Int. J. Engng Ed. Vol. 00, No. 0, pp. 1–10, 2008
Printed in Great Britain.

0949-149X/91 $3.00+0.00

Case study on the Perception of Learning when Tablet PCs are used as a Presentation Medium in Engineering Classrooms*

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New information technologies promise to enhance engineering instruction by facilitating the learning process. This study has been performed to examine the efficacy of using a tablet PC as a presentation platform for problem-solving methodologies in two different mechanical engineering courses of 40–50 students each. Compared with existing technologies that are commonly used to present information, the tablet PC exhibits several inherent advantages that facilitate learning of complex engineering concepts. To test this hypothesis, survey and focus groups were used to determine students' perspectives on how the tablet PC affected their comprehension and learning compared with other classroom experiences. Results of this study suggest that students are more likely to pay attention during the lecture and recognize the more salient points of the presentation when a tablet PC is used.

Keywords: tablet PC; large classrooms

INTRODUCTION

MANY upper-level undergraduate engineering courses have learning objectives aimed at developing students' capabilities to perform complex analysis involving mathematical relationships. These objectives require the expertise to recognize how a system's behavior is described using mathematical models. Therefore, a common instructional method is to derive fundamental equations that describe the behavior of a system and then to demonstrate with example problems how an expert would approach the solution in various contexts. This instructional method relies heavily on mathematical symbols as a descriptive language and is inherently linear. Therefore, an instructor typically uses a white board (or perhaps a chalk board) to express his or her expert reasoning and explanation for how to approach and solve related problems that illustrate progression of the thought process. The present work explores alternatives to more traditional techniques that maintain the linear progression but allow arbitrary complexity in the presentation in order to optimize students' learning. Specifically, the efficacy of a tablet PC as a presentation medium is investigated and compared with white boards, overhead transparencies, and static electronic presentations.

Many college classrooms now have the ability to project a computer display on a large screen for all students to view. Engineering instructors use this technology in a variety of ways. For example, instructors may: 1) use videos to expose students to phenomena they have never before encountered; 2) use a computational model to predict the behaviors of a complex system or 3); or use various visualization methods to demonstrate how parameter changes can affect system behavior [1]. Access to the web provides an additional set of resources that can be used in the classroom to increase students' ability to comprehend major topics. Some instructors use PowerPoint presentations to organize and structure their ideas and resources into an instructional lesson they will deliver during class. Engineering instructors can also construct PowerPoint slides with mathematical expressions by transforming the equations into images using special editing tools. Then the instructor can use PowerPoint's animation features to emulate the derivation process previously

* Accepted 2007.

conducted on the white board. When students ask questions, the instructor can use the white board to extend his or her explanation. These multimedia capabilities can provide engineering students with a richer classroom experience because notes are well organized, the visual display is clear and unobstructed, and various multimedia formats can be used to assist in developing students' knowledge. Furthermore, these notes can be posted in a 'course management system' [2] after class for students to review for homework and exams.

Portable tablet personal computers, or tablet PCs, can build and expand on these benefits of instructional technology in the classroom [3, 4]. The tablet PC is a portable computer with a special pen that allows the user to write on the computer screen using natural handwriting, which displays as 'digital ink' on the computer screen. Slate models have a screen that is similar to a standard laptop computer, but there is no built-in keyboard, and the total unit typically weighs less than a standard laptop. Convertible models are, essentially, a standard laptop computer with a tablet screen. For both model types, the user can hold the device cradled in one arm, like a clipboard, and write with the other hand. Now an engineering instructor can face the class and converse with the students as he or she writes the notes on the tablet PC and the content is projected at the front of the class. The tablet PC platform has several advantages over more traditional presentation media, some of which are shown in Table 1. In particular, compared with static pre-prepared electronic slides, the tablet PC presentation is dynamic in that it can adapt to students' rate of comprehension. In other words, content can be added in real-time if more details are needed, or side discussions can be explored more effectively. Compared with the white board, on the other hand, the tablet PC can seamlessly integrate multimedia instructional aids, and the students' view of the material is not obstructed as the instructor writes on the board. Table 1 provides a more comprehensive feature list for the common platforms used for visual classroom presentation. This table is subjective and represents our preconceived notions of the utility of the tablet PC for presentations. As shown, the tablet PC leverages many of the beneficial features of each traditional platform without the inherent disadvantages.

