iCAMPUS REPORT

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Research Focus: Tablet PC in Combination with Various Software Products, Teaching Styles, and Learning Styles

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Structure and Interpretation of Computer Programs
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OVERVIEW

Our research with the Tablet PC has demonstrated that it can be a valuable asset for learning. We have learned, however, that its true value must be assessed either in combination with the ***specific software products with which it is used*** or ***independently***. Second, we have learned that its value can be more accurately and specifically determined in the context of the ***teaching styles or methods*** that are used in different courses, and, third, that its value can be more accurately and specifically determined in consideration of the ***learning styles and preferences*** of the students who use the Tablet PC. By doing this, we obtained more convincing and meaningful results.

There was, in addition, a fourth factor that became central to our research. An analysis of past research with the Tablet PC and other hardware and software products made it clear to us that more comprehensive and empirical standards for use in the assessment of educational technology were necessary. In consideration of this observation, we developed a number of ***research controls***. This included a differentiated analysis of ***performance scores*** for each student. Through this process we also were able to quantify and validate some of the factors that seem to make the Tablet PC useful and effective in teaching.

RESEARCH SUMMARIES

FALL, 2003: Tablet PC use in Neuroscience and Behavior, 9.14

Our initial research efforts with the Tablet PC began in the fall, 2003, with an introductory neuroscience class, *Neuroscience and Behavior*. Initially this research primarily attempted to simply evaluate the effectiveness of the Tablet PC on the overall performance scores (i.e. the final grade) of students. Three additional factors, however, were ultimately considered and evaluated. First we undertook a more detailed evaluation of **performance scores** and how they were correlated with the use of the Tablet PC. In this case, for instance, we felt that students might perform better on examinations from using the Tablet PC than on course projects or homework assignments. Perhaps the opposite was true. Therefore, we evaluated each component score that contributed to the final grade. This factor had never been looked at in research related to the Tablet PC, let alone in most research using educational technologies. What constitutes a final grade can vary dramatically from course to course, and, because of that fact, may be a poor measure of the effectiveness and impact of any educational technology. Second, we considered the effect that different individual **learning styles/preferences** might have on the effectiveness of the Tablet PC. We reasoned, for example, that perhaps those students who relied on heavy note-taking would benefit from the Tablet PC more than those who emphasized reading. Third, we made the effort to introduce more **research controls** than have been usual in research involving educational technology. We wanted to see how feasible it was to employ such controls. As an example, we used the so called split-half method in this initial research project. In this method, a fixed percentage of students in a given course had use of a Tablet PC while the remaining students did not. By doing this we were more able to control for such factors as the teaching styles of different instructors. This and other controls had never been done in research using the Tablet PC and rarely in research involving other educational technologies, including laptops.

By employing these research strategies in this initial program, we made a number of important discoveries. We also developed ways to incorporate different performance scores, individual learning styles/preferences, and research standards/controls into educational research.

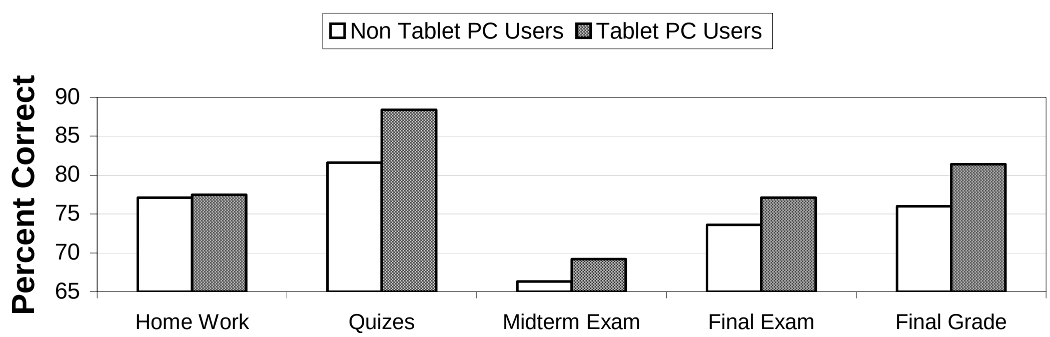
RESULTS

We did find that the use of a Tablet PC resulted in significant increases in performance on the final examination, ($p < .003$). Additionally, we found a statistically significant difference on their quiz results, ($p < .036$). There were insignificant increases, however, in the mean scores of Tablet PC users over non-Tablet PC users in their homework assignments and these assignments accounted for 30% of their final grade. As a result, the final grade that students received was not clearly indicative of the effectiveness of the Tablet PC or, just as importantly, of reasons why it may have been effective or ineffective.

This result indicated to us that differentiating the performance scores was an invaluable assessment to consider in research with the Tablet PC.

In this same study we made a more detailed analysis of the distribution of performance scores across all of the academic measures described above. When we examined the academic scores of those students who did poorly, a compelling result came to light. Students who performed in the bottom 15% of their class on the final examination and the final grade were only those who did not have the use of the Tablet PC. When we evaluated the lowest 15% on all measures of academic performance including quiz scores, homework and the midterm examination, similar results stood out (Figure 1).

Figure 1



Difference in Mean Performance Scores of Tablet PC Users and Non Tablet PC Users

This dramatic result suggested that the Tablet PC enabled struggling students or students who might have different learning styles, to adjust to course requirements because of its versatility or other characteristics. This is the first time that this type of analysis with regard to Tablet PCs had been done, and the results were encouraging and thought provoking. As a result, we evaluated students' individual learning styles/preferences through two surveys, classroom observations and interviews.

Students expressed their feeling that the Tablet PC helped them to organize their material. The most distinctive aspect was that hand written notes could be organized and integrated with other class material. When implemented with Stellar or any comparable web-based course delivery system, the Tablet PC enabled students to download an instructor's class notes, including slides, pictures, graphs, tables, and reference materials. All of this material could be coordinated with the student's notes and organized in any manner through such techniques as copy-and-pasting, captioning, auto formatting, and document merging. Additionally, the use of keyword searching enabled students to coordinate all material related to a specific topic. Students repeatedly described the ability to organize their course materials as one of the greatest advantages to using Tablet PCs. In response to end-of-semester survey questions given to students in this study, Tablet PC users reported that they were able to organize their time more efficiently than non-Tablet PC users ($p <.001$), their course materials at an even greater level of significance ($p <.00015$), and their notes at the highest level of significance ($p <.0001$).

A second advantage of the Tablet PC was the ability for students to download course handouts in color and edit them or add notes to them in color. Virtually all students who used Tablet PCs at least occasionally used colors to make their notes more legible, encode information pertinent to a given slide, highlight relevant information or to draw directly on diagrams and slides. In addition, more than 50% of these students used multiple colors to draw their own diagrams and graphs. Students who used Tablet PCs reported that their ability to understand course material improved with handouts that could be downloaded in color and which they could edit in color. When compared to students who used the standard printed handouts that were not in color, the difference in the final examination was highly significant ($p <.002$).

Approximately eighty percent of students mentioned the addition of color as being the primary change in note-taking style as a result of using the Tablet PC. What is clear in evaluating the students' notes was that color was used as a valuable note-taking resource for students with this learning style or preference. This was true for many students who did not have use of a Tablet PC. Their notes, however, rarely showed the use of color because of the inconvenience of using colored pens.

It is important to add that some students did not use color at all. It was not their learning style or preference. One student, in fact, said that he was color blind and had learned to depend more on different fonts and graphic styles to annotate notes and drawings.

The Tablet PC seemed to increase the effectiveness of learning because it was adaptable to the individual learning styles of students. Daily observations were made of the students' note-taking, and students were interviewed and surveyed. This revealed many different learning styles. All students in *Neuroscience and Behavior,* 2003, were provided with a CD on which to record their class notes. Although the stylus was the predominant means of note-taking on the Tablet PCs, some students relied primarily on the keyboard, and the majority utilized both. Several students took very few class notes but listened to the recorded course material after class in conjunction with the instructor's slides. Other students, rather than taking notes on paper, wrote most of their notes in color on the downloaded class slides.

Most apparent was that **the Tablet PC was adaptable to different learning styles, and preferences**. This characteristic of the Tablet PC has been largely unrecognized. The Tablet PC gave students distinct advantages, including the ability to integrate hand-written notes and course materials, use color, and increase the ease with which their course material could be organized.

Through this research we also were able to demonstrate that it was feasible to employ such research controls as the split-half method, multiple surveys, classroom observations and student interviews. These research controls enabled us to make direct quantitative comparisons between Tablet PC users and those who did not have the use of a Tablet PC.

