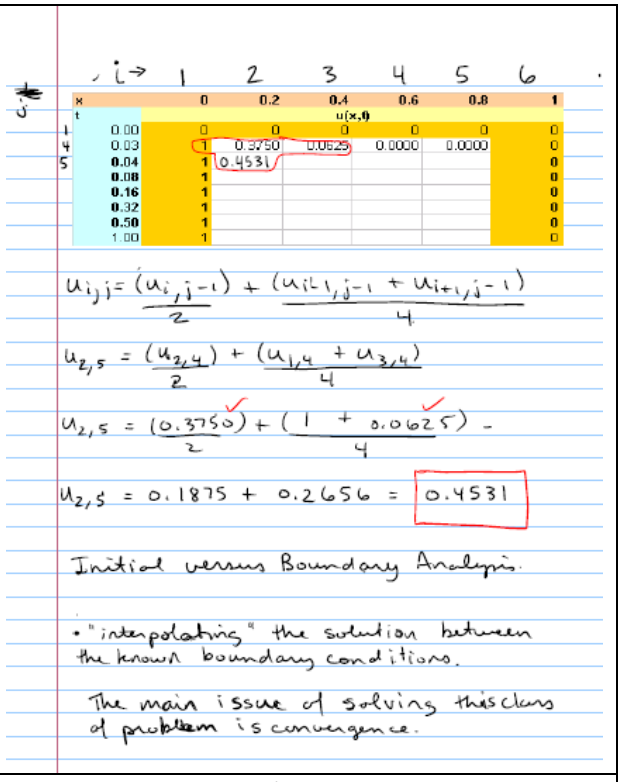

Figure 2
Example of Handwritten Notes

As discussed earlier, the Tablet PC supports the three pedagogical functions of presentation technology: to demonstrate a problem solving process, to provide visual aids, and to keep a record of instructional content. Using multiple presentation technologies at the same time can address these same functions, however, the extent to which they are supported is significantly different. There are three major differences between the use of a Tablet PC and the combined-use of traditional presentation technologies. First, the Tablet PC allows the instructor to place all digital information pertaining to a particular topic or problem into a single document by simple cutting and pasting. Second, the Tablet PC not only saves class instruction (class notes) but also records the detailed instructional process including handwriting and synchronized voice. These recordings can be played anytime, anywhere, either in full or in student selected excerpts. Third, everything saved by the Tablet PC is digitized and can thus be easily edited, archived, distributed, retrieved, and reused.

As Tablet PC use has increased, research on its use for teaching and learning has gained considerable interest. Anderson and his colleagues (Anderson, Hoyer et al. 2004, Anderson, Anderson, Simon et al. 2004) have investigated use of the Tablet PC for lectures in Computer Sciences classes. Their studies, however, adopt a design science or an engineering perspective rather than a user's perspective. For instance, they investigated usage patterns for digital ink by classifying electronic writing into three categories: textual ink (written text), attentional ink (stroke for emphasis), and diagrammatic ink (drawings or diagrams). In other studies they attempted to develop tools for automated recognition of digital ink (Anderson, Anderson, Hoyer et al. 2004) and explored the use of speech recognition techniques for interpretation of digital ink (Anderson, Hoyer et

al. 2004). Simon and his colleagues (Simon et al. 2004) also investigated the impact of using a Tablet PC and digital note taking from the users' perspective but their study concerned Tablet PC use in fully interactive mode in which instructors as well as students were equipped with Tablet PCs. Also, their study did not focus on investigating the effects of using the Tablet PC as a presentation technology. Arnett et al. (2005) investigated how students used a Tablet PC and digital ink to produce diagrams for class projects in Management Information Systems courses. However, they failed to study the instructor's use and the potential impacts of using the Tablet PC as a presentation technology. Blatz and Britton (2005) described their experiences in using Tablet PCs for their own teaching. However, they did not carry out a systematic study to capture their students' perception of the classroom use of the technology.

The current study departs from prior Tablet PC research in that this study investigates how Tablet PC use in the classroom affects learning in comparison with traditional presentation technologies. Furthermore, this investigation is guided by pertinent learning theory. We first develop a theoretical framework and then use that framework to guide our examination and evaluation of how various presentation technologies, and especially the Tablet PC, facilitate instruction and learning.