The tablet PC provides an interesting combination of traditional lecture-style presentation and dynamic visual support provided by simulations and models, plus access to a wide range of other resources. We anticipate that this tool can enhance the classroom-learning environment by increasing an instructor's effectiveness for communicating information to his or her students by maintaining a clear, continuous presentation of lecture material. We expect students will find that content presented with a tablet PC is easier to see and more expressive compared with standard white board and PowerPoint presentations. Therefore, our hypothesis is that students will pay closer attention in class and potentially increase their comprehension of the material during class.

In this study we investigated students' perception of this instructional method to improve: 1) visibility of the instructional materials and expressiveness of the presentation, and 2) their ability to learn in this classroom-learning environment. The tablet PC provides a mechanism to leverage dynamic, linear, problem solving lecture approaches similar to white-board presentations while incorporating instructional content available only to electronic media. Our results are based on observations of four mechanical engineering classes at Vanderbilt University. Preliminary results from a one-class study were presented at the 2005 ASEE annual meeting [3].

We note that there are additional classroom uses of a tablet PC, particularly when students have simultaneous access to their own computer. For

Table 1. Feature list of visual presentation platforms: dynamic—content can change depending on real-time feedback from students; rich content—content can contain annotations and highlight naturally; complexity—natural inclusion of mathematical symbols; flexible—can change formats easily; recall—previous material can be revisited; multimedia—other visual content can be included easily; concurrent—visual and audio are simultaneous with a fine granularity; integration—switching between platforms is natural; projection— content can be enlarged; visible— instructor does not obscure view. These somewhat subjective classifications are discussed in detail in the discussion section.

Feature	White board	Transparencies	Electronic slides	Tablet PC
Dynamic	×	×		×
Rich content				×
Complexity	×	×		×
Flexible	×	×		×
Recall		×	×	×
Multimedia			×	×
Concurrent		×		×
Integration			×	×
Projection		×	×	×
Visible			×	×

example, software tools such as Classroom Presenter [5] enable real-time interaction between the instructor and students, who can be in the classroom or 'present' via an Internet connection. This expanded idea was explored in [6] where different strategies for 'Cyber Learning' were explored. A variety of technological resources can be found at [7]. Tablets have also been explored for use in educational laboratory settings [8] and as facilitators of active learning mechanisms in engineering classrooms [9]. In this study we do not consider these additional capabilities; instead, we focus on the instructional mechanisms and believe the results presented here help establish a framework upon which further uses of the tablet PC can be built.

METHOD

This study evaluated the perceived benefits to using a tablet PC as the major display medium in an engineering lecture compared with traditional use of a white board and prepared PowerPoint presentations. The study was conducted in a junior-level fluid dynamics course (ME 224) and a senior-level heat transfer course (ME 248), two of the required courses in the mechanical engineering curriculum at Vanderbilt University. Data were collected in the heat transfer course in the fall of 2004 and the fall of 2005, with enrollments of 47 and 58 students, respectively. This course was taught both semesters by D. G. Walker. Classes for this course met twice weekly during the 13-week semester, with each class period lasting 75 minutes. Data were collected in the fluid mechanics course in the spring of 2005 and the spring of 2006, with enrollments of 57 and 42 students, respectively. This course was taught both semesters by M. A. Stremler. Classes for this course met three times each week, with each class period lasting 50 minutes. Note that 32 of the students who were enrolled in fluid mechanics in spring 2005 were also enrolled in the heat transfer course in fall 2005.