One question that did remain for us concerned the course content and the teaching style. We had not taken these factors into consideration. In this course, *Neuroscience and Behavior,* note-taking was essential. Color coding notes on the numerous neuroanatomical slides was very helpful, and there were over 1000 pages of reading material from different sources. Would different courses where such teaching or learning strategies were not as essential effect the usefulness of the Tablet PC?

FALL, 2005: Tablet PC use in Animal Behavior, 9.20, Beginning Chinese I, 21F.101, Structure and Interpretation of Computer Programs, 6.001

The results of the initial study enabled us to design and refine further studies utilizing the Tablet PC. Although this new research was designed to incorporate differentiated analysis of **performance scores**, individual **learning styles/preferences**, and improved **research controls**, we added two additional factors. The first was consideration of the effectiveness and utility of the Tablet PC when used with different **software products.** We reasoned, for instance, that using the Tablet PC with software that enabled students to have immediate feedback to their responses given in class might demonstrate different effectiveness and utility of the Tablet PC than another software product that did not. Second, we attempted to assess the **teaching styles or methods** of the instructor and analyze how this might alter the effectiveness and utility of the Tablet PC. As an example, we reasoned that an instructor who emphasized student engagement through class discussions or problem solving might result in students using the Tablet PC very differently compared to an instructor who primarily lectured and emphasized note-taking.

Although these five factors added a great deal of complexity to the research effort, we believed that it was possible to begin to incorporate these factors and, as a result, come up with much more valid and convincing results concerning the effectiveness and utility of the Tablet PC in education. We also wanted to demonstrate the feasibility and practicality of incorporating these five factors.

In the fall of 2005, we designed and assessed the Tablet PC in three different undergraduate courses at MIT. This included ***Animal Behavior, 9.20*** in the Department of Brain and Cognitive Sciences, ***Beginning Chinese I, 21F.101*** in the Department of Foreign Languages and Literatures, and ***Structure and Interpretation of Computer programs (SICP), 6.001*** in the Department of Electrical Engineering and Computer Science.

These courses were chosen because of the interests of each instructor, and also because they involved the assessment of the Tablet PC in the context of distinctive teaching styles as well as the use of different software platforms.

COURSE: Class size, Hardware, and Software

Animal Behavior, 9.20

Class Size: 12, 5 with Tablet PCs

Compaq TC1000 Tablet PCs, Acer TravelMate C110Ti
- 512 MB of RAM with a maximum of 2 GB
- Memory: DDR SDRAM running at 333MHz
- Essentially these were 3 year old Tablet PCs that ran quite slowly compared to current models (including laptops)
- Battery life was approximately 90 minutes; short compared to current models (including laptops)

Windows Journal®
- Microsoft's software that enables students to use their stylus pen to hand write, color code and edit their class and homework notes on the Tablet PC screen

Window XP®
- Microsoft's operating system used with the Tablet PC

Power Point®
- Microsoft's software presentation program

Stellar system
- MIT's web-based course delivery system that also enables instructors and students to record classes.

Beginning Chinese I, 21F.101

Class Size: 22, 8 with Tablet PCs

Compaq TC1000 Tablet PCs
- 512 MB of RAM with a maximum of 2 GB
- Memory: DDR SDRAM running at 333MHz
- Essentially these were 3 year old Tablet PCs that ran quite slowly compared to current models (including laptops)
- Battery life was approximately 90 minutes; short compared to current models (including laptops)

flashCube
- Software that mimics "flashcards" and enables students to test their knowledge of written or spoken translations of Chinese characters, pinyin and English

Created by MIT graduate student, Jordan Gilliland and owned by MIT (to his great dismay)

Windows Journal®

Microsoft's software that enables students to use their stylus pen to handwrite, color code and edit their class and homework notes on the Tablet PC screen

Windows XP®

Microsoft's operating system used with Tablet PCs

Power Point®

Microsoft's software presentation program

Stellar system

MIT's web-based course delivery system that also enables instructors and students to record classes.

Structure and Interpretation of Computer Programs (SICP), 6.001

Class Size: 20: All with Tablet PCs

Hewlett-Packard tc4200 Tablet PC, 1.73 GHz

Windows XP – Microsoft's operating system used with the Tablet PC

Athena – MIT's student computer system which enables students to save course material or class notes, whether keyboarded or hand-written on a Tablet PC.

Classroom Presenter – Software that supports student submission of digital ink answers to in-class exercises using a Tablet PC

RESEARCH CONTROLS

It is important to note here that the following research controls were central to our research, and each reflects a control that we believe is essential for good science. The importance and basis for some have been briefly described previously. A more detailed description of these controls will be presented in the research paper that will be submitted for publication in October, 2006.

Animal Behavior

- Split-half class application
  In the same classroom, a certain percentage (ideally 50%) of students received the Tablet PC and the other students did not.
- Random selection of participants followed by volunteering
  Students were randomly selected and then given the choice of participating and using the Tablet PC or not.
- Students received Tablet PCs and software after they had an opportunity to adjust to the class and after the first test or quiz. This also was done to have a control test prior to the distribution of the Tablet PC.
- Multiple Data Sources
  Pre- and post-surveys, interviews, multiple 5-minute classroom observations gave us

the opportunity to cross validate the information that was collected.

- Multiple performance measures
  Performance measures included the different scores the instructor used to determine the final grade. This may have included quiz and test scores, homework, projects. participation, etc. Each was evaluated separately with the Tablet PC.
- Differentiated results analysis
  Student performance measures were made of different percentage levels of the class Typically the top and bottom 25% or 33⅓% of the experimental and control classes were compared.
- Teaching styles/methods analysis
  See below. These are considered research controls because they could impact the effect that the Tablet PC has on learning.
- Learning styles/preferences analysis
  See below. These are considered research controls because they could impact the effect that the Tablet PC has on learning.

Beginning Chinese I

- Split-half class application
- Random selection of participants followed by volunteering
- Students receive Tablet PCs and software after adaptation to class and after the first quiz
- Multiple Data Sources
- Multiple performance measures
- Differentiated results analysis
- Teaching styles/methods analysis
- Learning styles/preferences analysis

Structure and Interpretation of Computer Programs (SICP)

- One experimental class
- Random selection of participants followed by volunteering
- Students received Tablet PCs and software after adaptation to class and after the first
- quiz
- Multiple Data Sources
- Multiple performance measures
- Differentiated results analysis
- Teaching styles/methods analysis
- Learning styles/preferences analysis

LEARNING STYLES/PREFERENCES

It is not difficult to demonstrate that students utilize a wide range of learning styles and preferences in their classes. What can be most striking are the differences that can be observed and measured. Whether or not these differences reflect learned or innate differences is not important. What is important relates to how these differences may affect the use of any particular hardware or software product. In the previously described research involving the use of the Tablet PC in *Neuroscience and Behavior* this effect was dramatically demonstrated. One further example emphasizes this point. A student in *Animal Behavior* reported that he thoroughly enjoyed the Tablet PC and that it helped him. Note-taking was very important in this course. Observations in class, however, indicated that he did not use his Tablet PC as most of the other students did. When interviewed, he stated that he never could learn from taking notes. He had an extremely strong auditory learning preference and ability. As a result, he listened to each lecture and recorded them using his Tablet PC. He received a B+ as his final grade and an A on his final examination. This example also points to the importance of having multiple data sources.

Through two surveys, classroom observations and student interviews, we distinguished several learning styles/preferences that had potential to relate to how the Tablet PC might be used - or not used. The major ones that we assessed are described below. It is important to note, however, that virtually all students have the ability to use all of the learning styles listed and probably do to varying degrees. In addition, in practice, almost all learning styles overlap in their actual use. The question relates to what the student's preference is, and what might each student, in fact, use, given the teaching style of the instructor and the hardware or software that is made available.

Auditory Learning

Preference is for listening rather than taking notes or even reading.

Auditory Processing

Preference is for being able to ask questions and repeat what is heard and understood.

Visual Learning

Preference is for reading, including printed material and looking at textural or mathematical/numerical information presented in classrooms.

Visual Processing

Preference is for solving visually displayed problems (through text books, computer screens, classroom board presentations, etc.) and learning from solving these problems mentally or through writing. (This closely overlaps Motor Learning described below.)

Visual-Color Learning

Learning with the use of colored-keyed information and taking notes or drawing using different colors.

Visual-Spatial Learning

Learning from drawings, diagrams, pictures, etc that minimizes text.

Motor Learning (Writing)

Learning from the act of writing whether taken from lectures, written material, photos, etc. or answering problems through writing.