THEORETICAL FRAMEWORK AND RESEARCH QUESTIONS

Instruction can be viewed as a systematic process that consists of four interrelated components: learner, learning objective, instructional materials, and learning environment (Roblyer 1997, Dick & Carey 1996). Learning objectives and attributes of the learner (e.g., age, learning ability, learning history) largely influence the selection of learning materials and environment (Dick & Carey 1996, Heinich et al. 1996, Crews 2004), which in turn contribute to achievement of the learning objective.

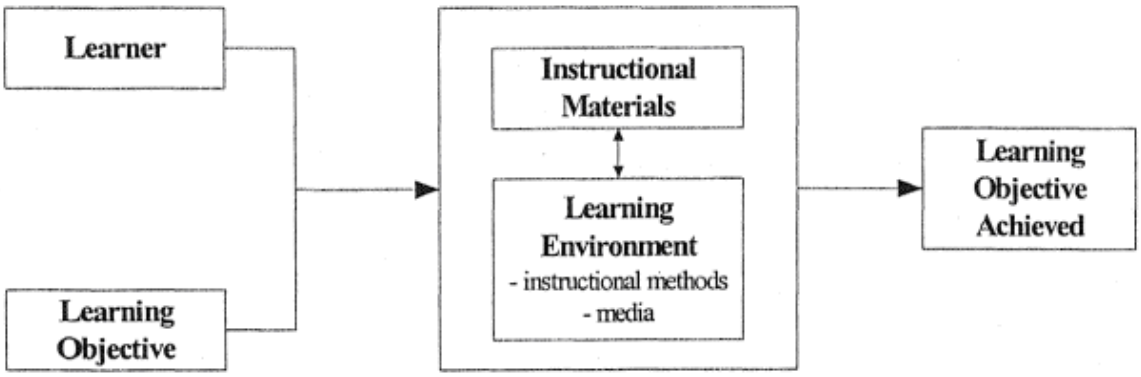

Figure 3: Instructional System (from Crews 2004, p.19)

Since learning objectives and instructional materials are domain specific, we will not focus on these components. The learning environment includes instructional methods (i.e., procedures of instruction) and instructional media (e.g., texts, computers, etc.) (Heinich et al. 1996). This paper investigates how presentation technology, a type of instructional media, affects learning. Presentation technology, however, can not be meaningfully examined in isolation from its interaction with the learner. While there are a variety of learning theories that address the interaction between learner and learning environment, we focus only on theory that we believe is most pertinent to our study. We discuss cognitive effort and active participation from the learner's perspective, and discuss multisensory learning, immediate feedback, and interactive learning from the perspective of the presentation technology.

The process of learning can be viewed as constructing a mental model or schema, which may change or evolve as new information is encountered and integrated into it (Rumelhart 1980, Glaser 1991, Crews 2004). The learner applies cognitive effort to construct a schema, make sense of new information, filter it, and integrate it with his/her existing knowledge (Rumelhart & Norman 1978, Sweller 1999, Hashway 1998 p.55, Crews 2004 p.21).

All persons have limited cognitive resources, one of which is working memory. Every mental task that an individual performs requires the use of some portion of working memory. The term cognitive effort refers to the active utilization of working memory to process a mental task, whereas cognitive load refers to the demand placed on the working memory

(Crews 2004 p.21). There are two types of cognitive load: intrinsic and extrinsic. Intrinsic cognitive load is the effort or demand inherent in the learning task itself while extrinsic cognitive load is the demand originating from outside sources that does not contribute to achievement of the learning objective (Crews 2004 p.21). One common type of extrinsic cognitive load is distraction. Therefore the total cognitive load for a particular task includes both cognitive effort, distraction and other types of cognitive load. Reducing extrinsic cognitive load, i.e. distraction, decreases the demand on working memory thus freeing those memory resources for support of the learning process. Increasing distraction levels, on the other hand, increases demand for working memory and thereby impedes learning (Crews 2004 p.21).

