Using Pen-Based Computers across the Computer Science Curriculum

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ABSTRACT
This paper describes our use of pen-based electronic classrooms to enhance several computer science courses. After presenting our motivation for undertaking this work, and its relevance to the growing interest in using tablet PC's in the classroom, we present an overview of our use of this technology to engage students during class. Finally, we present the students' reaction to the approach as measured through attitude surveys and a focus group.

Categories and Subject Descriptors
K.3. [**Computers & Education**]: Computer & Information Science Education – *Computer Science Education.*

General Terms
Human Factors, Design.

Keywords
Pen-based computing, Tablet PCs, groupware, collaborative computing.

1. BACKGROUND AND MOTIVATION
There is a nationwide call for science and mathematics educators to emphasize instructional methods that encourage student engagement during class. As one notable example we cite the National Research Council's suggestion that educators should provide "active learning environments for all students, even in large section, lecture-dominated courses"[11]. The authors of *How People Learn: Brain, Mind, Experiences, and School* confirm that active learning approaches are sound when considered from the point of view of contemporary learning theory; they further point out that interactive technologies can be used to create environments where students "learn by doing, receive feedback, and continually refine their understanding and build new knowledge" [3].

While previous projects such as [1, 8] have used electronic classrooms and/or electronic whiteboards to support teaching, we believe that it is also essential to provide computer science students with pen-based input capabilities and groupware that facilitates the bi-directional sharing of information, if the students are to move beyond simply observing a presentation to *interacting* with the material, the teacher, and each other. Thus, we believe that pen-based computing can play a role in supporting the type of interactive technologies called for by [3] (as described above).

To understand the need for pen-based input capabilities, consider typical topics from the undergraduate computer science curriculum such as two-dimensional arrays, pointer-based linked lists, binary search trees, directed and undirected graphs, digital logic diagrams, and finite state automata. These concepts are very difficult to communicate quickly and extemporaneously using a keyboard, and they are also difficult to describe orally.

Many instructors have had the experience of trying to modify a diagram on the board as a student calls out vague instructions from his or her desk such as "no, no… I want to know what would happen if you take the pointer from that other node and point it over there instead of where you have it now…" Imagine how much easier it would be if the student could use an electronic pen to sketch his or her version of the diagram on a display at the front of the room – even while seated at a desk in the back row. Imagine, too, how much more interactive the class would become if another student could then be given control of the system so that she could make additional changes to the diagram building on the work of her peer.

With the exception of specialized research projects such as [2] electronic whiteboards and pen-based computing devices that would enable scenarios such as the one described above were not considered mainstream enough for classroom use until recently. However, the introduction of the tablet PC in January 2003 is rapidly changing this. Tablet PCs are essentially laptop computers augmented with screens that can be drawn on (with a special electronic pen). Tablet PCs are proving popular as PC and laptop replacements at a number of universities (the reader who is interested in details of the tablet PC is referred to [7]). In writing this paper, the authors hope to share their experiences teaching with pen-based computers so that others can build on our work as Tablet PCs become more commonplace.

In the remainder of this paper we describe the first author's experiences teaching several computer science courses in a pen-based electronic classroom that uses a locally developed instructional groupware system to facilitate a variety of classroom interaction patterns. After a brief discussion of the cost-effectiveness of the hardware we utilized, we then describe the students' reaction to the approach as measured both through surveys and a focus group.

2. ENVIRONMENT AND PEDAGOGY

The classes described in this paper were each taught in one of two pen-based electronic classrooms located at DePauw University. The larger of the two classrooms houses a teacher station and thirty student stations each of which is comprised of a Pentium PC with a pen-enabled flat-screen video tablet as shown in Figure 1 [12]. The teacher's station is attached to a 72" diagonal rear-projection electronic whiteboard [10] located at the front of the room and configured so that the image from the teacher's video tablet is echoed to this whiteboard (Figure 1). The electronic whiteboard is approximately five feet wide by four feet high. Since the electronic whiteboard is touch-sensitive, the teacher can use a finger or just about anything else to draw directly on the surface of the board.