Interpersonal Learning
Learning through personal interaction with instructors, students or other people

TEACHING STYLE/METHODS

An analysis was made of the teaching style/methods that were used by each instructor. This was done through multiple 5-minute assessments of each instructor during the semester. The teaching style/methods were based upon the sensory format used and whether information was presented as a monologue or a dialogue. As an example, the percentage of time an instructor lectured with little supporting visual input (e.g. writing on the blackboard or presenting slides) would be described as Auditory Lecture teaching time. The percentage of time an instructor might spend asking or answering questions would be described as Auditory Processing teaching time. In this case, the student is not just taking in rote information but rather, is analyzing, assessing, configuring information, that is to say, "processing" information. These teaching styles/methods actually reflect very different and well known ways in which the nervous system integrates information.

What is important to recognize is that each of these teaching styles/methods could have significantly different impacts on students with similar or different learning styles or preferences. They could also result in very different ways in which a Tablet PC is utilized or how effective it is.

The following is a list of some of the most basic teaching styles/methods that we assessed:

Auditory Teaching
Lecturing with no or little essential visual support such as slides or blackboard notes

Auditory Processing
Teaching through asking or answering questions or opinions of students

Auditory-Visual Teaching
Lecturing with essential and necessary support of slides or notes

Visual Teaching
Teaching through reading assignments. This is primarily done out of class, i.e. homework.

Visual Processing
Teaching by having students answer questions that are written or drawn. This is primarily done out of class, i.e. homework.

A more detailed description of the assessment of these teaching styles will also be given in a paper that will be submitted for publication in October, 2006.

The percentage of time that each instructor spent engaged in each teaching style/method within the classroom is listed below. The percentages may or may not add up to 100%. This is because only percentages that were greater than 3% were listed and some Teaching styles/methods overlapped.

Animal Behavior

Auditory Lecture (59%-85%)
Ancillary Multimedia Support (15%-20%)
Review of study questions
Attendance not required
Lecture notes and recording of lecture available on line
Text and handouts essential

Beginning Chinese I

Auditory Processing (66%)
Auditory Lecture (12%)
Visual (7%)
Interactivity Instructor↔Student or Student↔Student (66%)
Attendance required
No lecture notes available. Recordings of class available on line
Text and Handouts essential

Structure and Interpretation of Computer Programs

Audio-Visual Teaching (65% - 70%)
Audio-Visual Processing (25%)
Interactivity Instructor↔Student or Student↔Student (7%)
Attendance "strongly encouraged" and incorporated in the final grade.
No recordings of recitation class available
Text and handouts not required (except for problem sets)

PERFORMANCE SCORES

Animal Behavior

Homework	10%
Project	30%
Quizzes	10%
Midterm	20%
Final Exam	30%

Beginning Chinese I

Five tests	40%
Aural and written components.	
Class participation	20%
Aural interview	20%
Homework	20%
No midterm or final exam	

Structure and Interpretation of Computer Programs

Quizzes	25%
Participation	10%
Projects	30%
Problem Sets	10%
Final Exam	25%

RESULTS AND ANALYSIS

Animal Behavior, 9.20

The Tablet PCs could not be used for their intended purposes because they did not work consistently and were slower than expected. (They were three years old.) Many styluses worked erratically. In sum, the hardware was not reliable. As a result, the students did not use the screen-writing format, and we could not assess the effectiveness and utility of the Tablet PC in this course. Despite this problem, some indirect but highly relevant information was obtained that contributed to our research in other courses.

Teaching Style

The predominant teaching methodology was Auditory Lecture with spatial representation of information via slides minimized and serving only an ancillary function. In addition, course examinations were based directly upon study questions that were gone over in detail for almost every class during the semester.

This style/method resulted in a high average (32%) of class time spent writing notes by all students whether they had use of a Tablet PC or not. Further, this teaching style resulted in a greater than 50% reduction in notes being made on slides presented in class when compared to our previous study with the Tablet PC.

When notes were taken, the Tablet PC was used for keyboarding 90% of the time and not handwriting notes on the Tablet PC screen. Through interviews, the students indicated that they felt "obligated" to use the Tablet PC even though keyboarding made it more difficult to take as many notes as they had wished or organize them the way that they normally would have. **They were not able to incorporate their own unique symbols, order and configurations of notes as they were used to. The consequence of this lack was that the more typed class notes that Tablet PC users took, the less well they did on their tests ($p < .008$). Further, students who had Tablet PCs did significantly worse than students who wrote notes by hand on the midterm and final examinations (Midterm Exam: $p > .007$, Final Exam: $p > .0001$).**

This rather dramatic result would seem to indicate that with this teaching style/method the handwriting of class notes served an essential and beneficial purpose that directly contributes to students' learning. Student note-taking, itself, often shows the uniqueness of each student. Use of abbreviations, symbols, and drawings, as well as general organization, varies tremendously among students.

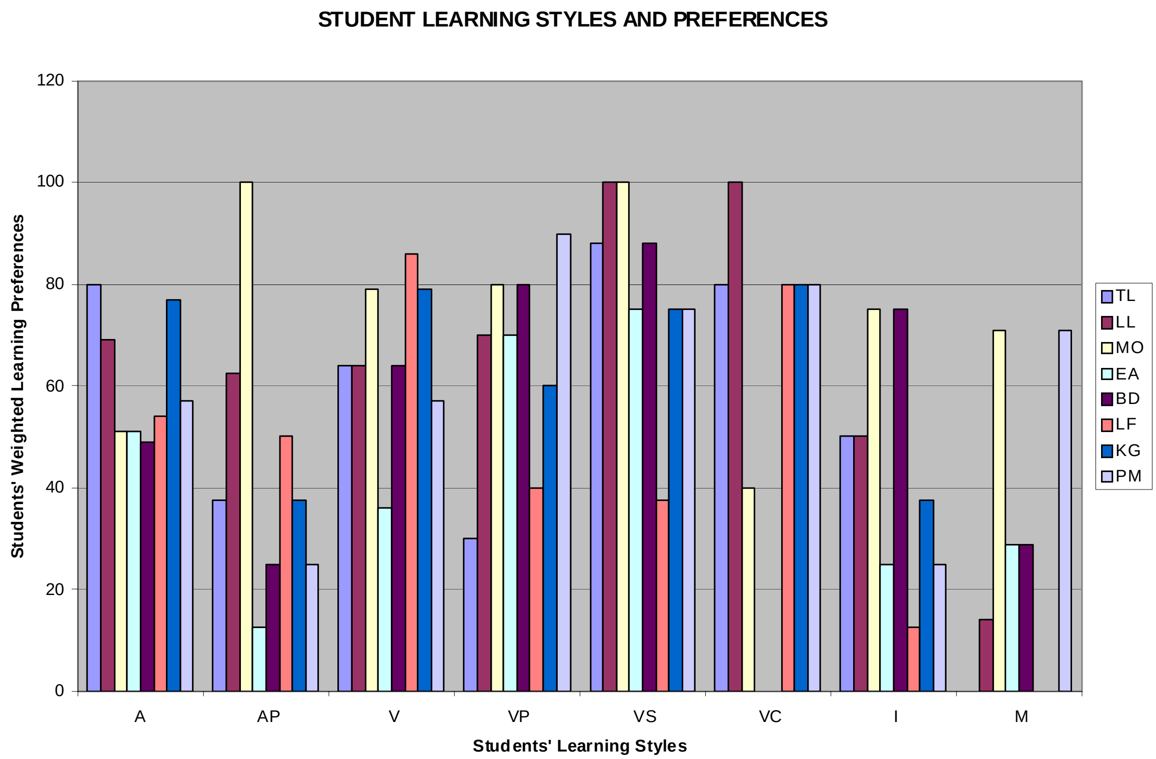
Related to this, students who had use of the Tablet PC reported in both surveys and interviews that they preferred to listen to lecture presentations. Additionally, students who had use of the Tablet PC performed better than Non-Tablet PC users on both homework grades and most quizzes ($p < .0001$). This may have been a compensatory adjustment by students because of their feeling that their notes were not adequate, but it appeared that they preferred listening to lecture presentations because of their problem with keyboarding their notes.

<u>Learning Styles</u>

In the present study, delineations were made of some of the students' learning styles/preferences. Students were evaluated on these styles/preferences through surveys, interviews and observations. The relative weights for each learning style for each student are depicted in Figure 2. The term "relative weights" in Figure 2 refers to the maximum score that a student could receive for that learning style/preference (i.e. 100). While a score of 80 or higher could indicate a strong preference for a particular learning style/preference, this would also have to be compared to the student's other learning styles/preferences. For instance, student TL had a learning style/preference rating of 80 for Auditory Learning (A), but he also had a slightly greater learning style/preference rating of 87 for Visual-Spatial Learning (VS). He also did not like Motor Learning (M). His learning style/preference rating for this was 2. Through surveys, and classroom observations it was clear that this student, in fact, did not take notes in class (Motor Learning), but he listened intently (Auditory Learning) to explanations of photographs and slides (Visual-Spatial Learning) presented in class.