Not every lecture of each course was presented using the tablet PC. In each class, the instructors prepared and presented a few lectures using traditionally prepared PowerPoint slides and/or the white board combined with overhead transparencies. This inconsistent presentation mode was typically motivated either by legacy content that could not be easily migrated to the tablet PC or by technical problems. For example, each instructor has, on rare occasions, forgotten the tablet pen and resorted to the white board. This change in format allowed the students to evaluate their own learning and understanding when the tablet PC was used compared with traditional methods. Furthermore, the vast majority of their other classes are taught with more conventional approaches.

The heat transfer course was taught in a large lecture hall that can accommodate 150 students and has sliding white boards at the front of the hall. Two smaller white boards are one each side of the central sliding white boards. The design of the room requires lowering a projection screen in front of the central white boards to view material projected from the computer and images from a document camera. Simultaneous display of material on the white board and the projection system was difficult, and switching media generated momentary downtime when no additional information could be provided. The fluid mechanics course was taught in a classroom that is wide and shallow and can accommodate approximately 60 students. This arrangement allows for a large front white board but makes it difficult for students at the sides of the class to see the opposite end of the board. In this classroom, the projection screen covers the center section of the white board. There is enough space to the sides of the projection screen for the computer projector and white board to be used simultaneously.

In addition to using the tablet PC as a white board, both instructors often linked to, for example, web resources or prepared Labview virtual instruments to demonstrate pertinent concepts. Also, the heat transfer instructor used an ELMO document camera connected to the main projector

Table 2. The four survey periods differ in several aspects

Course	Students	Computer	Software	Other tools	Responses
Fall 2004 Heat transfer D. G. Walker	Class of '05	NEC VERSA LitePad 933MHz Intel PIII-M Windows XP Tablet Edition	PowerPoint, Journal	Document camera	41 of 47 (87%)
Spring 2005 Fluid mechanics M. A. Stremler	Class of '06	Motion Computing M1400 900MHz Intel Celeron M Windows XP Tablet Edition	OneNote	Projector	48 of 57 (84%)
Fall 2005 Heat transfer D. G. Walker	Class of '06	NEC VERSA LitePad 933MHz Intel PIII-M Windows XP Tablet Edition	Journal	Document camera	46 of 58 (79%)
Spring 2006 Fluid mechanics M. A. Stremler	Class of '07	Motion Computing M1400 900MHz Intel Celeron M Windows XP Tablet Edition	Journal, OneNote	Projector	29 of 42 (69%) –

to present static images from the text and other sources to share with the students. Consequently, the instructor could effortlessly move from one presentation medium to another using a few simple gestures with the tablet PC stylus or the touch screen console at the front podium. The fluid mechanics classroom was not equipped with a document projection system, so overhead transparencies were used instead, with the images displayed on the white board to the side of the projector screen.

INSTRUMENTS

Each class was surveyed in order to evaluate the perceived contrast between tablet PC based instruction and more traditional approaches. The surveys consisted of a written evaluation form (see Appendix) and group discussions. Items were constructed to measure the visibility of the materials, the clarity of expression by the professor, the ease of following a presentation, and improvements in student comprehension of the material. Several open-ended questions allowed students to share additional comments they had about the benefits and constraints of the tablet PC in the classroom. Some of the items were worded in the negative tense in an attempt to avoid biasing students towards a particular outcome.

Mid-way through each semester a portion of a lecture period was used to administer the survey. This assessment was typically held immediately prior to the midterm exam to reduce the possible bias introduced upon receiving their midterm score. Each survey session was moderated by one or two senior staff members of the Vanderbilt Center for Teaching [10] (J. Johnston and D. Bruff), and two of these sessions were also moderated by S. Brophy, a learning scientist with the VaNTH engineering research center. The instructor introduced the moderator and stressed the importance of the results for improving the effectiveness of his teaching methods. The instructor then left the room and the students took approximately 15 minutes to complete the written evaluation. Then the moderator led a 10–15 minute focus group during which students could share their thoughts with the rest of the class and the moderator could ask follow-up questions. Following the class period, the moderator compiled the results of the survey and reported back to the instructor. The written and oral responses were kept anonymous in order to avoid biasing the students' responses and the instructors' interpretations of the results.

