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Improving Learning in CS1 via Tablet-PC-based In-Class Assessment

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ABSTRACT
This paper describes two pilot studies, one completed and one ongoing, that evaluate the use of Tablet PCs and a Tablet-PC-based classroom presentation system in an introductory computer science class. The presentation system, Classroom Presenter [2, 3], supports student wireless submission of digital ink answers to in-class exercises. In these studies, we evaluate the hypothesis that the use of such a system increases student learning by: (1) increasing student focus and attentiveness in class, (2) providing immediate feedback to both students and instructor about student misunderstandings, (3) enabling the instructor to adjust course material in real-time based upon student answers to in-class exercises, (4) increasing student satisfaction. The studies evaluate each of the above four parameters by means of classroom observation, surveys, and interviews.

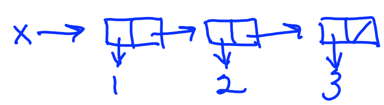
Categories and Subject Descriptors
K.3 [**Computers and Education**]

General Terms: Human Factors, Performance

Keywords: Educational technology, in-class assessment, computer science, Tablet PC

1. INTRODUCTION
Efforts are underway to improve computer science teaching and learning by employing a classroom format in which students take an active role in their learning, and are no longer simply passive listeners in a lecture-style classroom, e.g., [13, 20, 21]. Some of the most recent efforts have focused on the development and use of computational systems to support classroom activities and student interaction, [e.g. 2, 6, 15, 17]. Of particular importance are those systems that support in-class assessment, as there is compelling evidence that feedback to students improves learning, especially when the feedback occurs at the time a new concept is being introduced [5, 11, 17, 18]. With such in-class feedback, instructors can modify their explanations to fit student misunderstandings, and can assess student learning without disrupting the learning process. Students can identify their own misunderstandings. In addition, when different student answers are the focus of class discussion, students can observe alternate answers and reasoning processes and can contribute to a shared understanding of the topic.

In computer science, classroom systems that support in-class assessment also need to support pen-based interaction so that students can handwrite and sketch answers. Wireless polling systems, such as Personal Response System (PRS)[1], support in-class assessment, but instructors are limited to asking questions, such as multiple-choice, which have pre-existing sets of possible answers. These sorts of close-ended questions assess recognition rather than engaging students in higher-order tasks such as analysis, synthesis, and evaluation, which are necessary for learning [8]. As one example of a higher-order task, consider the sort of question we routinely use in our introductory computer science course, which employs Scheme[2] as the programming language. We ask students to draw the data structure that results from evaluating the expression `(define x (list 1 2 3))`. We would like for students to handwrite an answer indicating something like:



The goal of the research reported in this paper is to evaluate in an introductory computer science class the use of a classroom interaction system that supports in-class assessment of student handwritten and sketched answers such as the answer shown above. The pilot studies reported in this paper evaluate the use of Classroom Presenter in introductory computer science classes of sizes 16 and 18. In the studies, we evaluate the hypothesis that the use of such a system increases student learning by: (1) increasing student focus and attentiveness in class, (2) providing immediate feedback to both students and instructor about student misunderstandings, (3) enabling the instructor to adjust course

[1] In classrooms that employ a wireless polling system, students use a transmitter to submit anonymous answers to multiple-choice, true and false, or matching questions. The results are tabulated and displayed on the instructor's computer in the form of a histogram. (See [10] for one study of the use of PRS in a classroom.)

[2] Scheme is dialect of Lisp; it is used in our introductory computer science curriculum in conjunction with [1].

material in real-time based upon student answers to in-class exercises, (4) increasing student satisfaction. These studies evaluate each of the above four parameters by means of classroom observation, surveys, and interviews.

The pilot studies are the first phase of a research project aimed at supporting in-class assessment in large classes by means of software that interprets and aggregates handwritten and sketched answers. The interpretation and aggregation components are necessary because instructors are easily overwhelmed when receiving more than a small number of student answers. (More than eight can be overwhelming [4].) Aggregation of answers, along with the necessary accompanying interpretation, enables an instructor to receive not 100s of answers, but a representative few and a histogram showing distribution of answers throughout the class. The system under development, Classroom Learning Partner (CLP), is being built on top of Classroom Presenter, so we expect the results of evaluating Classroom Presenter to be relevant for Classroom Learning Partner as well.