Figure 2 also graphically demonstrates the variety of learning styles/preferences that students may exhibit.

Figure 2



Those students who had the highest preference for visual-spatial presentation of information had the lowest grades on the final and midterm examinations, while students with the lowest preference for visual spatial presentation had the highest grades on the final and midterm examinations ($p < .041$, $p < .027$).

There was also a tendency for those students who had the highest preference for auditory learning to have the highest grades on the final and midterm examinations. On the other hand, students who had the lowest preference for auditory presentation of information had the lowest grades on the final and midterm examinations. This result was not significant but was a consistent trend.

Since the predominant teaching style/method was Auditory Lecture with Visual-Spatial representation of information minimized and serving only an ancillary function, those students who had a learning preference for visual-spatial learning were at a disadvantage. Those who preferred auditory learning and writing were not.

Based upon this research in *Animal Behavior*, we can only surmise that the Tablet PC would have been a great advantage to students who relied on their handwritten notes in this lecture-based course.

From this study we also learned that Learning Styles/Preferences can be factored into educational assessment, and that they do have relevance to the teaching styles, and thus, to the educational technologies that are incorporated into the classroom.

Beginning Chinese I, 21F.101

The first impression of our research with the Tablet PC in Beginning Chinese I was that it was not necessary for use in the classroom format used. The predominant teaching style was Auditory Processing, that is, the instructor spoke to the students in Mandarin in order to familiarize them with sounds, tones and words, and asked questions of the students in Mandarin. The students were required to respond in Mandarin. Second, note-taking was not necessary. All information presented in class was available through handouts, text and from the software used (flashcube). Third, the primary software program that the students used (flashcube) was as easily adaptable to a student's desktop or laptop as it was to their Tablet PC. This software program enabled students to practice writing, speaking and listening to Mandarin. It was expected that flashcube would also enable students to write Chinese characters on the Tablet PC screen and immediately receive feedback as to whether or not they had been written in the correct stroke order. This additional functionality, however, was not developed in time by the creator of flashcube. Surprisingly, we still found an advantage in using the Tablet PC when evaluated from the perspective of the students' learning styles/methods.

The students with Tablet PCs had a higher mean score on all tests and their oral examination than students who did not have use of the Tablet PC. Although there was no significant difference on each test individually, when assessed as a repetitive sequence, the results were significant ($p < .025$).

Students with Tablet PCs represented 40% of all students taking Beginning Chinese I class. (There were three separate Beginning Chinese I classes.) In this class, however, the students with Tablet PCs represented 52% of the top performing students and only 25% of the lowest performing students. (The highest and lowest performing students were based upon the 25th percentile.). Although this difference is not significant, this result is in keeping with all previous testing we have done over three years with the Tablet PC. That is to say, fewer students do poorly in all cases and, more often than not, more students do better.

Even more notably, remembering that Tablet PC users represented only 40% of all students taking beginning Chinese I, on the oral examination the students who had use of the Tablet PC represented 67% of the students on the top 25% of their class and only 20% of those students in the bottom 25% of their class. Again, this result is consistent with our previous research findings with the Tablet PC. In this case, half as many students who used the Tablet PC did poorly than would have been expected by chance, and 27% more students performed in the top 25% of their class than would have been expected by chance.

The reasons for these results were not obvious until we evaluated the individual learning styles of the students.

The most statistically significant factor that resulted in the performance benefits of the Tablet PC was the ability to use color in editing or writing notes or in doing homework. As students became more familiar with their Tablet PCs, they found ways to use them to their advantage, even in a class where the benefits were not obvious. (Test 3 → $p < .015$, Test 4→ $p < .036$, Final Grade → $p < .01$). Students reported that color enabled them to learn more efficiently because they could use the colors to practice stroke order and note tone accents in pinyin (the Roman alphabetic translation of Chinese characters). That is to say, the higher the students valued learning by using colors to take notes, do their homework or practice, and the more they used the Tablet PC for that purpose, the higher their test scores were. The Tablet PC gave such students with this learning style/preference the opportunity to perform better. When this learning style was eliminated from the analysis, there was no significant difference between Tablet PC users and non-Tablet PC users.

Accounting for the benefit that the Tablet PC provided to performance on the oral examination is not as direct and may not be related to the ability to use color, hand-write notes on the screen or organize material. Rather, students reported that the Tablet PC was so easily carried that they used it in other classes and were much more likely to use the flashcube software with it when they had the time. In other words, the benefit might merely have been the convenience that grew out of carrying their Tablet PCs around campus. If this speculation is true, we would have expected that students who had use of the Tablet PCs used the flashcube software more often. We do know that the flashCube software had the most beneficial result on the students' performance on their oral examination ($p > .008$). This benefit occurred because flashCube enabled students to listen to the sounds of the Chinese language. Unfortunately, we did not anticipate this finding, and, as a result, we were not able to quantify how much more students used flashcube with their Tablet PCs.

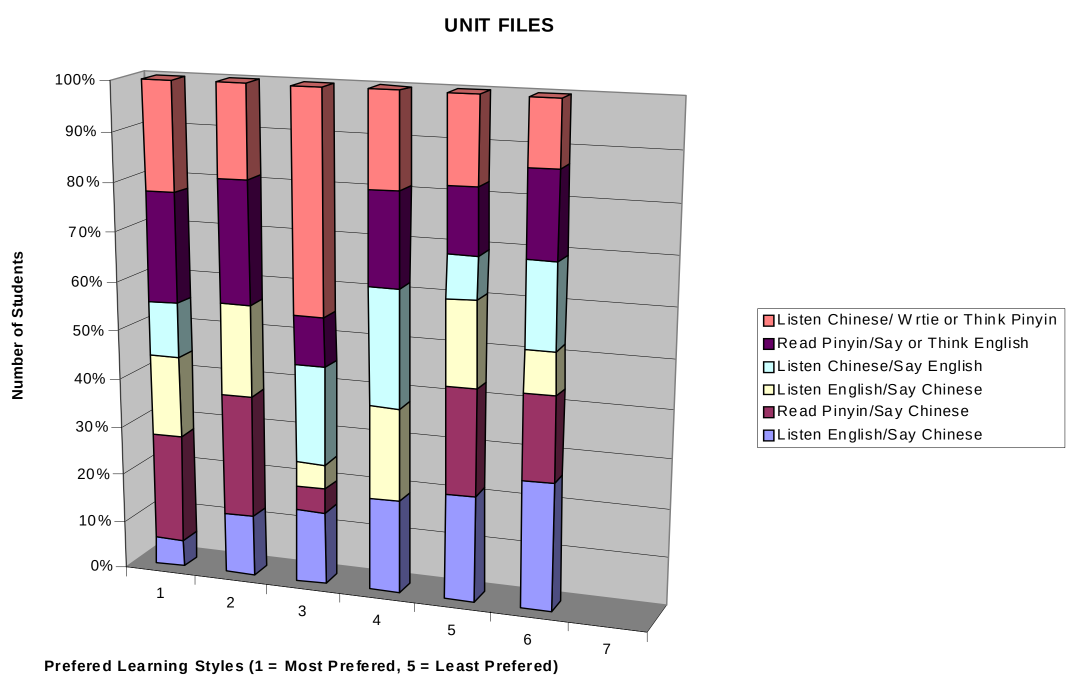
There were some additional findings with regard to individual learning styles that do have relevance when considering the potential benefits of the Tablet PC. Two-thirds of the students using Tablet PCs and who also described themselves as the most extreme visual learners (That is, they preferred reading rather than listening in class) had the lowest results on their tests (Test 2→ $p < .007$, Test 3→ $p < .004$, Test 4→ $p < .014$, Oral Exam→ $p < .034$). Related to this, the students' tests increasingly required listening to Chinese words and sounds and answering questions in response to them (Test questions related to listening increased from 39% to 52% over the course of the semester). As a result, those students who were preferentially visual learners, rather than auditory learners, may have been at a greater disadvantage. Despite this they did not do as poorly as their counterparts who did not have the use of the Tablet PCs. We can only surmise that these students may have used color more frequently in writing Chinese characters or while listening to Chinese sounds through flashcube. It is also possible that these students compensated for their decreased preference for auditory learning by listening to flashcube software even more. We were not able to quantify this, but these results would lead us to investigate this possibility in further research. The statistic remains that use of the Tablet PC independent of the flashcube software or in combination with it provided an advantage.