RESULTS

A frequency analysis of responses from all courses was summarized and compared with the qualitative results from the survey to identify major trends in students' reaction to lecture-based instruction using a tablet PC as the central presentation medium. In addition, correlations were used to identify potential dependencies between instructional methods and students' perceptions of their learning in the courses. Finally, the qualitative responses to the benefits and drawbacks to learning with the tablet PC were coded into specific categories and a frequency analysis was conducted on these comments.

The results are categorized into directed and indirect data. The quantitative results are considered direct because the survey questions were designed to extract opinions on a particular issue. Of these issues, the results are further broken into the mechanics of the presentation and the students' ability to synthesize the information. The open-ended questions are considered indirect data because these survey responses allow us to learn about unforeseen issues that are important to the students and to deduce those issues that are most important to the student.

Mechanics

Items A, B and F in Fig. 1 summarize students' perception of the expressiveness and clarity of using the tablet PC to develop lecture material during class. The students agree that the tablet PC presentation is easier to see compared with the white board. One student commented—'It's easy to read the class notes. It's easier for [the instructor] to distinguish things using a different color font. I also prefer to see the problems solved in real time, as opposed to seeing a slide of the answer.' Students agree that they like to watch the instructor develop equations and solutions to problems in real time on the tablet PC better than from pre-prepared slides. Item F received the strongest positive response of all items in the survey, and this result is consistent across every course in the study. This result suggests that the linear development of mathematical solution methodologies is much better served with a white board or tablet PC. An alternate explanation, however, could be the 'boredom factor' long associated with static presentations in class. In either case, instructors should be cautioned against using PowerPoint or pre-prepared overheads in classroom situations.

A It is easier to see the lecture notes when the professor uses the white board
B I pay attention more when the lecture is presented with the tablet PC.
C I find it harder to comprehend with the tablet PC.
D I'm often overwhelmed with information when we use the tablet PC to present notes.
E The combination of different electronic formats on the tablet PC helps me understand.
F I prefer real-time instruction compared with pre-prepared slides.

Items C, D, and E in Fig. 1 summarize factors associated with the students' comprehension of the materials presented with the tablet PC and their

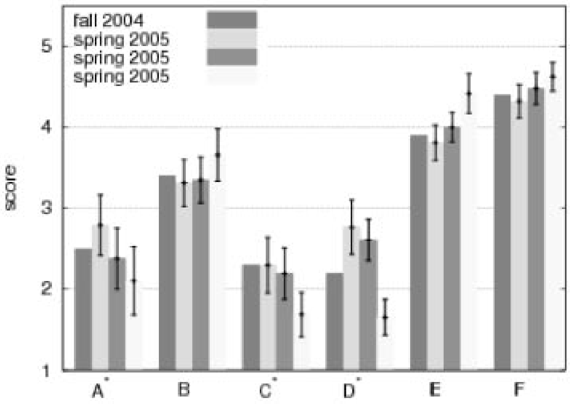

Fig 1. Survey results that identify instructors' expression and students' attention where 1 is strongly disagree and 5 is strongly agree. The starred labels indicate that the question was worded negatively against the tablet PC. The label descriptions are paraphrased from the original question and the error bars indicate the 95% confidence interval.