2. CLASSROOM PRESENTER AND 6.001

Classroom Presenter [2, 3] is a Tablet-PC-based classroom presentation system, which supports student wireless submission of digital ink answers to in-class questions and exercises [15, 16]. Using Classroom Presenter, an instructor lectures using slides on a Tablet PC, annotating the slides by writing on them with digital ink. The slides and ink are displayed simultaneously on a large screen and on the instructor's and students' Tablet PCs. When an instructor displays a slide containing a question or exercise, the students handwrite their answers on their Tablet PCs, then anonymously submit the digital ink answers to the instructor via a wireless network. An instructor can then select submissions to display on the public screen and discuss with the class.

Shown in Figures 1 through 8 are examples of the use of Classroom Presenter in MIT's introductory computer science course, 6.001, in Fall 2005 and Spring 2006 terms. The course in not a programming course *per se*; students complete several programming projects, but the emphasis in the course is on understanding the nature of computational processes, tradeoffs in design and implementation of programming languages, and methods for controlling complexity. Students taking the course attend sessions five times weekly: two 50 minute lectures per week (taught by a faculty member), class size of between 100 and 300; two 50 minute recitations per week (taught by faculty members), class size of between 15 and 30; one 50 minute tutorial a week (taught by a graduate student teaching assistant), class size of five to seven. Lectures are the primary vehicle for introducing new material; recitations expand on the lecture material, allowing students to practice working with the material; and tutorials provide students with the opportunity to get individual help and further practice.

Student performance in 6.001 is assessed for the 15-week term by means of two exams and a final exam (each 25% of the course grade), five programming projects (30%), weekly problem sets submitted via an online tutor system (10%), and class participation in recitations and tutorials (10%).

Classroom Presenter is being used in the first author's 6.001 recitations to elicit responses to three kinds of questions: in-class exercises aimed at letting students practice course topics; "clear" and "muddy" questions, which ask students to articulate their best and least understood concepts; and self-confidence survey questions, which ask students about their confidence level in understanding particular topics [5]. Each kind of question is illustrated in the figures below. In-class exercise responses were used in the analysis reported in sections 3 and 4. Studies in academic year 2006-2007 will include all three kinds of questions.

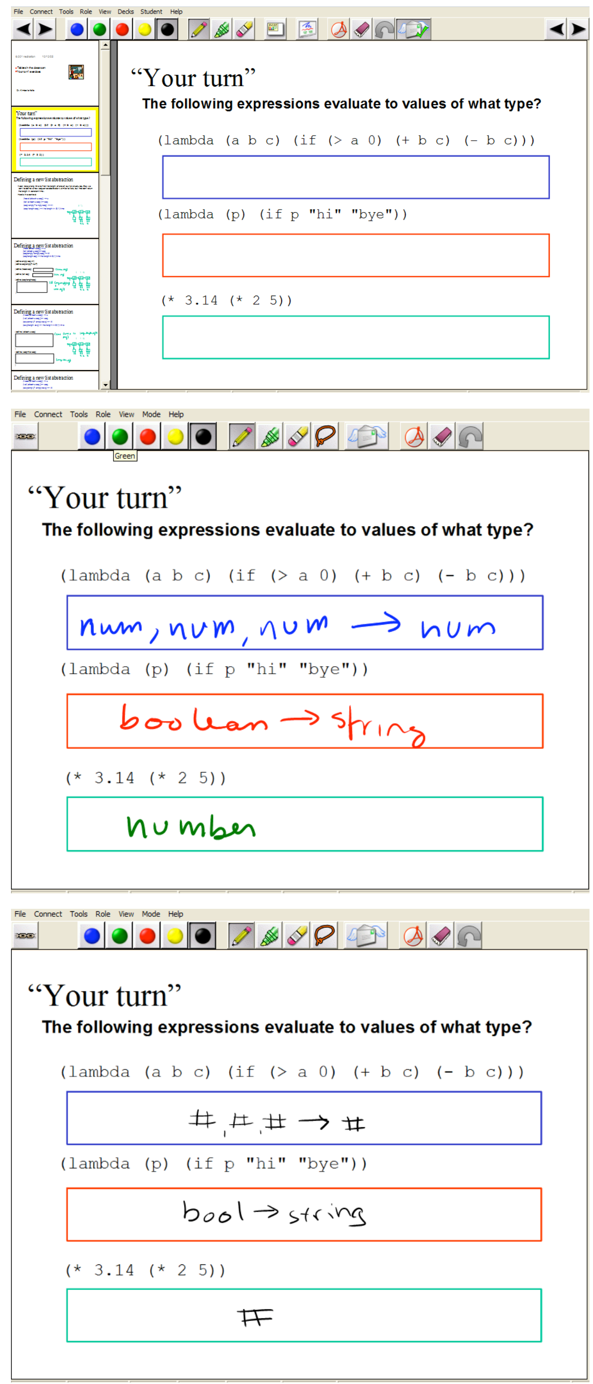


Figure 1. Instructor screen and two student screens with alternate correct answers; "film strip" on the left of instructor screen shows the presentation slides