By putting forth cognitive effort, the learner actively participates in the learning process. However, active participation refers not only to the learner's cognitive engagement but also to the learner's physical engagement (Piaget 1980). Examples of physical engagement are note taking and performing physical experiments requiring use of the hands.

The central premise of multi-sensory learning is that human beings learn through their sensory perceptions (James & Galbraith 1985). Three primary perceptual modalities are used for learning: visual (learning by seeing), aural (learning by hearing), and kinesthetic (learning by doing) (Wislock 1993, Crews 2004 p.22). Although an individual learner may prefer a particular perceptual modality for her primary learning channel, the engagement of multiple perceptual modalities is thought to encourage the development of reliable mental models (Crews 2004). A student might learn by first watching a video clip, then observing an instructor demonstrate a problem solving process while listening to the instructor's oral explanation, and afterwards solving a similar problem or performing a related exercise.

A learner uses different senses (e.g., seeing, listening) to perceive the world, and engages cognitive effort to construct mental models or schemas to represent the received perceptions. These models may either be reinforced or may bear adjustment upon receipt of new information. Timely feedback plays an important role in the learner's process of evaluating and adjusting a mental model in sufficient time such that new information can be most readily assimilated (Guskey 1997, Marakas 1995, Anderson, Spiro & Montague 1977).

Another concept that pertains to the learning environment is interactive learning which refers to the interaction between the learner and instructor, between the learner and technology, and among learners. Interactive learning provides immediate feedback which helps students focus their attention on the learning task, contributes to deeper information processing, and reinforces newly minted mental models (Crews 2004).

A learning environment with its associated presentation technology that supports one or more learning principles should have a positive impact on learning. Figure 4 portrays a theoretical framework that incorporates the learning principles described above. This framework guides the analysis of the case study presented in this paper.

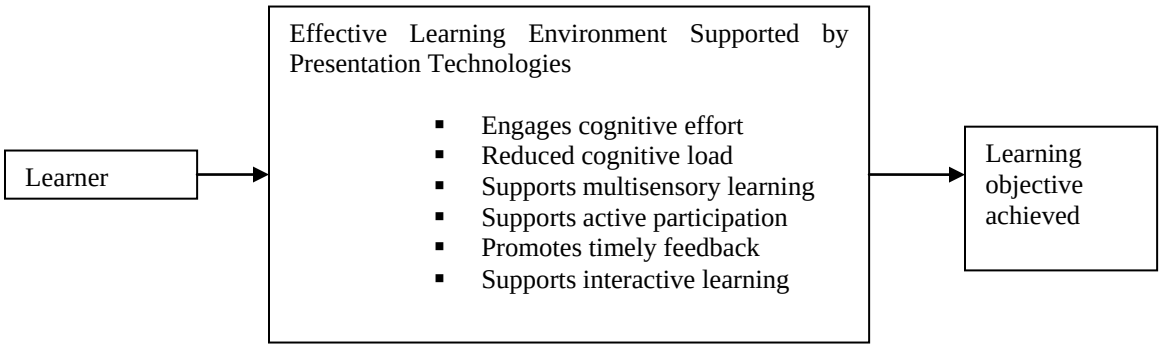

Figure 4: An Effective Learning Environment Supported by Presentation Technologies

In classrooms supported by Tablet PC and the students are told in advance that a complete record of instruction will be available after class, we expect that the availability of the class record should reduce the distraction or anxiety inherent in note taking thus allowing students to focus their cognitive resources on the learning task. In addition, students will be able to

pay more attention to the lecturer and will have additional cognitive resources with which to process information, pose questions, and receive appropriate feedback from the instructor. There should be also increased levels of interaction between the instructor and students. After class, if students need to review particular portions of the instruction, they not only have the class notes, but they can also play the video all or part of the lecture session. Archival video provides an additional multisensory learning opportunity for students who can see the writings or drawings and can listen to the instructor's synchronized voice for explanation. Moreover, since the instructor can store all information for a particular topic in a single document, students do not have to search for information in multiple sources (e.g., the textbook or the Web).