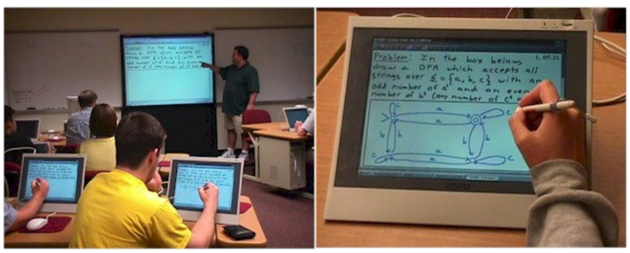

Figure 1 Left: Classroom, Right: Pen Video Tablet

The hardware in our electronic classrooms is supplemented by a locally developed software system originally named DEBBIE (DePauw Electronic Black Board for Interactive Education) and now available as a commercial product named *DyKnow* (Dynamic Knowledge Transfer [5][1]). The system allows the students and teacher in a pen-based electronic classroom to share written information. For example, when using the system, the teacher can extemporaneously draw sketches directly on the surface of the teacher-station's video-tablet or electronic whiteboard. The teacher can also use a keyboard to type material, and can import material (freehand notes, power point style slides, etc.) that was prepared ahead of time for use during class. All information sketched, typed, or imported by the teacher immediately appears on each student's video tablet.

Each student can write freehand on his or her display to make private annotations to the teacher's material. Generally these annotations are not visible to others; however, one or more students can temporarily be given the ability to make sketches that will be transmitted interactively to the entire class as each stroke is drawn. Alternatively, the students can submit portions of their workspaces, for example a section that contains a solution to a problem, to the teacher who can then display this material for the entire class to see and discuss. Because of this process, class sessions have the potential to unfold as highly interactive activities. In an ideal scenario the teacher first uses the electronic whiteboard to introduce new material to the class, and then asks the students to interact with the material by sketching answers to problems that are related to this material. The teacher then uses the system to share some or all of the student's answers with the class, responds to questions about these answers, offers alternative solutions, and determines if the class is ready for new material in which case the cycle repeats.

Since each student's workspace is indefinitely scrollable like a word processor, the electronic notebook can store an entire class session of material. At the end of the class the electronic notebook can be printed or saved electronically for later study. Sections of the electronic notebook can optionally be replayed in a stroke-by-stroke fashion, which allows a student to review how a complex diagram evolved. The reader who is interested in more information about the software is referred to [5].

3. USE IN COMPUTER SCIENCE CLASSES

Since the spring 2000 semester the first author has taught seven classes that used the pen-based classrooms on a daily basis. These courses enrolled a total of 156 students and included Theory of Computation (spring 2000), Compilers (fall 2000, fall 2001, and fall 2002), Computer Organization (fall 2002), Data Structures (spring 2003), and Computer Science One (spring 2003). The first author has taught an additional four courses that have made partial use of these facilities (for example, because of scheduling, a recent offering of Human Computer Interaction could only meet in the pen-based electronic classroom during half of the class meetings.) Six other computer science faculty members have also used the system either to deliver entire courses, or on a more limited basis.

For courses taught by the first author, the specific uses of the pen-based system varied from course to course, and from day to day within a given course. Nevertheless, we attempt to provide the reader with a more detailed understanding of the range of ways in which the system can be used by presenting several scenarios, each based loosely on experiences in the first author's classroom.

Scenario 1: As an introduction to *Deterministic Finite State Automata (DFAs),* the teacher has illustrated how to build a DFA which accepts all strings over the alphabet {a, b} with an odd number of a's. In response, a student, we will call him Sam, asks "what if you wanted to do odds and evens?" The teacher clarifies what Sam is asking, and then devises an exercise for the class in order to discover the answer. To begin, the teacher uses his finger to write (in freehand) a question on a large touch-sensitive electronic whiteboard. The question asks the students to design a DFA that accepts all strings over the alphabet {a, b} having an even number of a's and an odd number of b's. As the teacher writes the question on the board, each pen stroke is drawn on each of the student's pen-based video tablets in real time.

The students work to answer this question by sketching on the video tablets with electronic pens. Each student's free-hand annotations are made locally, so each student can work on his/her own copy of the problem while engaging in discussions with neighbors. After about ten minutes, the instructor, who has been coaching the students while roaming the room, transmits Justin's answer to the front of room thereby making it available to other students. Mary raises her hand and points out a minor flaw in Justin's solution. The class agrees on a correction, and the

[1] The DEBBIE and DyKnow technologies are patent pending. In the remainder of this paper we refer to the systems collectively as DyKnow since this is the more current name.

instructor uses his finger to correct the original answer on the electronic whiteboard. This correction immediately shows up on each student's display. Before the instructor can ask if there are any other questions, Scott says "Lindsay and I were working on this together. We have a different approach, but we are not sure if it is right. Can we look at it too?"