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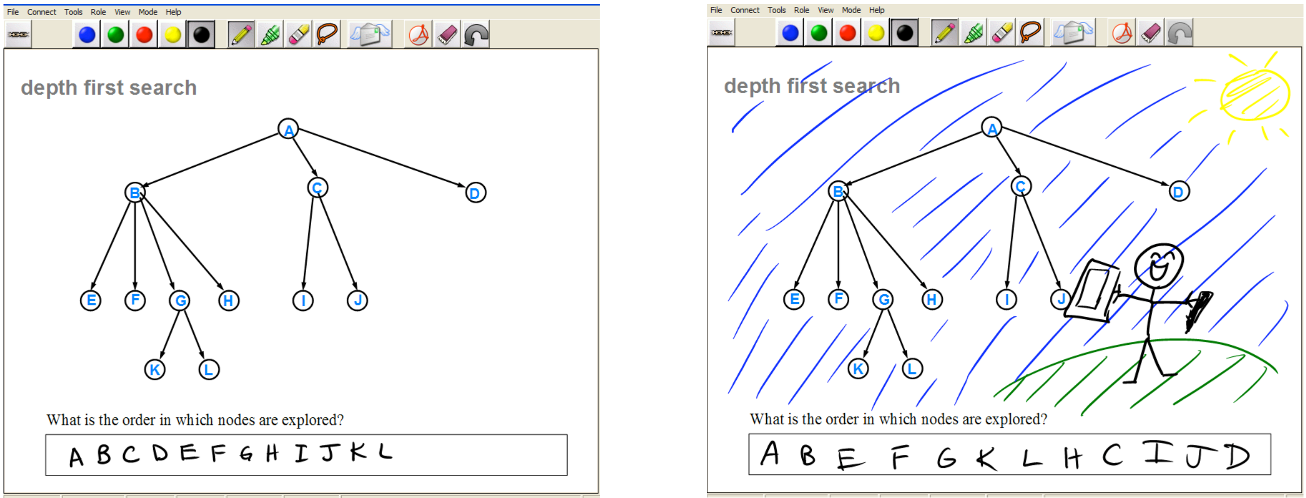

Figure 2. Two student screens: left screen shows incorrect answer (it gives breadth-first order instead); right screen shows a correct answer and an illustration (not uncommon for this particular student); students can "debug" incorrect answers as a class

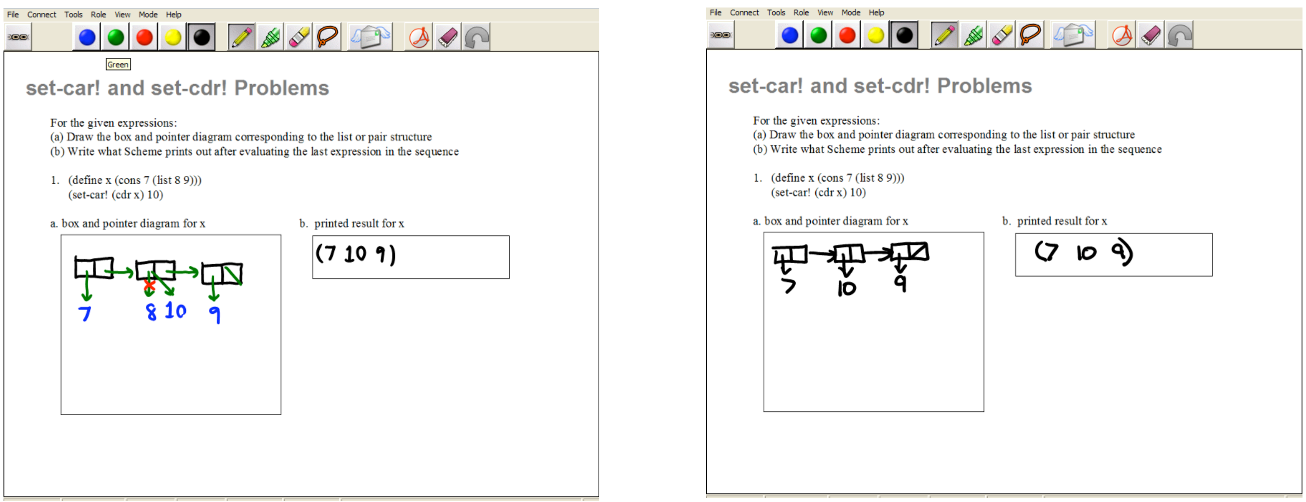

Figure 3. Two student screens with correct answers: left screen shows derivation of answer with "x" designating pointer removal