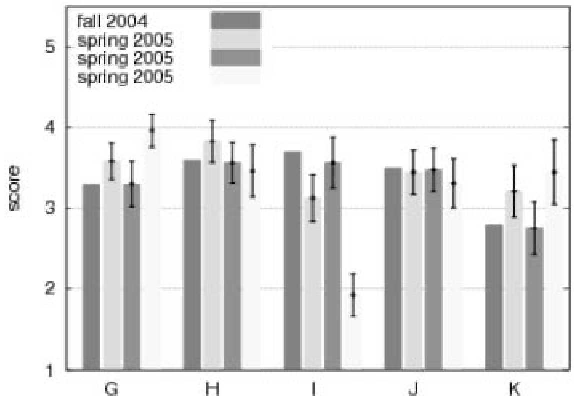

Fig. 2. Survey results that identify learning and preparedness where 1 is strongly disagree and 5 is strongly agree. The label descriptions are paraphrased from the original question and the error bars indicate the 95% confidence interval.

general approach to how they process information during a class session. Most students either agreed, or were neutral, on using class time to make sense of the material as it is presented in class, rather than simply copying the notes to study later. The students who agree tend to notice the salient concepts during class. In general, students do not find lectures harder to comprehend when presented on the tablet PC versus a white board and they are not overwhelmed with information when the tablet PC is used in class. In fact, at least 40% of the students' agree that they pay more attention in class when the tablet PC is used. One reason for this could be related to how the single display encourages students to concentrate on what the professor is saying rather than trying to catch up on information displayed on a different board. For example, several students made comments like this student— ' . . . [the tablet PC] allows me to focus on a single location rather than jumping around to all the different white boards. It also ensures the entire class is on the same concept because everyone must copy the notes from a slide before a new one can be started.' Another student stated a similar idea as— '[the tablet PC] forces us to keep up with lecture and encourages you to not be late because the notes go to a new page after 1 is filled up (its not all up there like on the white board).'

Synthesis

Figure 2 shows survey results designed to discern students' prior knowledge and their perception of their own comprehension during class. In these data (particularly items G, I and K) we see a marked discrepancy between the different semesters. In the first three semesters, approximately 30% of the students were neutral on the benefits of the multimedia presentation. These exact same students also report not having sufficient knowledge to understand the basic concepts in this course. Three other students felt they have sufficient prior knowledge and agreed the multimedia presentations were helpful. This correlation suggests that those students who see no benefit to the tablet may not obtain a solid understanding regardless of the presentation format. While this correlation is true for the final semester of the study, we also note that the students' perception of their prior knowledge and learning appears to improve dramatically.

G I notice the important concepts in class.
H I copy notes to study later.
I I am often confused at the end of class.
J I try to understand the concepts as they are presented.
K My prior knowledge is sufficient for this class.

At least half of the students in the first three semesters agree that they are confused at the end of class. Half of these students were part of the group that identified not having sufficient knowledge to understand the basic concepts in this course. Much of this could be attributed to the complexity of the material for students to comprehend. Several students made comments similar to these— 'tablet is a good way of presenting material however, the material itself is too hard to understand,' or 'make the course materials not so difficult.' These comments highlight the fact that the tablet PC alone can not compensate for a poor lesson plan or poor student preparation. Yet, the final semester of the study shows a reversal of this trend.

Indirect results

The survey included two open-ended questions related to how the instructors' use of the tablet PC has enhanced or inhibited their ability to learn. Students provided a variety of responses to these questions. Table 3 provides a list of major categories of students' responses that emerged from the question on how the tablet PC enhanced learning. Each student's response was placed into one or more categories. For example, one student responded:

Table 3. Categories of comments students made about the use of tablet PC for enhancing the ability to learn in the courses. The percentage is based on the number of respondents each semester. Note that comments are not available for spring '05. The parenthesis indicates that students claim they do not pay better attention because notes are made available after class.

Category	Description	Fall '04	Fall '05	Spring '06
Visible	Easy to see, large font, no obstruction	46%	13%	41%
Expression	Easier for professor to explain, convenient for professor, dynamics of presentation, spends more time on derivation, ease of use	24%	22%	17%
History	Record of prior slides, can return for review	24%	9%	66%
Face	Facing the class while speaking, increases sense of interaction	15%	17%	3%
Multimedia	Flipping between multimedia include document projector	15%	26%	34%
Attention	Increases attention to material, encourage students to view what instructor is talking about	12%	7%	24% (10%)
Efficient	Saves time—don't have to erase	10%	0%	10%
Format	Tablet page matches note-taking page	0%	9%	3%

> I love the idea. Incorporating different media (web, graphs, notes) all in one is great. Also [the instructor] doesn't have to erase. When a page is full he simply uses a new one, then he can refer back to a previous one. I like the point about him being able to face us instead of turning around and blocking the board.