In this study, the benefit of having and using a Tablet PC in a course where auditory processing was the primary teaching style was demonstrable and more specific. Students were able to utilize their hardware and software to accommodate their learning styles and preferences. The flashCube software enabled students to use any combination of teaching formats to learn the material.

The benefit on performance of the Tablet PC, independent of the flashcube software, can be explained on the ability to use color and editing in making homework notes and doing homework. Color was extremely beneficial to some students, again suggesting that this reflects an individual learning style or preference. There were other students who did not use color because they were able to depend upon different learning styles and preferences. Several students had a very strong auditory learning style that enabled him to easily memorize sounds with the associated pinyin text and Chinese characters that they read.

The relevance of individual learning styles and preferences has been suggested by this research. In as much as we have demonstrated that this might be a measurable variable that can be incorporated into a course, we decided to assess all of the students in Beginning Chinese I on additional individual learning styles and preferences. One of five additional assessments is shown in Figure 3. In this figure students identified their preferential way of learning Beginning Chinese I. What this graph shows is that each way of learning Beginning Chinese I varied from most preferred to least preferred depending upon the student. All of these additional analyses indicated the great variety of learning styles that students employ.

Figure 3



With this in mind, one might ask how it can be possible to accommodate the learning styles and preferences of all students. The answer is direct. Just as flashcube was able to accommodate the learning styles and preferences of students, enabling them to study and practice in a multiple of ways without adding time and difficulty, the Tablet PC further enabled students to benefit from using color with great ease. It added at least one additional way to learn for students even in a course where the most obvious benefits of the Tablet PC were not needed

It is also important to note that in interviews with students who had use of the Tablet PC, all noted that they used them for other courses where the need to write and take notes was much more critical. Most notably this included Chemistry, Computer Programming, Physics and Biology where formulating equations, and writing or drawing and editing figures were most prevalent. This is a great segway for the third course where we researched the effectiveness and usefulness of the Tablet PC, i.e. Structure and Interpretation of Computer Programs.

Structure and Interpretation of Computer Programs (SICP), 6001, Fall, 2005

In one of five recitation classes of Structure and Interpretation of Computer Programs, the Tablet PC was introduced in combination with a software product called Classroom Presenter. This was the first of four planned semesters in which the Tablet PC would be used in combination with Classroom Presenter and its subsequent modifications. As such, this first semester served as a pilot program.

The initial question posed by this research was whether or not immediate feedback to incorrect answers within the classroom could be provided to all students. Compared to personal response devices, the goal was to enable students to send detailed handwritten answers to the instructor via the Tablet PC. With such in-class feedback, the instructor could also then modify explanations to fit student misunderstandings and assess student learning. This research was dependent upon both the Tablet PC and the associated software, Classroom Presenter. It also was dependent upon a teaching style that encouraged active engagement of the students. Pedagogically, this research also attempted to incorporate the well known benefits of immediacy of feedback in the learning process. This has not been possible in the past because providing feedback to all students within a class requires much more time than is possible.

In this first pilot study we did not control for the differences in teaching styles/methods of different instructors. Comparisons were made only of those students in one recitation class who used the Tablet PC with Classroom Presenter and four other recitation classes whose students did not have use of these technologies. However, in an effort to control for this very important variable, we did not introduce the Tablet PC until after the first test. This occurred during the fifth week of the semester.

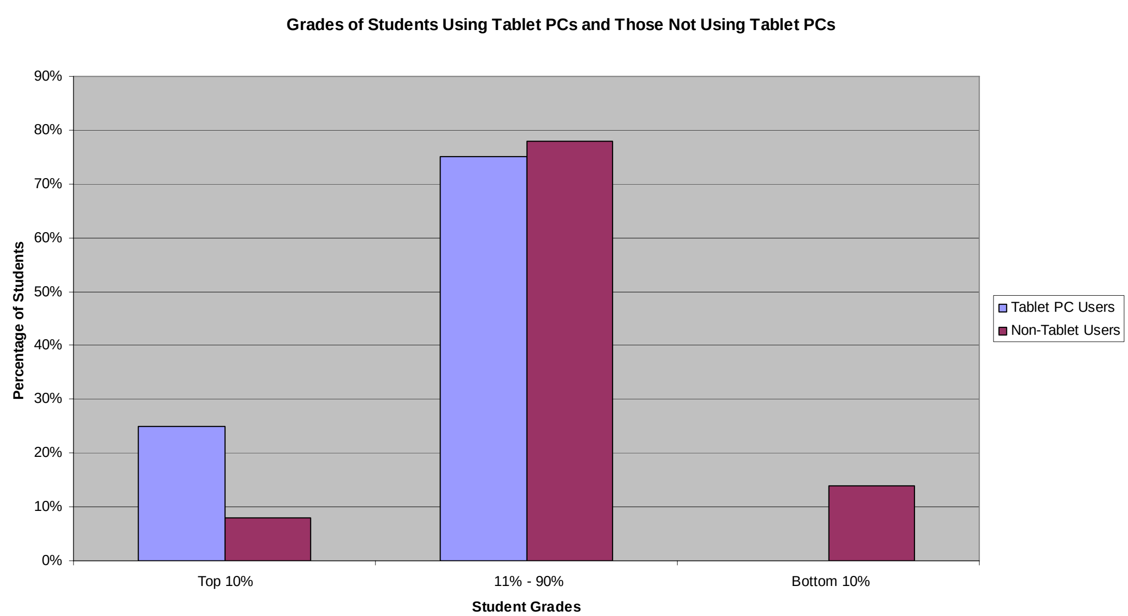
The mean scores of this test were not significantly different from the other recitation classes. When a differentiated analysis was made of the test scores, however, several findings stood out. These students represented 36% of students scoring in the top 10% even though the students in this recitation represented only 15% of all students taking the computer science class. In other words, they represented two and one half times as many students as would have been expected by chance.

This pre-Tablet PC/Classroom Presenter result probably reflected the teaching methods of the instructor which emphasized both Auditory and Visual Learning simultaneously as well as active engagement of all students (Auditory Processing). Typically the students spent no less than 90% of class time in answering problems or listening and watching solutions to class problems. In this first pre-Tablet PC test, there was no difference in the percentage of student who represented the bottom 10% or 25% of all students taking this computer science course.

After the introduction of the Tablet PC and Classroom Presenter, the contrasts increased. On the subsequent test, students in this recitation now represented 44.4% of all students in the top 10% of all students taking SICP. This was three times greater than expected by chance.

More interestingly, and as we have seen in all previous studies where the Tablet PC was introduced, students who had use of the Tablet PC now represented only 8.3% of those students in the bottom 25% of the entire student body taking SICP (100 students). This is approximately half of what might have been expected by chance. Further, no student received a D of F. In the entire course consisting of five recitation classes, 8% of the students received a grade of D or F (Figure 4).

Figure 4



The reasons as to why the Tablet PC and Classroom Presenter software seemed to benefit the highest performing students to some degree and the students who performed in the bottom third of their class to an even greater degree required a detailed analysis of the survey, observational data, and interview data. The results were fairly complex. Both the top and lowest performing students found personal advantages in using the Tablet PC and Classroom Presenter software. This, we believe, reflects the adaptability of the Tablet PC and Classroom Presenter to the individual learning styles and preferences of the students.

Based upon the total grade score, the top five students all described the Tablet PC with Classroom Presenter as having helped them. Interestingly, 3/5 of the students with the bottom five total performance scores also reported that the Tablet PC helped them.

Another interesting finding was that 4/5 students with the top five total performance scores believed that they learned best from interpersonal classes rather than from studying alone ("interpersonal" here means that they had the opportunity ask questions, give answers or discuss issues in class). All of the top students liked to have options if they felt that they knew the material being presented. Two of the five top students felt that feedback was sometimes essential to them. Students who performed in the top third of this class also noted that this course was much easier than anticipated ($p > .001$) specifically because they were able to get immediate feedback on the questions that gave them difficulty. However, no one was interested in feedback if they already knew the material. Three of the top five students also used the Tablet PC for doing other work when they got bored. One adaptation made to this was the opportunity for these students to answer more challenging problems that they could then submit to the instructor for review. This will be more formally introduced in subsequent research.