Scenario 2: After explaining the standard selection sort algorithm to an introductory computer science class, the teacher draws a ten element array and fills it with values. As the teacher draws, the diagram is transmitted to the students stroke by stroke. The teacher demonstrates the first pass of the algorithm by circling the largest element in the array and swapping it into its correct position (which involves erasing and rewriting values). Again, as the instructor makes each change it is reflected on each student's display interactively. Next, the instructor asks for a volunteer to carry out the next pass of the algorithm. Sandy volunteers and the teacher gives her control of the system. Now that she has control, although Sandy is still seated at her desk, everything she draws is *immediately* transmitted to every other student. Sandy circles the largest element in the unsorted portion of the array and swaps it into its correct location. At this point the teacher takes back control, before turning control over to another student to execute the next pass. Several weeks later, while studying for an exam, students are reviewing the Selection Sort algorithm in their electronic notebooks. After reviewing the pages that contain the instructor's description of the algorithm, one student decides to replay the in-class exercise stroke by stroke. As the student watches, the elements of the array are redrawn stroke by stroke, showing how the data elements move to their new locations.

Scenario 3: The instructor begins a data structures class by importing several pages of previously prepared notes that explain how to delete a node from a binary search tree. As the teacher imports each page of notes to his screen, the notes are simultaneously displayed on each student's video tablet. The students use their pens to make additional annotations based on the teacher's explanation; for example several students make annotations when the teacher orally explains the worst case running time of the deletion algorithm. Next, the teacher imports a quiz question that requires students to redraw a binary search tree after several items have been deleted. The students begin to work on the problem by sketching diagrams on their video tablets. Since the teacher has not given control to any student, these annotations are made locally and are not shared with others in the class. After five minutes, the teacher presses an icon that captures each student's work up to this point. The teacher scans this work quickly, and sees that many of the students are having trouble deleting the node that has two children. Based on this, the teacher makes a few suggestions to the class, and then asks the students to work with a neighbor to revise their solutions. Students lean toward each other sharing their original answers and discussing the teacher's suggestions, and some of the students erase their work and make changes. After another few minutes the teacher again collects the students' answers. At this point the teacher imports a previously prepared "answer key", thus making it available to the entire class. When grading the quiz, the teacher can see the student's original solutions as well as the solutions produced later by the pairs.

Although the preceding scenarios are presented as disjoint activities, we emphasize that the pen-based system was used on a daily basis for most of the courses listed at the start of this section, and moreover the system was used as the primary means of information delivery in these classes. Students would routinely come to class and launch the software application even before the instructor arrived, and after a day or two the students did not even bother to remove paper and pencils from their backpacks. At the end of each class session students saved their notes electronically so they could later be viewed from essentially any computer using a Web interface. Most students also printed them to a laser printer and stored them in a three-ring binder. The students clearly considered these materials to be their sole sets of notes for the course.

4. COST EFFECTIVENESS

We have been fortunate to secure internal and external funding to support our work. Because of this, we have been able to build two pen-based electronic classrooms, each of which is regularly used by a large number of classes during the day, and one of which is also used for research and development purposes. Since each workstation also has a keyboard and mouse, the pen-based classrooms are made available as conventional student computing laboratories during off hours thereby improving cost effectiveness.

Because our pen-based computing classrooms are used as conventional laboratories, we believe the cost of equipping the pen-based electronic classroom is best considered in terms of the *additional* expense required to build a pen-enabled classroom/laboratory as opposed to one that has only conventional input devices. Considered in this light, the additional cost per station is the cost of a pen-enabled video tablet less the cost of the standard monitor that would have to have been purchased in its stead. Currently this difference is approximately $1,300 for the WACOM Cintiq video tablets that we are using [12]. Therefore, the additional cost for a twenty station classroom is approximately $25,000. This estimate assumes that the teacher writes on a video tablet whose image is projected onto the front wall using a standard LCD projector that is already available in the classroom. We have tested this arrangement and find it to be quite satisfactory. Otherwise, there is an additional expense of between $3,000 and $9,000 for an electronic whiteboard depending on the model.