Each sentence in this response was summarized by one of these categories including a reference to using multimedia (Multimedia), efficient use of time because the instructor doesn't have to erase the white board (Efficient), faces the class increases interaction and finally more visible because he is not blocking the board (face). Every mention of one of these categories was tallied in the frequency count in Table 3. The second heat transfer course saw a significant deviation in what was deemed advantageous. This is a direct result of learning how to use the new platform effectively as a teaching tool. Because the white board was not used at all in fall 2005, the students did not realize the actual advantage in terms of visibility of the tablet PC in the large classroom setting. Furthermore, the instructor became more adept and collected more multimedia resources for the fall 2005 semester. Therefore, the multimedia category received more positive comments.

There were very few comments related to how the professors' use of the tablet PC inhibited learning. Thirty percent of the students reported the pace was too fast, except during spring 2006 when there were only two negative comments (6%) in the entire class. In general, the issues related to copying the notes generated by the professor before continuing to a new slide. However, they also acknowledged the professors' sensitivity to this issue because he asked if they had questions or were ready to continue before moving on to a blank screen. These same students also acknowledged that they valued the professors' ability to return to a previous slide to address questions. The only other comment was to use colors with sharp contrast to the white background (e.g. don't use yellow on white).

Finally, students were offered the opportunity to provide additional comments. During the first three semesters, the most frequent comment was to provide the lecture notes after class. This approach was initially resisted by the instructors for two reasons. First, the required textbooks provide an extensive, accurate discussion of the course content that the students are already expected to read. Any gaps in the lecture notes, either planned by the instructor or as a result of student transcription errors, are best filled by making use of this material. In the instructors' experience, students typically do not make adequate use of the textbook, and providing electronic lecture notes may further reduce student use of this material [11]. Second, the motivation behind providing an oral lecture is that this format is more beneficial for learning than relying on written material alone [12, 13]. The instructors expect that some students will use the provision of lecture notes as an excuse to miss class. Despite these reservations, electronic copies of lecture notes were provided after each class in the Spring 2006 fluid mechanics course. The perceived impact of this change in procedure is discussed below.

DISCUSSION

The instructor's use of the tablet PC in the heat transfer class, which met in a large lecture hall with stadium seating, clearly provided the anticipated benefits for assisting learning in a classroom setting. From a practical point of view, the visibility of the lecture notes was equal to or better than the white board for several reasons. 1) The larger font and various colors made it easier for students to see the notes, even from the back of the room, compared with the white board. 2) In this room, it is difficult for students from all angles to see the white board. Now the notes are displayed in almost three times the size of an original white board and consolidated to a central location, making them visible to all the students. 3) In addition, the 'digital ink' never runs dry. White board markers are notorious for going dry, and instructors can lose valuable class time searching for a pen. The fluids dynamics instructor realized only the last two benefits because of the smaller size of the room. The content from the tablet PC in this case was presented on approximately the same scale as that presented via the white board. Nevertheless, the ease of switching colors, the central location of the projected material, and the consistency of the 'digital ink' improved the clarity of the presentation.