There were differences for the five students with the lowest total performance scores. Four out of five believed that they learned best from studying alone rather than from lectures and tutorials. Three out of five of these students felt that the lectures and/or the tutorials were sometimes too brisk or too difficult for them. Recitations apparently did not have that effect. These students mentioned that using the Tablet PC and Classroom Presenter to save answers, modify answers on the Tablet screen and keep "me focused when I began to get lost" was an advantage. On the other hand, if they felt rushed, they did not benefit from seeing other students' answers in class. The result was that these students saved the handwritten answers that other students submitted via their Tablet PC and Classroom Presenter and reviewed them at a later time. In this somewhat indirect way, the use of the Tablet PC and Classroom Presenter probably contributed to the result described above. That is, there were fewer students who performed in the bottom 25% of the entire class.

Forty percent of the top five and bottom five performing students (i.e. 2/5) felt that solving problems with Classroom Presenter helped them more than if they had attempted to solve those same problems without it. Similarly, 40% of the lowest five performing students and 60% of the highest performing students felt that seeing the answers others gave helped them in understanding many of the concepts in this course. What is noteworthy is that these technologies and classroom strategies helped a wide range of students. It might have been a reflection of their abilities, learning styles and learning preferences. Nevertheless the end result seems to be that a significant number of students at both ends of the spectrum were helped. This again suggests that the ability and opportunity to adapt the technology to the students' learning styles and preferences provides an advantage to a wide range of students.

The students who comprised the "middle level" were almost unanimous in their feeling that they benefited from seeing others students' answers. That was the one notable similarity in their surveys and interviews. Still, their mean scores on all performance variables were essentially the same as those students in the other recitation classes. Based upon the findings described previously, as well as in our previous study, this may indicate that the impact of the Tablet PC and Classroom Presenter is greatest for students at the top end, and particularly the bottom end, of the performance scales.

There were no apparent significant differences in specific learning styles or preferences between the top 33% and bottom 33% of students. Based upon the surveys given to students, classroom observations and interviews, however, there seemed to be greater variability in the learning styles and preferences for the bottom 33% of students. That is to say, poorer performing students seemed to have used a wider variety of learning styles to learn. If true, the possibility is that poorer performing students may have been more open to trying different learning strategies and technologies in order to improve their performance. Better performing students may have simply adapted the technologies to learning methods that they already used and which have served them well. This result could not be quantified, but the impression was somewhat strong. This would be a very interesting topic for further research.

Independent of performance scores, one statistically significant observation can be made with regard to the students' study habits. The more students described themselves as organized, neat and methodical in their study habits, the more ways they experimented with and used their Tablet PCs ($p < .01$). This was independent of their performance scores. In addition, those students who had experience in using their laptops in other courses liked the Tablet PC more and felt more comfortable integrating it with the Structure and Interpretation of Computer Programs class. In other words, familiarity with related technologies bred greater use and comfort. In assessing any educational technology, this factor should probably be taken into consideration.

One further result is noteworthy. The students who performed in the bottom third of this class felt that they learned a tremendous amount even though the course was difficult (9.4 on a 10 point scale). This was significantly greater than the top performing students (6.8 on a 10 point scale). This result was significant ($p < .025$). The top performing students also described Structure and Interpretation of Computer Programs as a class that was much easier than anticipated compared to the bottom third of this class. This result was also significant ($p < .001$). One indication here is that the lower performing students still had a positive experience and believed that they learned a great deal. The Tablet PC and Classroom Presenter probably contributed to that feeling and accounted for their relatively high performance scores.

In sum, we differentiated the performance scores of students, and as a result, we were able to see that the Tablet PC and Classroom Presenter software did have an impact on student performance. In this research project we also identified characteristics of teaching styles and methods, individual learning styles and preferences and software that may help account for these findings. The results led us to refine our methods and implement them in our next research project.

SPRING, 2006

COURSE: Class size, Hardware, and Software

Structure and Interpretation of Computer Programs, 6.001

Class Size: Experimental Class: 17 All with Tablet PCs
Control Class: 17 No Tablet PCs

Hewlett-Packard tc4200 Tablet PC, 1.73 GHz
Windows XP – Microsoft's operating system used with the Tablet PC
Classroom Presenter – Software that supports student submission of digital ink answers to in-class exercises using a Tablet PC
Athena-MIT's student computer system which enables students to save course material or class notes whether keyboarded or handwritten on a Tablet PC

RESEARCH CONTROLS

See Page 7 for details

- Experimental and control classes/same instructor
  The instructor's teaching styles/methods were assessed through multiple 5 minute observation periods throughout the semester
- Random selection of participants followed by volunteering
- Students received Tablet PCs and software after adaptation to class and after first test or quiz
- Pre- and post-surveys, interviews, classroom observations
- Multiple performance measures
- Differentiated results analysis
- Teaching methods analysis
- Learning styles analysis

LEARNING STYLES/PREFERENCES

See Pages 7-8

TEACHING STYLE/METHODS

(Also See Page 8)
Audio-Visual Teaching (65% - 70%)
Audio-Visual Processing (25%)
Interactivity Instructor↔Student or Student↔Student (7%)
Attendance "strongly encouraged"
No recordings of recitation class available
Text and handouts not required (except for problem sets)

PERFORMANCE SCORES

Tests	25%
Participation	10%
Projects	30%
Problem Sets	10%
Final Exam	25%

RESULTS AND ANALYSIS

Both the experimental class (those students who would have use of the Tablet PC and Classroom Presenter) and the control class (those students who would be taught by the same instructor but would not have use of the Tablet PC and Classroom Presenter) were given the first class test in the fifth week of the semester. This was prior to the deployment of the Tablet PC with Classroom Presenter. By using this experimental control, we could insure that both classes were comparable in performance. The difference in the mean scores was only 3.6% and this was insignificant.

After the deployment of the Tablet PCs, the difference increased 9.2% on the second examination. The mean score for non-Tablet-PC students was 78.5, and for Tablet-PC users it was 85.3. The results, although 2 1/2 times greater, were still statistically insignificant. Similar results continued for all other performance scores throughout the semester. There were no statistically significant differences between the experimental and control classes when assessed as a whole. However, based upon our previous research, we expected to see more significant results when we did two more specific analyses of the results.

First we undertook a differentiated analysis in order to compare students who performed in the top and bottom 25% of the entire SICP class. When compared to all of these students, we would have expected 25% of both the experimental and control classes to be in both the top and bottom 25% of the class. However, 43.8% of the Tablet-PC class, and 35.3% of the control class were represented in this group. Statistically these findings were weak but still indicative of a positive effect, particularly as it related to the Tablet PC and Classroom Presenter

More decisively, only 6% of those students using the Tablet PC performed in the bottom 25% of the entire SICP class. This was less than one fourth as many as would have been expected by chance. This result was significant ($p < .045$). In the control class 23.5% of non-Tablet-PC students were in the bottom 25%.

These results compliment our previous findings. That is, use of the Tablet PC improves the performance of those students who might otherwise have done poorly.

Second, we evaluated what pedagogical factors might contribute to the effectiveness of the Tablet PC and Classroom Presenter. We were particularly interested in the actual number of submissions that were made by the students in class using their Tablet PCs and Classroom Presenter. This would, in fact, be the most direct way to see the relationship between the actual use of the technologies as they were intended and performance scores. When we did this, the result was dramatic. We compared the performance scores of the top one-third and bottom one-third of the experimental class. When we did this, the correlation between the number of responses that students submitted through their Tablet PCs to in-class problems and their performance on the final examination was .021. When correlated with the total performance score, the correlation was .001. This result was independent of the correctness or incorrectness of the submission. It is interesting to note there also were more than four times as many correct answers submitted as incorrect answers. In addition, approximately fifteen percent of the submissions were resubmissions, evenly split between students correcting an error that they discovered in their first answers and students trying a more elaborate or alternate solution. These results suggest that active involvement in the class through working in-class exercises using Classroom Presenter and the Tablet PC contributes to learning. This more in depth level of analysis also further demonstrates the importance of undertaking and using more controlled and specific assessment strategies.

A further analysis of learning style and performance scores gave more incites. We found that students with an auditory learning style and preference did significantly better than students with any other learning style or preference (avg. $p < .035$). However, we also found that there was a significant correlation between students with visual learning styles and preferences and their performance on the final examination and final grade. ($p < .028$ and $p < .027$).

The most plausible explanation as to why the highest performing students had both auditory and visual learning preferences relates to the teaching methods used in SICP. Note-taking (Motor Learning) was not necessary. No student in the top third of the Tablet PC class took notes. It is not difficult to believe that those students who preferred to listen to an instructor and were more capable learning this way might have a benefit over those students whose learning style emphasized note-taking. Further, a subset of students' submitted answers to all class problems were both visually and aurally explained in detail. This accounted for up to 70% of class time (Auditory-Visual Teaching). Students who did not demonstrate a strong preference for learning through visually presented problems that were then explained aurally would clearly be at a disadvantage in such classes. In this class, there were two such students. These students, who did not do well on their final examination, stated in interviews that when instructors explained answers to them they often got more confused than when trying to find the answers themselves.