In summary, we speculate that the Tablet PC will, to varying degrees, support all of the learning principles discussed above. However, will we observe that support in actual use? How will instructors and students evaluate the efficacy of a class in which the instructor uses a Tablet PC as the primary presentation technology? We address these questions by investigating two classes in which the instructor used a Tablet PC.

RESEARCH METHODOLOGY AND PROCESS

A case study approach was used for this investigation. One reason for this choice is that case study research allows researchers to gain an in-depth understanding of the phenomena of interest in the rich context where it manifests (Yin 1994). A second reason is that there is little research concerning the Tablet PC's impact on learning and a case study approach is appropriate for gaining initial insights into a phenomenon of interest (Yin 1994).

Two classes in Civil Engineering of a university were studied in the fall semester of 2005. Class A was a Geotechnical Design course, and Class B was a Solid Mechanics course. Both courses contained significant mathematical and design-based problem solving content. As such, much of the material presented to students during lecture consisted of detailed calculations and diagrams used to demonstrate the concepts being studied. There were 35 and 87 students respectively in the two classes.

Data were collected from instructors and students through observation, survey, and semi-structured interviews. Interviews were taped and transcribed for content analysis. In addition to interviews, both classes were directly observed by one author to examine how instructors used the Tablet PC during lecture. At the end of the semester, students in the two classes completed a voluntary survey on their perception of the course. A small random sample of students was also selected for interviews. Two of these students did not attend their interview session due to their schedule conflicts. Eight of the interviewees were from Class A, six were from Class B, and one student was enrolled in both classes. Each interviewee was paid a nominal fee for participating in the interview which generally lasted from 10 to 20 minutes. While the survey was used to gain an overall picture of how students evaluated the classes, the interviews were used to reveal the possible rationale behind the evaluations provided.

Typically, the Civil Engineering instructors used applications such as Microsoft Word™ to prepare documents in advance of their lectures and both used Microsoft Journal™ in the classroom. In addition, Instructor A used Silicon Chalk™, the software for recording voice. Instructor A posted PDF and digital video files on a website after each class. Instructor B posted a lecture outline and a set of questions with blank spaces in advance of class so that students could print the document and take notes by filling in the answer blanks during lecture. Instructor B, however, did not post his lecture notes following class since he was afraid that students might be discouraged from attending the lecture if notes were readily available.

FINDINGS

The following findings have been summarized from the classroom observations, student surveys, and student and faculty interviews. Students' evaluation of the Tablet PC teaching approach is summarized in regards to the three major pedagogical functions.

Students' Perceptions of Using the Tablet PC

A simple survey (Figure 3) was employed to assess students' general perception of Tablet PC use. A 7-point Likert-style scale was used for six non-demographic questionnaire items with 1 indicating strongly disagree, and 7 indicating strongly agree. Overall, students were moderately satisfied with the way in which the instructor used the Tablet PC (Class A: $\bar{X}$ = 5.96, σ= 0.24; Class B: $\bar{X}$ = 5.32, σ= 0.21); they would recommend other instructors use the Tablet PC in classes (Class A: $\bar{X}$ = 5.59, σ= 0.27; Class B: $\bar{X}$ =5.05, σ = 0.21); and they slightly agreed that the classes with the Tablet PC had apparent

advantages over other classes without it (Class A: $\bar{X}$ = 5.07, σ= 0.32; Class B: $\bar{X}$ = 4.42, σ = 0.21). Interviews with students identified what learning principles may underlie the three major functionalities of the Tablet PC and how they affected students' learning process.

Support for demonstration of a problem solving process.

As with blackboards and overheads, the Tablet PC allows instructors to demonstrate the process of solving a problem. During interviews, several students compared the Tablet PC with PPT. Students preferred the Tablet PC approach over PPT and they commented that since PPT did not allow "write as you go", the instructor tended to read the PPT slides too fast, perhaps due to the fact that everything on slides had been prepared in advance. Students also stated that when the instructor used the Tablet PC, the motion inherent in the act of writing was likely to keep their attention on the topic and to slow down the instructor's explanation so that they had time to think about the subject matter.