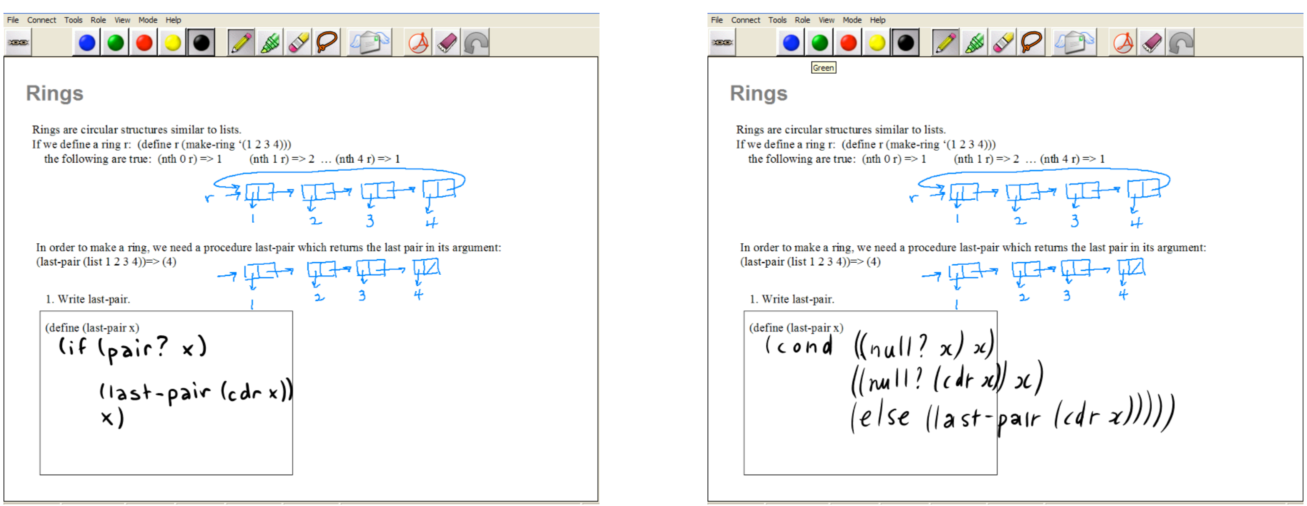

Figure 4. Two submissions from the same student: the first, shown on the left, is incorrect; the student submitted a second one, shown on the right, without being asked

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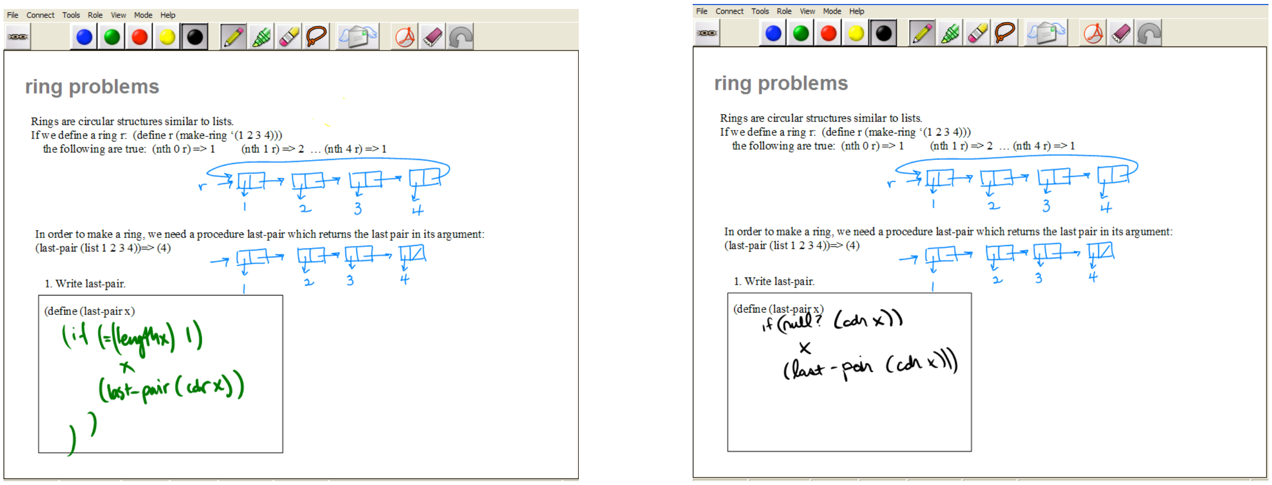

Figure 5. Screens showing alternate correct answers from two different students; the class can discuss the pros and cons of each