Student attention

From the survey results, we have deduced that students learn more and their comprehension is better as a consequence of the improved visibility and expressiveness. This effect can be seen because students report an increase in their attention with the tablet PC. These findings support the assumption that the unobstructed view of the tablet PC content is an important contribution to the delivery of instruction, especially in an engineering classroom. Concurrent visual and verbal information can have a large effect on a learner's ability to process and attune to information [14]. Dynamic animation of information is one instructional technique for helping people construct a mental model of how a system functions [15]. Therefore, in theory the simultaneous construction of images (mathematical representations) and verbal descriptions should have a positive impact on students' comprehension. However, what is not known is how well synchronized this dual information must be in order to assure students' processing of information. With white board or overhead projector presentations, the professor typically blocks portions of the material while writing. The instructor's back is to the students, so that verbal comments are made indirectly over his or her shoulder. Therefore, students must often wait to see what the instructor is talking about. This time delay to link the verbal description with the visual description may have an effect on students' comprehension of the material. Human short term memory is limited [16], which will put a larger burden on students to process the information. Minimizing this delay could contribute to students ease of processing information. Additional research could be conducted to evaluate the interaction between comprehension and latency when presenting concurrent visual and verbal information.

We did not anticipate the students' positive reaction to having the professor facing them as he talked. From their comments, they identified a different connection with the professor as though they were involved in a conversation. This could have an important effect on the classroom community that is formed, which invites students to either share information or ask questions. Furthermore, the comments suggest that the lecture was more engaging, which is essentially a form of active learning that promotes comprehension and retention [17]. More research could be done to evaluate the benefits of this connection to students' attention and motivation to participate in the classroom lessons. For example, future studies could identify the types and frequency of questions asked to determine if students are indeed engaging in the content.

Another factor influencing students' attention is narrowing the bandwidth of information delivery to a single screen. This can encourage students to keep pace with the instructor and process the information as the professor presents the information. As such, students may be more likely to spend their time processing the information as the instructor talks about it versus simply copying the information down in their notes and making sense of it after class. Most of the students surveyed attempt to keep up with the professor regardless of the delivery of information, as indicated in the survey item in Fig. 1. The second offering of fluid dynamics is one obvious exception to this observation, which will be discussed below. Nevertheless, the fact that the presentation format more closely matches the format of the students' notes eases the organizational burden on the students, which should improve processing of the material.

The synchronization of visual and verbal information may be one reason why the majority of students prefer to watch the instructor develop and solve problems in real time on the tablet PC rather than view materials from a prepared overhead slide. Yet another explanation can be found in the dynamic nature of active development of equations. This, as well as white-board presentations, engages the student more than static images, which promotes better attention. Additional explanations can be found in students' responses to items in the survey and their qualitative comments. For example, most of the students found the use of multimedia content to be effective in helping them understand the concepts. Research related to media formats in classrooms illustrates the potential for expressing ideas in multiple contexts and formats. Hegarty [14] found that using a variety of media is beneficial to students by increasing their comprehension.

Opportunities

The results of the survey highlight several opportunities for change to better meet the students' needs. Many students report that the pace of the class was too fast. The increased efficiency of delivering the instructional materials could be one factor. Here efficiency describes the material per time ratio. No longer do students have natural pauses from transitioning between media or time taken to erase the white board. Therefore, they do not have time to catch up on their notes, or to think more deeply about newly presented ideas. Research has shown that periodic pauses help reinforce recently presented ideas [18]. The instructors attempted to address this issue by stopping periodically to ask students if they have questions or if they need additional time to complete their note taking. Perhaps more deliberate and conscious efforts should be made by the instructors to introduce more frequent pauses as a result of the new technology. Another effective method for encouraging reflection on the material is to ask thought provoking questions that require the students to apply the new concepts and to solicit students' thoughts. Various classroom technologies such as the Personal Response System [19] can be used to poll student responses and can be integrated easily with the tablet PC presentation approach. The instructor can use this simple formative assessment method to evaluate if the majority of the class comprehends the material and if they should continue with the next topic of conversation or continue with the current topic. [20, 21]