> *(*Interviewee_ClassB*): PowerPoint is terrific if …you want to instill an overall impression on somebody... But, if you want to dissect, …an engineering problem or a scientific problem, step by step is really the only way to go*
>
> *(*Interviewee_ClassB*): I feel like I'm not [paying much] attention to it (PPT) because like there's nothing in motion.*

More importantly, the "write as you go" feature allows students to receive information using two senses: they see how the instructor solves the problem and listen to the oral explanations of the process. Several student interviewees also pointed out that other presentation technologies such as blackboards and overhead projectors also support "write as you go" and that the Tablet PC performed essentially the same function.

Support for presentation of visual aids

The students we interviewed judged the Tablet PC to be a more effective visual aid than other presentation technologies. The Tablet PC allowed instructors to copy and paste all the information (e.g., formulae, tables, diagrams, graphics) pertaining to a problem or topic into a single document. Students identified three benefits associated with this copying and pasting: 1) instructors could cover more topics or spend more time explaining a topic when using the Tablet PC rather than other technologies because they did not have to spend time redrawing diagrams or rewriting questions; 2) the copied diagrams and graphics tended to be more accurate and contain greater detail than the ones that might be drawn free hand in real time; and 3) the students did not have to reference multiple documents to review all related information after class.

> (Interviewee_ClassA): *If we need any tables or charts he'll (the instructor) go into the actual text notes that are on the net, he'll copy and paste a table or figure into his written notes. This way you have it right there and you don't have to flip back into the textbook…*
>
> (Interviewee_ClassA): *So it* (having the pictures inserted into the Tablet PC document) *saves more time then we can learn more*.

Students also mentioned that the Tablet PC documents made it easier to follow the lecture, because: 1) the instructor could use different colors to emphasize important processes or calculations; 2) the Tablet PC produced a document that was very clean and without smudges; 3) everyone in the classroom had a good view of the Tablet PC projection because the position of the projector screen was elevated (in contrast, students sitting at the back of the classroom could not easily see writing at the bottom of the blackboard); and 4) the size of the instructors handwriting was more consistent when the instructor used the Tablet PC since Microsoft Journal™ provides faint lines or rules on the document such as those found on notebook paper.

Student comments suggest that the Tablet PC provided more accurate visual aids, more information about a particular topic, and better organization of the information than other approaches. Its use may have increased students' learning by reducing their cognitive load.

Support for maintaining a permanent record of the lectures

The Tablet PC has the potential to provide a permanent record of lecture output (notes) as well as the lecture process itself (the writing or presentation process with synchronized voice). Students who thought that the Tablet PC approach was similar to the use of overhead projectors or blackboards agreed that saving the class notes was an advantage. Even the interviewees from class B, in which the instructor usually did not post the class notes, indicated that saving the document was a distinct advantage. In fact, only one of 15 student interviewees failed to state that keeping a record of lectures was a benefit. As predicted, the advantage of having a PDF file and Silicon Chalk video file posted after class was evident. Students who preferred not to take notes could simply focus on listening intently rather than being preoccupied with note taking. Students who still preferred to take notes also indicated that they could pay more attention to the lectures because they did not have to worry about taking down every detail or possibly making mistakes. Three of eight student interviewees from Class A stated that Tablet PC use resulted in the class becoming more interactive and more discussion-oriented.

> (Interviewee_ClassA): *It is hard to listen and write at the same time*.
>
> (Interviewee_ClassA): *It just makes it a lot easier to have a complete set of notes for studying.*
>
> (Interviewee_ClassA)*: You don't have to waste any time in class writing notes. You can actually sit and listen and pay attention…If I have any questions or any uncertainties, I'll pick them out better by paying attention in class rather than writing notes…*
>
> *…Tablet PC definitely makes it more interactive, the class. … Everyone was just in tune to what the prof (professor) was saying because they knew they could download it afterwards and then of course it almost became like a discussion class all the time*.