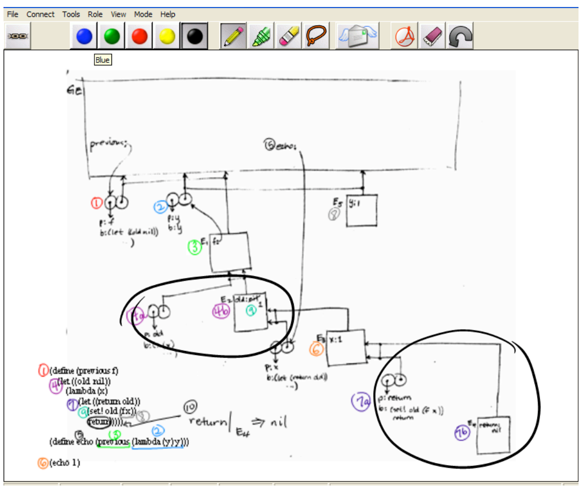

Figure 6. A spontaneous activity: the instructor asked students to mark the "let" statements on an environment diagram (which illustrates scoping rules)

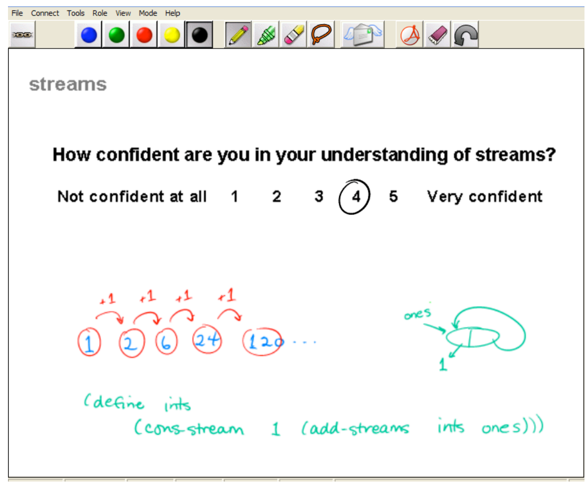

Figure 7. A student's self-confidence survey response

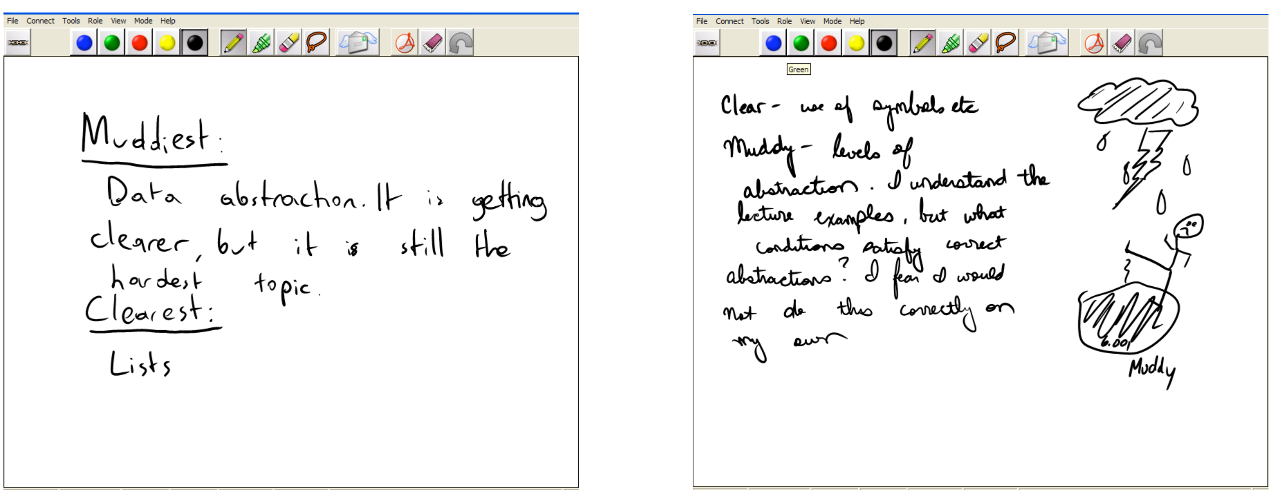

Figure 8. Submissions for "muddy" and "clear" concepts, which can be used as topics of class discussion or viewed privately by the instructor

3. PILOT STUDY 1: FALL 2005

In the fall term of 2005, Classroom Presenter was deployed in the first author's introductory computer science recitation class of 16 students [12]. As noted earlier, the class met twice a week. Through classroom observation, surveys, and interviews by the second author, we investigated student performance, focus and attentiveness in class, feedback to students and instructor, adjustment of course material by instructor, and student satisfaction.