If an institution is constructing a pen-based facility from scratch, tablet PC's are another option, particularly if the facility does not have to double as a traditional computing laboratory during off hours. With educational discounts, tablet PCs can be purchased for approximately $1,600 per unit. Tablet PCs have the advantage of being portable. However, they have smaller screens and are generally less powerful than standard desktop machines supplemented by video tablets.

Fortunately, the cost estimates provided above can likely be lowered in a number of ways. First, we note that the additional cost per student seat of $1,300 is down from approximately $2,500 just three and one half years ago. As pen-based video tablets and tablet PCs continue to gain in popularity, prices are expected to drop drastically. Additionally, we believe that schools interested in using a pen-based electronic classroom would be good candidates for the National Science Foundation's Course Curriculum and Laboratory Enhancement (CCLI) program under the "Adaptation and Implementation" track. This track provides funding, including funding for equipment, to help institutions adapt externally developed educational materials, practices, and experiences for local science and mathematics education initiatives [6].

5. EVALUATION THROUGH SURVEYS

Evaluation activities comprised of written surveys and a focus group were conducted with the approval of the local human subject review board. The survey was administered during the last few weeks of class to 117 students (86 males and 31 females) in all five of the first author's computer science classes during the 2002-2003 academic year. The classes surveyed included an introductory level computer science class (Computer Science 1), two 200-level computer science courses (Data Structures, and Computer Organization), one 300-level class (Human Computer Interaction), and one 400-level class (Compilers). It is worth noting that the Computer Science 1 course counts as the first course in the major and is also a general education class that is used to partially satisfy a science distribution requirement. Because of this, the course enrolls students with a wide range of backgrounds and a diverse set of interests. The other courses generally enroll only students who are completing majors or minors in Computer Science.

The purpose of the survey was to measure student attitudes toward using the DyKnow system. Because the audience for the Computer Science 1 course is quite different from the audience for the other classes, the survey was specifically designed to investigate differences between various courses. In addition the survey provided information necessary to investigate gender differences; as illustrated in [9] it is important to consider possible gender issues when considering pedagogical and curricular reform.

The full set of questions, along with mean responses computed over all 117 respondents, is given in Table 1. All questions were answered using a 5-point rating scale of 1=strongly disagree, 2=somewhat disagree, 3=neutral, 4=agree somewhat, and 5=strongly agree. All analyses described later in this section were conducted using a .05 significance level for determining differences among means and linear relationships among variables.

Table 1. Mean survey responses across 117 respondents.

Survey Item	Mean Response
Using DyKnow is enjoyable.	4.47
Using DyKnow is stressful.	1.44
Using DyKnow enhances my understanding of the course material.	4.35
Using DyKnow provides me with a better set of notes.	4.62
I am more attentive during class because DyKnow is used.	4.04
I would be more likely to recommend this class to others if DyKnow were used.	4.14
I would be more likely to take another class if DyKnow were used.	4.05

Correlations among the rating scales revealed that all these variables had significant linear relationships. Thus, if students rated DyKnow as enjoyable, they also believed that it enhanced their understanding of the course material, provided them with a better set of notes, made them more attentive during class, made them more likely to recommend the class with DyKnow to others and to take another class were DyKnow to be used. Finally, such students also felt that using DyKnow was not stressful.

Analysis of variance comparing the mean scores for males and females on the questions revealed two important themes. First, all students, regardless of gender, rated the DyKnow system in an extremely positive manner (all means were above 4 on the 5 point scale, except for the question about stress, which had a mean of 1.44). Second, no gender differences were revealed in five of the seven questions, and the differences for the remaining two questions revealed that females felt more strongly that DyKnow enhanced their understanding of the course material (females M= 4.65 versus males M=4.23) and that it provided a better set of notes (females M=4.87 versus males M=4.52).

Comparison of student responses among the four courses revealed no differences for all questions but two. Thus, students in all four courses felt that using DyKnow was enjoyable, was not stressful, made them more attentive, and made them more likely to recommend a DyKnow course and to take another course that uses DyKnow. However, students in Computer Science 1 (M=4.71) felt more strongly than did the students in Human Computer Interaction (M=4.13) and Computer Organization (M=4.08) that DyKnow enhanced their understanding of the course material. In addition, students in Computer Science 1 (M=4.86), Data Structures (M=4.72), and Compilers (M=4.71) agreed more strongly that DyKnow provided them with a better set of notes than students in Computer Organization (M=4.25). It is important to note, however, that all mean scores were above 4 on the 5 point scale regardless of the course. The authors are particularly pleased to note the high ratings offered by the students in the Computer Science 1 course since this course enrolled students with the widest range of backgrounds.