Playing Silicon Chalk™ files helped students review the lectures after class. Three out of eight interviewees from Class A indicated that they played a class video file five or six times during the term. Sometimes they played the entire video while at other times they only played those parts about which they had questions. One student who had not yet played any of the video indicated that he would do so for the final exam. Four students reported that playing video files was too time consuming or that they had not taken time to install the software required to play the files on their home computer. Yet another student, who reported having not having missed any classes, felt that simply reviewing the PDF files was sufficient. All students liked the convenience, flexibility, and accessibility of downloading the class notes and printing them. Among the eight interviewees from class A, four interviewees reported taking complete notes in class, two occasionally took notes, and two did not take any notes at all. Instructor A reported that students often sent him email to remind him to post the notes if he failed to do so immediately following the class. Even though the class B instructor did not post notes after each class, the interviewees complained very little about this. They did, however, state that they would have preferred to have had the notes posted for two reasons: 1) they could print the class notes from the web if they missed the class; and 2) they could compare their own notes with the instructors' to identify missing information or mistakes.

The students we interviewed indicated that the greatest advantage of using the Tablet PC derived from its ability to provide a full record of lecture content. Because students do not have to take notes, or worry about missing anything important or making a mistake while note taking, they are able to pay greater attention to the class content, ask questions more frequently, and find the classroom to be more interactive. Moreover, the full record of the class lecture allows students who miss a class to study the content at a later time without incurring a significant learning penalty. It also allows for self-paced learning when students review for exams.

When asked to describe the disadvantages of using a Tablet PC, all students interviewed suggested one particular drawback: that students might not make a concerted effort to come to class if the full notes were posted after class. One of the 15 student we interviewed indicated it he would personally skip class if class notes were posted. However, most of the interviewees indicated that they would still come to the class regularly because the instructor might not write everything down. These accounts suggest that, although class attendance may be a concern, it is not likely to be a major concern. In fact, Instructor A, who posted class notes, reported that attendance had not been an issue.

Students reported that instructors should pay attention to the mechanics of using the Tablet PC in order to make it a more effective tool for classroom. In particular: 1) instructors should be careful not to scroll the screen up or down too fast, an action that makes following the text impossible; 2) instructors should be skilled at using the Tablet PC and its related software in order to avoid dead spots in their delivery; 3) instructors' handwriting should be precise enough for students to

read easily (although, according to our interviewees, this had not been a major problem); and 4) instructors need to choose a pen color that is easy to read (for example, yellow was reported to be a particularly poor choice).

Instructors' perceptions of using the Tablet PC

Instructor insights into Tablet PC use were gathered through interviews and provide additional insights. Instructor A was a novice teacher who did not have extensive experience using alternative presentation methods (overheads, blackboards, PPT) in his teaching. He was, however, comfortable with using the Tablet PC and identified three major advantages of its use: 1) since the class notes were posted after class, students had the option to take class notes or not; 2) students could play the digital video file following his lectures to review the class session; and 3) the instructor could also play the digital video file to identify opportunities to improve his teaching.

Instructor B was an experienced teacher. He indicated that his class involved a lot of calculations and that PPT was "not good for classes with a lot of calculations". He preferred to use blackboards over the Tablet PC since the blackboard use encouraged note taking. The blackboard in his classroom was large enough so that he could use one side of the board first, and then use the other side. This ensured that he did not have to erase the board too frequently, thus giving students time to copy notes while he lectured. In contrast, when he used the Tablet PC, he had to scroll down to a new page when the current page was full. When he scrolled down, the program often jumped to an empty new page and class notes on the previous pages were no longer displayed. It required considerable practice for him to make the transition between pages smooth enough so that students were able to copy all the written content from the previous page before it scrolled off the display. Instructor B reported two advantages for using the Tablet PC: 1) the instructor can cover more content since there is no need to redraw diagrams or copy problems onto the blackboard; and 2) the instructor does not get his hands dirty.

Both instructors indicated that writing on the Tablet PC was more difficult than writing on a blackboard due to a lack of frictional resistance and Instructor B emphasized that instructors should prepare most documents prior to lecture. Both instructors indicated that the Tablet PC was useful for demonstrating a problem solving process because of the ability to display free-hand writing. While neither instructor explicitly compared the functionality of displaying visual aids with a Tablet PC to other traditional approaches, they both suggested that other instructors should consider using a Tablet PC.