3.1 Methodology

1. Students were assigned randomly to the class. This pilot study took place in one of five recitation sections to which students were randomly assigned for an MIT introductory computer science class. With random assignment we did not bias our sample by asking for volunteers, who may have had a predilection for using Tablet PCs. Students were given the opportunity to switch recitations if they did not want to participate in the study. None switched; one chose not to participate. The students spent the first five weeks in recitation without using Tablet PCs. After the first class exam, they used Tablet PCs in the class for nine of the remaining ten weeks of the term.

2. The Tablet PCs were associated with the class, not with each student. Students had the use of a tablet during class; they were not assigned a particular tablet. This study focused on instructor-student interaction, rather than student-student interaction, so students did not share tablets. We chose not to loan each student a Tablet PC for the term as some researchers have done because: (1) we did not want the machines to be lost or damaged; (2) we wanted to increase the amount of data collected by making sure machines were not forgotten or uncharged; (3) we wanted to simulate our long term vision of technology: that it is ubiquitous, e.g., embedded in the classroom furniture, and that data and information, rather than technology itself, is of primary importance to people. We imagine, for example, that when a student stood up to leave class, her notes would be saved automatically to the location of her choice.

3. The instructor used Classroom Presenter; students wirelessly submitted answers to in-class exercises. Each class typically started with the instructor reviewing lecture material and answering student questions for approximately ten minutes. The review was followed by approximately 35 minutes of students working exercises on their Tablet PCs, wirelessly and anonymously submitting answers, and participating in class discussions of correct and incorrect submitted answers. The class generally ended with a five-minute summary. At the beginning of the term, students were told that they could work in groups of two or three if they chose, but most worked alone.

4. Three categories of data were collected. Data collection included (1) two surveys, one given at the time the students began using Tablet PCs, the second at the end of the term; (2) five-minute classroom observation periods for each student; and (3) short after-class interviews with students, which validated or clarified observed learning styles and individual surveys. The survey data collected related to the students' learning styles and preferences, self-perceptions, and levels of satisfaction.

5. Students saved their work. At the end of each class, students could save their Classroom Presenter slides, which contained both the instructor's ink and their ink. Slides, in PDF format, were saved to a USB device or directly to a campus directory; most students chose the directory option.

3.2 Metrics

3.2.1 Student Learning Metric

We assessed the increase in student learning by collecting data on all grades for exams, programming projects, problem sets, the final examination, and class participation for the entire class of 98 students. The results for students in our pilot class were compared to results for students in the other four recitation classes. In addition, we are in the process of correlating student learning with the learning styles, attentiveness, and levels of satisfaction as assessed through classroom observation, surveys, and interviews. This comparison serves as a good basis for determining how well the Tablet PC may function in a large classroom setting.

3.2.2 Instructor-Student Interactions Metric

Our pilot study sought to quantify the following four parameters through classroom observation, surveys and interviews.

(1) Student Focus and Attentiveness in Class: We assessed student focus and attentiveness by timed and sampled observations of the students in each class throughout the term. These observations included the time students spent solving problems or taking notes on class material. This data was contrasted with the amount of time students spent doing non-class related activities (e.g., doodling, surfing the web, etc.).

(2) Feedback to Students and Instructor about Student Misunderstandings: Through classroom observations we assessed the feedback given to students by the amount of time the instructor spent explaining and clarifying incorrect or almost correct answers. This number correlates with the amount of feedback the instructor received regarding student misunderstandings or the desire for elaboration.

(3) Adjustment in Course Material made by Instructor: We assessed the adjustment that the instructor made based on comparing the preplanned presentation of course material with the changes that the instructor made during class and in subsequent recitations.

(4) Satisfaction and Self-Perceptions: We collected data on student satisfaction and self-perceptions through interviews with students done by the second author. We also administered surveys to students both at the start and the completion of the course.

3.3 Results and Interpretation

3.3.1 Student Learning Results

Tablet PCs were introduced into the class after the first exam, which occurred in the fifth week (of 15) of the term. Prior to that introduction, the instructor used a blackboard, overheads, and paper handouts. The engagement style of teaching, which encouraged student involvement, resulted in 35.7% of students scoring in the top 10% on the first exam, even though the students in this recitation comprised only 16.3% of all students taking the computer science class.

After the first exam, students were introduced to the Tablet PC in conjunction with the Classroom Presenter software. The teaching style that encouraged engagement remained the same, but students also had the added advantage of wirelessly submitting to the instructor digital ink answers to in-class exercises. The instructor displayed a subset of answers for each exercise, giving immediate feedback on correctness and engaging the students in class discussion of the answers.