Several Ancillary findings

There were two distinct populations of Tablet-PC students who responded to questions and exercises in class. On a scale of 1-10, 43% (mean score of 3.0) said that if they were unsure of an answer to a question/exercise, they were less likely to answer it in class. On the other hand, 57% (mean score 8.0) said that not being sure of an answer would not inhibit them from answering. The anonymity possible in using the Tablet PC in combination with Classroom Presenter, however, enabled most of those more inhibited students to be less hesitant about submitting an answer. Over 70% of those more inhibited students submitted answers using their Tablet PCs and Classroom Presenter.

Attendance declined as the semester went on as is usual in most classes at MIT. This decline was evident in the non-Tablet-PC class as well. While the attendance was virtually the same for the Tablet-PC and non-Tablet-PC classes through the end of March, in April and May attendance in the Tablet-PC class was much higher than in the non-Tablet-PC class (61% vs. 42%). When surveyed, 43% of the Tablet-PC students said that attendance was positively affected by the use of the Tablet PC.

On a 1-10 scale, the average rating on how much students liked using the Tablet PC was 7.8, with very little deviation. This result would normally be considered very positive. The main criticisms came from students who believed that they knew most of the material and did not benefit from submitting answers or seeing the responses of other students. All but one of these students, however, noted that they benefited at specific times when they did not understand some of the material completely.

Students in both recitation classes were given initial interviews in the fifth week of classes and prior to the distribution of the Tablet PC in the experimental class. There were a number of significant findings when these results were correlated with the students' performance scores.

In the control class, there were recurrent correlations that indicated that better performing students liked more independence and reliance upon their own learning styles rather than teaching strategies that reviewed and expanded upon written material and classes where questions were asked of students. These students also did not wish to use the Tablet PC. They anticipated no benefit from it. On the other hand, those students who performed the poorest in this control recitation felt that they would have liked to have tried using the Tablet PC and Classroom Presenter if it were made available to them. These perspectives were made early in the semester and prior to the distribution of the Tablet PCs

The indication here is that students who do well are satisfied that the way they learn does not have to be modified and they would prefer not having their time wasted on activities or educational technologies that they believe might interfere with that. If it has worked well before and it isn't broken, it doesn't need to be fixed. On the other hand, those students who eventually did poorly, possibly anticipating difficulties, were open to aids at the outset. This result suggests that the use of any educational technology might be done on a voluntary basis, preferably after the students have the opportunity to see what is being offered.

ADDITIONAL WORK

During this research period, we began development on a software program that will enable us to administer surveys over the internet and have students enter their responses directly into a statistical database. Through this program we will be able to apply any statistical analysis to the data that has been entered without the need for researchers to enter the data themselves by hand. In this way we will be able to minimize experimental error from human transcription. In addition, we estimate that this will lower the cost of statistical analysis five-fold and save an estimated 90% of the time needed to complete such analyses. Although this project did not get to the point that we could use it for our research, we expect that this program will be available for use by November, 2006.

REPORT SUMMARY

The results of the research studies described above lead to a number of important conclusions.

Overall, the Tablet PC has proven to be adaptable to the requirements of a wide range of university courses. This adaptability has also served students well. Students whose learning styles may not have been compatible with the teaching styles or methods of the instructor have been able to adapt the Tablet PC to their educational advantage. One recurrent effect has been to help those students who might otherwise have done poorly.

Several unique uses of the Tablet PC seemed to have consistently positive effects on students. Many students benefited from the availability and convenience of using color with their notes, especially if they had a learning styles or preference for using colors or the course made the use of color an advantage (e.g. biological sciences). Equally as beneficial to many students was the ability to integrate handwritten notes from the Tablet PC with the downloaded reading material required in their courses. Technologically, the Tablet has all of the pedagogical advantages of a laptop but also has the important added features described above.

In our research we emphasized the importance of research controls and the inclusion of a number of important variables for the purpose of assessment. We found that we could successfully incorporate these research controls and variables. By doing this, we came up with a number of results that reflected the importance of each of them and contributed to the validity of our results. This includes the following:

Software Products

Software products can profoundly influence the way that the Tablet PC is used and the effectiveness and usefulness that it may have. This is true whether the software products were developed specifically for use with the Tablet PC or for use with any desktop, laptop or Tablet PC.

For the course, *Structure and Interpretation of Computer Programs,* the Tablet PC was used with Classroom Presenter software. This software product was developed for use with the Tablet PC and enabled students to submit hand-written computer programs to the instructor for evaluation and correction. Such software products require the use of the Tablet PC and enable the transmission of drawings, graphs and equations that are difficult or impossible to transmit using a keyboard. In a software product called flashcube, students will soon be able to practice the hand-written stroke order of Chinese characters on the Tablet PC screen and receive immediate feedback regarding the correctness of their efforts.

Equally as relevant is the realization that many of the software products that can be used on any desktop or laptop can be used more effectively with a Tablet PC. For instance, architectural drawings created with any current architectural software product such as Autocad can be annotated on the Tablet PC screen with individualized sketches and notes. The Tablet PC will also enable students to edit, add notes, color code or write out possible solutions on their Tablet PC screen with almost any educational tutoring program.

Teaching Styles/Methods

The teaching styles or methods that instructors use in their courses vary widely, and different teaching styles or methods affect the way that a Tablet PC is used.

In our research, we distinguished five basic types (Pages 9-10). This included Auditory Teaching, Auditory Processing, Auditory-Visual Teaching, Visual Teaching, and Visual Processing. The distinctions of these teaching styles or methods were based upon the most common sensory formats used by instructors and whether information was presented as a monologue or a dialogue. The courses that we choose to do research in with the Tablet PC demonstrated the variability in teaching styles and methods that different instructors may employ.

In *Animal Behavior* the primary teaching style/method was Auditory Lecture, while in *Beginning Chinese I* it was Auditory Processing and in *Structural Interpretation of Computer Programs*, Auditory-Visual Processing was the primary teaching style/method. These different teaching styles and methods directly affected how the Tablet PC was used.

In *Neuroscience and Behavior*, for example, note-taking was essential as was drawing and sketching of neuroanatomical systems. There were also over 1000 pages of reading material from different sources, and numerous slides were presented in each class. Students used their Tablet PCs to integrate and coordinate their notes and drawings with the reading material and the class slides. They also color coded their notes, drawings, sketches and the slides that were presented in class. Such teaching styles and methods resulted in the Tablet PC being used in these very specific ways, and the students performed significantly better as a result. In another example, *Structure and Interpretation of Computer Programs,* note-taking was not essential. Submitting hand-written answers to complex computer programming problems was. Those students who used their Tablet PC for that purpose benefited the most.

Learning Styles/Preferences

Through surveys, interviews and classroom observations it became clear that the learning styles and preferences of the student had much to do with how the Tablet PC was used or not used.

In order to evaluate how this might affect the usefulness of the Tablet PC, we distinguished eight different learning styles (Pages 8-9) and related each to performance scores. We found examples of learning styles and preferences that directly impacted the use that was made of their Tablet PCs. Some of these differences were dramatic. For instance, approximately 10% of students were highly dependent upon color to take notes, draw and annotate slides. Another 10% never used color. The Tablet PC dramatically facilitated the use of color in note-taking. As a result, we saw examples of improved performance directly correlated to a learning style/preference related to color (Visual-Color Learning).

In other examples, we observed students who took excessive notes and reported that they learned through the very act of writing. In one example, a student wrote over 500 pages of notes for one course. This included taking notes from all of the required reading material. She stated that that was the only way she could learn the material. The Tablet PC enabled such students to edit and organize their notes as well as integrate their hand-written notes with downloaded reading material. To do this, students used such techniques as copy-and-pasting, captioning, auto formatting, keyword searching and document merging.

There were approximately 5% of students who took virtually no notes in classes where note-taking was important, even essential, for most other students. These students had a learning style and preference for auditory learning and often recorded lectures using a USB on their Tablet PC. Similar results were consistent through all of our research studies.

In *Structure and Interpretation of Computer Programs*, a visual learning style/preference correlated significantly with performance on the final examination as well as the final grade ($p < .028$ and $p < .027$). In this course answers to complex class problems were submitted visually through the Tablet PC during every class. These problems could have multiple correct answers and student submissions offered the opportunity for students to see the different processes involved in their solution. Although verbal explanations usually accompanied these displays of the solutions, students had the opportunity to copy the alternative answers that were given.