Perhaps the most striking result of the study is the deviation in the students' perception of their prior knowledge and learning in the course during the second offering of fluid dynamics (spring 2006), which was the final semester of the study. The primary difference between this class and the others was that the instructor provided electronic copies of the in-class notes after each lecture. As indicated above, this approach was initially resisted for 'pedagogical' reasons. Providing notes after class does, in fact, result in some students paying less attention during lectures (see Table 3) or not attending lectures. This class had the lowest survey participation (see Table 2), with 31% of students absent for that lecture period. There were even a small number of students who came to class only for exams, which had not happened in the five previous semesters that M. A. Stremler taught ME 224. However, the students' overall evaluation of the tablet PC and their comprehension of the class material is much more positive in this class than the other classes. Similar results have been observed by Radosevich et al. [22]. It is possible that the self-selected sample resulting from the low response skewed the results. In our opinion a more likely explanation is that the provision of these notes frees the dedicated students from the compulsion to copy every bit of information communicated and instead allows them to focus on understanding the material as it is provided. In other words, students can focus on comprehending the important concepts during class (Items G and J) and still have the details to study at a later time (Item H). Note that the students in all classes exhibited similar interest in understanding the concepts in class (Item J). However, having the notes provided after class appears to make that effort more productive. This may lead to less confusion at the end of class and the impression of overall better preparedness for the class (Items I and K).

CONCLUSIONS

This initial study evaluated students' perception of how well the instructor can express ideas using a tablet PC. We found that students identified the intended benefits of the technology as well as several other unforeseen benefits to learning. The working hypothesis was that a tablet PC was well suited to engineering instruction that relies on linear, problem-solving demonstrations. In this way the tablet behaves like a white board by making thinking visible. On the other hand the tablet also provides capabilities associated with electronic media. In particular, graphs of scientific relationships with arbitrarily complex annotations or animations of physical phenomena can be used to illustrate points. The survey results suggest that the students appreciated this combination of capabilities. In fact, there is reason to believe that students pay attention longer compared with a traditional white board lecture and certainly much longer than a PowerPoint based lecture. Although these advantages are self-evident, instructors need to ensure that coverage of the material does not proceed too quickly. When using the tablet PC, the tendency to progress through the material without a pause is inherent. This degrades the students' ability to absorb the material. Furthermore, instructors must decide whether they wish to post the lecture notes. The results indicate that students are overwhelmingly in favor of this practice, but the pedagogical advantage must be studied further.

Acknowledgements—This work was supported by the Engineering Research Centers Program of the National Science Foundation under Award Number EEC9876363. Also, the office of the Provost provided funding for the classroom technology under the Innovation in Teaching and Learning with Technology Program.

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APPENDIX: TABLET PC SURVEY (FINAL FORM)

Instructions

For each statement below, please choose a number from 1 to 5 (1-strongly disagree, 2-disagree, 3-neutral, 4-agree, 5-strongly agree) that most closely matches your sentiment.

1. It is easier to see the lecture notes when the professor uses the white board instead of the tablet PC.
2. I pay attention more when the lecture is presented with the tablet PC.
3. I find it harder to comprehend what the instructor is saying when I can see him writing it on the tablet PC at the same time he describes it.
4. What I learned in this class will be useful to me after graduation.
5. I'm often overwhelmed with information when we use the tablet PC to present notes.
6. The combination of different electronic formats on the tablet PC (web, lecture notes, images, graphs) helps me understand the concepts being presented.
7. I prefer to watch the instructor develop and solve problems in real time on the tablet PC rather than view materials from a prepared overhead slide.
8. In this course, I concentrate on copying the instructor's notes to study later.
9. In this course, I find I do not understand when to apply the concepts we are learning.
10. I am often confused at the end of class.
11. What I learned in the course is important and valuable.
12. I find my prior knowledge sufficient to understand the basic concepts in this course.
13. I am confident in my ability to use mathematics to describe the behavior of the systems investigated in this course.
14. Rate how good you think you are in the class on a score from 1 (good) to 5 (poor).

General Questions

1. How has the professor's use of the tablet PC enhanced your ability to learn in this course?
2. How has the professor's use of the tablet PC inhibited your ability to learn in this course?
3. Please provide any additional comments on how the tablet PC could be used more effectively in class.

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