The students in this class performed better than would be expected by chance. They comprised 44.4% of students in the top 10% of the class in final grades—an 8.7% increase over performance on the first exam, and almost three times greater than expected, since these students represented 16.3% of the entire computer science class. The students also were much less apt to perform poorly: Only 8.3% of these students placed in the bottom 25% of the entire class. The expected percentage again was 16.3%. Further, no student received a D or an F. (In the entire class of 98 students, there were four Fs and three Ds, evenly distributed between the other two recitation instructors.) Our sample size was slightly too small for us to achieve statistical significance with the results that we obtained. We expect to repeat the study in academic year 2006-2007 with a larger sample of students.

3.3.2 Instructor-Student Interactions Results

(1) Student Focus and Attentiveness in Class: Based on the cumulative average of seven five-minute observations made of each student over nine weeks of Tablet-PC usage, we identified that fourteen of sixteen students spent over 90% of class time focused and attentive to classroom material. The remaining two students spent 80%-85% in the same manner. Deviations from focus and attention reflected two factors. First, some students were bored because they knew the material extremely well and did homework instead. In other cases, students reported in interviews that they had missed lecture and could not follow the examples being discussed. There were only six observed incidents when one, two, or three students used their Tablet PCs for unrelated work. Students, thus, were focused and attendant to material presented. A basis for comparison with other similar classes was not made.

(2) Feedback to Students and Instructor about Student Misunderstandings: Seventy-five percent of the class time was spent providing feedback to students in response to written answers submitted to exercises and verbal questions related to the exercises. All students whose grades placed them in the middle third of the class reported that feedback helped them. The top third of students primarily benefited only on the relatively few problems on which they had difficulty. The bottom third also benefited but often felt that they needed more time spent on the answers that they did not understand.

(3) Adjustment in Course Material made by Instructor: The instructor placed emphasis on responding to student misunderstandings, which were evident from incorrect submitted answers or oral questions. She postponed introduction of new in-class exercises in three of thirteen recitations in order to spend more time on misunderstood concepts. The postponed exercises were either presented in the following recitation or posted as practice exercises on the instructor's website. In two recitations, the instructor introduced new, more challenging exercises because all submitted answers to preplanned exercises were correct. The instructor, thus, presented both preplanned and extra exercises, while also responding to all student questions.

The instructor valued being able to peruse answers from all students and use student answers as the basis for class discussion. She found it difficult, however, to decide which responses to choose for display and class discussion, as the number of responses could exceed twenty—students sometimes submitted multiple answers, either correcting mistakes in a first answer or sending more alternate correct answers. Time did not allow showing all responses, and silently evaluating various responses while the class waited for one to be displayed would have been awkward. Instead, the instructor quickly skimmed responses, generally choosing at least one correct answer and one or two incorrect answers, but without the confidence that she had chosen the most pedagogically interesting responses. Hence there is a clear need for the interpretation and aggregation components under development in Classroom Learning Partner: In a working prototype, to be deployed in upcoming studies, the instructor is presented with a histogram of student responses for exercise answers that are numbers, strings, or sequences, and representative example responses. (Aggregating sketches is a focus for this next year.) It should be noted that a teaching assistant could play the role of Classroom Learning Partner, evaluating student responses as they are submitted and suggesting representative ones to the instructor. When the number of responses is high however, as in a large lecture class, the teaching assistant will be overwhelmed.

(4) Student Satisfaction and Self-Perceptions: Student satisfaction was extremely high, but can be more precisely analyzed when based upon level of performance in class. The top third of the students perceived the computer science course to be much easier than anticipated because they were able to get immediate feedback in recitation on the few questions that caused them difficulty. The three students who felt that they did not benefit from the use of the Tablet PC had the bottom three grades in the class. (These students may have benefited, however, since their grades were 1 B and 2 Cs.)

3.3.3 Summary

Our preliminary results indicate that student learning seems to be positively affected by the use of engagement strategies, the Tablet PC, and the Classroom Presenter software. The feedback mechanism in particular seems to have been beneficial, resulting in fewer students than expected performing poorly. The sample size of this pilot study was small, however, and there was no control group of students without Tablet PCs. Several more Tablet PC deployments with control groups and additional quantitative measurements of instructor-student interactions are planned. In the next section, we describe an ongoing study.