DISCUSSION

Presentation technologies are an integral part of a traditional learning environment. In the past few decades, presentation technologies have evolved to support three major instructional functions: 1) to demonstrate a problem solving process, 2) to provide visual aids, and 3) to keep a record of instructional content. The Tablet PC appears to support all three functions to a greater extent than previous technologies either alone or in combination. Furthermore, a learning environment should support as many of the six learning principles identified earlier in this article as possible. Specifically, a learning environment should: 1) engage students' cognitive effort, 2) reduce students' cognitive load, 3) allow timely feedback, 4) support multisensory learning, 5) promote active participation, and 6) support interactive learning.

Our study suggests that the Tablet PC indeed supports all six of the learning principles listed above. By providing a means for the instructor to demonstrate a problem solving process in free hand, the Tablet PC supports multisensory learning - students learn by watching a demonstration of process while listening to the instructor's oral explanation. By providing better organized visual aids (e.g., all information on a topic or problem located in one place, different colors for different type of information, a crisp, clean document), the Tablet PC reduces the students' cognitive load of searching for and identifying pertinent information. By keeping a complete record of the instructional output and process, the Tablet PC frees or reduces students' cognitive effort from note taking so that students can focus more on the lectures, ask more questions, get timely feedback, and make the class more interactive.

The students we studied generally liked the classes in which the Tablet PC was used, and both students and instructors recommended that other instructors use the Tablet PC as a presentation technology. However, the observations and conclusions reported in this paper should be interpreted in light of the following limitations. First, as discussed earlier and illustrated in Figure 1, learning is affected by four interrelated factors: learner, learning objective, learning materials, and learning environment. There is an interaction between learning materials and the learning environment, and the learning environment consists of at least the instructional method, instructional media (e.g., presentation technology), and instructor. By focusing solely on the presentation technology and investigating only two classes in Civil Engineering, the generalizability of the study to other contexts is problematic. When the Tablet PC is used by different instructors, for different subject areas, or for different learning objectives, the students' evaluation of its efficacy may be very different.

Second, this is a case study employing only limited measurement of students' perceptions. The study did not develop scales with which to quantitatively measure students' perceptions of the extent to which the Tablet PC may have engaged their cognitive effort, reduced their cognitive load, allowed timely feedback, supported multisensory learning, increased active participation, or fostered interactive learning. The study was designed in this manner because we felt that the six learning principles might prove to be too abstract for students to comprehend and accurately assess given the limited time available to us for the survey and interview. Without these measurements, however, the conclusion that the Tablet PC supports all six learning principles is not as strong as it might be.

Third, this study investigates the effects of using a Tablet PC in teaching and learning processes, it does not investigate the effects on the desired outcome, in this case, learning. Learning students' and instructors' attitude toward the technology does not tell us whether it helps students obtain better learning outcome. Maybe students like the use of the technology, however, their actual learning may not improve.

Despite these limitations, the study does provide insight into the use of the Tablet PC and other presentation technologies from both theoretical and practical perspectives. From a theoretical point of view, the study helps us understand what instructional functions are supported by presentation technologies and how these functions are related to learning principles. From a practical point of view, the study sheds light on the advantages of using a Tablet PC rather than traditional presentation technologies and provides suggestions for more effective use of the technology. The study also indicates that several questions related with Tablet PC usage are worth further pursuing. First, a quantitative study is needed, it should i) use an experiment design where the control group use the traditional presentation technologies and the treatment group use the Tablet PC technology, ii) measure the degree to which the presentation technologies provide support for the six learning principles, and iii) investigate the effects of using presentation technologies on the learning outcome in addition to learning process. Second, future research need to investigate how Tablet PC could be used in distance learning instead of classroom teaching. For example, MIT currently provide online courses by posting class materials on its university website for anyone to download, if instructors record their lectures by using Tablet PC and appropriate software, they may post all recorded lectures to the university website. How effective is the approach compared with just posting PPT slides? Another related issue we need to address is how the Intellectual Property of the Teacher could be protected if the lecture can be freely stored and replayed.

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