6. EVALUATION USING FOCUS GROUPS

In order to better understand students' perception of the system, the third author led a focus group that met over a meal during the penultimate week of the spring semester. In order to include students with a common experience, yet with the widest backgrounds possible, we invited students from the Computer Science 1 (CS1) course. Five students (20% of the students in the course) participated, and the group included three males, two females; one definite computer science major, two tentative Computer Science minors, and two students who were neither considering a major nor a minor in Computer Science. The third author was not affiliated with the CS1 course and the students were assured that individual comments would not be revealed to the course instructor.

Although the focus group was designed to be small in size we hoped it would suggest some interesting issues that could be investigated more carefully in subsequent semesters. For example, at one point during the focus group, the moderator asked the students to explain what they considered to be the best aspect of using DyKnow in class, which is an issue that was not directly addressed in the quantitative data. Each of the student's answers related to "increased interaction". Upon further exploration, however, it became clear that the group was divided with respect to what they meant by "interaction". Several of the students seemed to appreciate the interaction they experienced with the instructor and their fellow students. They cited the ability to collaborate with classmates and to see other students' work alongside their own as being the best aspects of their experience. The remainder of the group cited interaction with the course material and the computers as the best thing about using the DyKnow system. Consistent with the rating scale data presented in the previous section, these students stated that they felt more confident because they knew they were leaving the classroom with a quality set of notes that was consistent with the notes of their peers. Although instructors may not like hearing this, the students also commended the availability of class notes even if they were unable to attend a class session. Recognizing the importance of classroom involvement and attendance, no one saw the notes as a replacement for regular attendance; however, these students felt more at ease, knowing that they had access to quality notes in case they did have to miss class. This discussion suggests a new set of survey questions that we can pose to large groups of future students in an attempt to better understand whether or not certain groups of students value the system for different reasons.

Later during the focus group the students were asked to identify the worst thing about using DyKnow. The most common response concerned the distractions that the computer based classroom afforded. Students identified emails, instant messaging, internet browsing, and other computer applications as common distractions in the classroom. On the other hand, and in a somewhat contradictory manner, the students maintained that the computer-based distractions did not interfere with their learning any more than doodling or gazing out the window would interfere with learning in a traditional classroom. The students suggested that the easiest and most effective method for curbing classroom distractions (regardless of the presence of computers) lay in the instructor's teaching method; for example, one student suggested that the more the teacher lectures without seeking student involvement, the more problematic the distractions will be.

The issue of distractions afforded by computer based classrooms has been expressed frequently in the recent literature. For example [4] lists a number of "laptop etiquette" rules collected from professors; these include "if you engage in unauthorized communication or entertainment during lecture you will be marked absent". Based on the literature, the comments made by the focus group participants are not surprising. On the other hand, returning to Table 1, we recall the mean response of 4.04 to the question "I am more attentive during class because DyKnow is used." This response appears to be at odds with some of the student comments made during the focus group. While we do not believe it is possible to draw any conclusions from a focus group consisting of five students; we do believe these comments suggest directions for future work as described in the next section.

The focus group was concluded by asking the students if they would recommend the pen-based version of the course to a friend over the same course taught in a traditional classroom. The answer was a resounding and unanimous yes!

7. CONCLUSIONS AND FUTURE WORK

As pen-based computers in general, and tablet PC's in particular, gain in popularity, we believe it is important to carefully explore the proper role of these devices in the Computer Science classroom. The evaluations presented in this paper have focused primarily on assessment of student attitudes toward the use of the system. In the future we would also like to assess the impact of our approach on student learning. While we are cautious about drawing conclusions from a five person focus group, we believe the issue of minimizing student distractions is also worthy of future investigation, perhaps starting with a study to measure the frequency with which students engage in distractive behaviors when working in standard and electronic classrooms. In the meantime, the attitudinal data presented in this paper suggest that pen-based computers are well-received in the Computer Science classroom, and that these devices can be used appropriately with a wide range of students.

8. ACKNOWLEDGEMENTS

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