Performance Scores

The final grade that a student receives has often been the basis for evaluating the usefulness and effectiveness of any educational technology, including the Tablet PC. However, what constitutes a final grade varies dramatically from course to course and university to university. The components of a final grade can include examinations, multiple quizzes, tests, projects, homework assignments, class participation, group work, oral examinations, etc. Because of that fact, a final grade may be a poor measure of the effectiveness and impact of a Tablet PC or any other educational technology.

In *Neuroscience and Behavior*, for instance, we found that the use of a Tablet PC resulted in significant increases in performance on the final examination, ($p < .003$). There were insignificant increases, however, in the mean scores of Tablet PC users over non-Tablet PC users in their homework assignments, and these assignments accounted for 30% of their final grade. As a result, the final grade that students received was not clearly indicative of the effectiveness of the Tablet PC or, just as importantly, of reasons why it may have been effective or ineffective.

If a Tablet PC is used primarily for note-taking, for instance, but the final grade in a course is significantly based upon an oral examination, then this factor must be considered separately. We demonstrated the subtlety of this in our evaluation of the Tablet PC when used in *Beginning Chinese I.* Surprisingly, we found that the Tablet PC was very effective in improving students' performance on the oral parts of their tests and their separate final oral examination, but the reasons were unexpected. The most significant factors that resulted in the benefit of using the Tablet PC was the ability to use color in noting tone accents in pinyin (the Roman alphabetic translation of Chinese characters). In addition, it appeared that the ease in carrying their Tablet PC around campus because of its size and weight enabled students to use it to listen to the recordings that were available to them.

Research Controls

It was central to our research efforts to introduce more research controls than has been usual in the assessment of educational technology. Although this added some complexity to our efforts, we felt that this was essential. Too often research controls have not been incorporated into the research design. Misunderstandings or concern about the complexity of assessment that might result may have contributed to this.

We believe that we demonstrated that it is feasible to employ a number of important research controls. Many had rarely, if ever, been attempted before. The research controls that we used were previously described (Page 7). It was not difficult to employ the <u>split-half method</u> in three of our research projects (*Animal Behavior, Neuroscience and Behavior, Beginning Chinese I*). By doing this we were more able to control for such a crucial variable as the teaching styles of different instructors. By using a <u>random selection</u> of participants (followed by the option of using the Tablet PCs or not), we were able to insure that we did not have a biased sample. (Only about 1 in 15 students choose not to take part in the research after being randomly chosen.) By distinguishing different <u>learning styles and preferences</u> of students and different <u>teaching styles</u> <u>and methods</u> of teachers, we were able to determine some of the specific conditions which lead to the effective use of the Tablet PC and the reasons why and how the Tablet PC could be beneficial to students. By using a <u>differentiated results analysis</u> we were repeatedly able to see that the Tablet PC may selectively affect the lowest performing students, and sometimes the highest performing students, rather than the entire experimental group of students. These results would not have been seen without this research control. Through the assessment of different performance scores, we were able to demonstrate the importance of distinguishing the specific ways that a Tablet PC might help students learn.

RECOMMENDATIONS

Over the past three years at MIT we have not seen the use of as many Tablet PCs as we might have expected. In interviews and surveys with the students involved in our research up to 75% of students stated that they would be interested in purchasing a Tablet PC over a laptop. The main reasons why students said that they would not were predominantly based on concern about cost, battery life or they wanted to see "any kinks worked out" since this was a relatively new technology. When these students were asked about purchasing a Tablet PC if the Tablet PC were comparable in price and reliability, 90% said that they would prefer the Tablet PC. The remaining 10% stated that either they were very happy with their laptops and did not see the need to change or that they keyboarded and did not prefer to handwrite notes even if it allowed the use of color or the ability to sketch and write equations.

Through informal observations in the 2004-2005 academic year, we observed that approximately one in every one-hundred students had a Tablet PC. In the 2005-2006 academic year the number was approximately one in every fifty students. We can pose at least five possible reasons for this apparent lack of interest. First is cost. Second is availability. Third is that habits do not change readily (even if the "habit" of using laptops is relatively new). Fourth, is that students have not been exposed to the benefits that the Tablet PC might have for them individually, or, fifth, that students have not been convinced of the usefulness or utility of the Tablet PC.

Through informal interviews, the fifth reason stood out. At a recent visit to MIT by Howard Everson, Vice-President and Chief Research Scientist of the College Board, he said that they were trying to reevaluate a number of the Advanced Placement Tests but were having difficulty. He said that educational research studies were not helping. "Every study given to us has positive results, but none have convincing results. None have controls that make us think that we might be on to something." One gets the impression that few studies involving educational technology are convincing enough to make heads turn. In our analysis of over two hundred papers related to educational technology, we could see that many did not have controls that would be standard in scientific research. In this research we have tried to incorporate research controls and variables that might help bring us to a point that we have convincing results, whatever those results might be. With this in mind, we would strongly recommend that such research includes the following:

Selected educators that utilize measurable teaching styles and methods

- Distinguish teachers, professors or instructors who use different teaching styles

- Use those that have teaching styles that are easily assessed or which are most closely associated with the particular aspect of the Tablet PC that is being evaluated. Most notably, this might include those courses that utilize as many of the following as possible: note-taking, colored slide presentations, equations, sketches, and notes that cannot be easily keyboarded

Differentiated performance scores

- Recognize that instructors base their final grades on a wide variety of performance scores including tests, quizzes, homework, projects, class participation, portfolios, etc.
- Choose instructors whose performance scores are clearly measurable and most closely associated with the particular aspect of the Tablet PC that is being assessed.

Adequate research controls

- Employ most or all of the research controls that have been described in this report.
- In particular, use the split-half method of experimental design

Measured learning styles or preferences of students

- Measure the students' learning styles or preferences using a professionally developed survey, or use a standardized test such as *the Student's Styles Questionnaire, Cognitive Styles Analysis* or the *Learning Attitudes Questionnaire.*

Selected courses that incorporate specific software products

- These would be software products that either directly require the use of handwriting on the Tablet PC screen such as flashcube and Classroom Presenter or software products that students would benefit more from by being able to write on their Tablet PC screens. This would include virtually any educational software, but particularly ones where students could benefit from first handwriting possible solutions to problems, such as MyComputerTutor (Physics).

Online survey techniques and data recording devices associated with statistical software programs

- <u>This will tremendously minimize cost, time, effort and human error.</u>
- <u>This will enable research using educational technology to incorporate the important variables and research controls previously described.</u>

FUTURE WORK

Our goal is to apply what we have learned from this last year's research into a new series of experiments. We will be able to continue for the 2006-2007 academic year in *Structure and Interpretation of Computer Programs* using 25 Hewlett-Packard tc4200 Tablet PCs. However, we also hope to be able to incorporate Tablet PCs and the research controls and variables we have been using in two or three additional courses. We have been looking at a number of courses. In *Introductory Physics*, we would be able to use a popular software product called MyComputerTutor. In *Beginning Chinese I* we would be able to use the latest version of flashCube. In Introductory Neuroscience, we would be involved in a course that relies on numerous anatomical slides and considerable note-taking.

Kimberle Koile and I have been experimenting with the use of Tablet PCs in one elementary school. This is one of the first times that this has been attempted, and we have met with considerable school and teacher support as well as with the enthusiasm of the students. We believe that this contrast with university level students will offer important information that relates to the adaptability of the Tablet PC and our experimental procedures across a wide range of ages. If funding becomes available, we will introduce the Tablet PC and Classroom Learning Presenter into K-12 schools on a more formal basis.

In these or other courses that we might consider, we would also match distinctive teaching styles or methods in courses that have populations of at least 25-40 students. In this way we will have a larger number of students. This would be a significant advantage for the purposes of statistical analysis.

If technically feasible and funding for assessment becomes available, we will introduce the Tablet PC and a version of Classroom Learning Presenter being developed by Kimberle Koile's research group into a larger lecture-type course. This will allow us to assess the benefits of personalization and student-instructor engagement using the Tablet PC, Classroom Learning Presenter and in-class submissions, as has been done in smaller classes. This newer version called Classroom Learning Partner is being developed specifically for use in large courses (i.e. over 100 students) and using Classroom Learning Presenter as a framework. This version contains modules for interpreting and aggregating students' handwritten answers.

In each of these courses in which Tablet PC research continues, we expect to be able to incorporate our new online assessment software, which was described above. We believe that this software will significantly decrease cost, time, effort and human error in the input and evaluation of data.

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