4. PILOT STUDY 2: SPRING 2006

In Spring term of 2006, we ran another pilot study using Classroom Presenter in two introductory computer science classes, one of which served as a control group: The first author taught one class with Tablet PCs, one without. This study followed the same methodology as the Fall 2005 study, but with the added control group and with the ability to count individual student submissions as a measure of instructor-student interaction.[3] We currently are analyzing the data, and again anticipate that use of the Tablet PC system may result in fewer students performing poorly. We suggest that the Tablet PC system enables students who might otherwise struggle, to have additional means by which to understand the material and correct mistakes. Feedback and the opportunity to redo incorrect responses would seem to be effective as a means of improving learning. Those students who would do well without the Tablet PC system, also may increase their understanding even more.

4.1 Preliminary results

4.1.1 Student Learning

Preliminary analysis of exam grades for Tablet-PC and non-Tablet-PC students seems to support the positive effect of the combination of teaching style, Classroom Presenter, and Tablet PCs on poorer performing students.

There was no significant difference in performance among students in the two classes prior to deployment of the Tablet PC. On the first exam, prior to deployment, the mean score was 76.4 (out of 100) for the non-Tablet-PC students (N=19), and 80 for the soon-to-be-Tablet-PC students (N=19)—a difference of 3.6. Both scores were considered Bs. The mean for the entire class was 75.0 (N=239).

The second exam performance showed a slightly larger difference, of 6.8, between the groups: The mean for non-Tablet-PC students was 78.5 (N=18); for Tablet-PC users it was 85.3 (N=18).[4] The mean for the entire class was 74.5 (N=227). While the difference in performance on the second exam is not statistically significant because of a small N, it is nevertheless worth noting that the mean for the Tablet-PC class increased 10.8% and into the A range, which was 84 to 100 for this exam.

Slightly more students performed in the top 25% in the Tablet-PC class than in the non-Tablet-PC class: 43.8% of the Tablet-PC class, vs. 35.3%; expected value in each case based on normal distribution was 25%.

Perhaps more importantly, however, fewer students than expected did poorly on the second exam in the Tablet-PC class: 23.5% of non-Tablet-PC students were in the bottom 25% of the class, vs. 6.0%. Again, the expected value in each case was 25%, so only one quarter as many students as expected performed poorly in the Tablet-PC class. In addition, the mean score of the bottom 25% of students in the non-Tablet-PC class was 51.8 (of 100); the mean score for the Tablet-PC class was 70.4. The significance was $p < .05$.

[3] A submission is still anonymous in that it only contains the machine's name, not the student's name. A mapping of student name to machine name is made when students log in at the beginning of class, but is only used by the second author in relating classroom interaction to performance.

[4] One student in each of the two recitations in the study dropped the course.

4.1.2 Student Interaction

We noticed that the attendance in the Tablet-PC class was better than in the non-Tablet-PC class, but found no correlation between attendance and the second exam scores. Here are the preliminary results of a short survey (N=12) and a preliminary analysis of student submission data.

Attendance: 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, however, 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 their attendance was positively affected by the use of the Tablet PC. So students may have come to class more often than they otherwise might have if the Tablet PC had not been used.

It should be noted that the non-Tablet-PC class met at 11:00 am, the Tablet-PC class at 1:00 pm, and students in the 11:00 am class indicated that the "early" time of day was a factor influencing their attendance. We plan to repeat the study next Fall 2006 with the times reversed.

Enjoyment: On a 1-10 scale, the average rating on how much students liked using the Tablet PC was 7.8, with very little spread.

Submissions: There were two distinct populations of Tablet-PC students who responded to 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 an 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. We speculate that many students are much less likely to respond to an exercise if they are unsure of the answer. The anonymity of the Tablet PC system, however, enables students to be less hesitant about trying out an answer. (This attitude has been evident in interviews with students.)

Submissions and performance: Those students who gave an average of 3.5 answers per class or higher averaged 89.6% on the second exam. (There were on average three or four problems per class.) Those students who gave an average of 1.1 answers or less per class averaged 75.5% on the second exam. The correlation between average number of student submissions and performance score for the term was significant ($p < .001$). This result directly ties the submission of answers to increased student performance, and suggests that active involvement in the class through working in-class exercises using Classroom Presenter and the Tablet PC contributed to the learning of course material.

5. CONTRIBUTIONS, CURRENT WORK

In the two pilot studies reported in this paper, we evaluate the hypothesis that the use of a Tablet-PC-based classroom presentation system such as Classroom Presenter increases student learning by: (1) increasing student focus and attentiveness in class, (2) providing immediate feedback to both students and instructor about student misunderstandings, (3) enabling the instructor to adjust course material in real-time based upon student answers to in-class exercises, (4) increasing student satisfaction. Our preliminary results seem to indicate that this hypothesis holds true, and that use of the Classroom Presenter and the Tablet PC may be directly responsible for an increase in performance of students taking introductory computer science. We particularly are struck by the increase in performance of those students who might otherwise have done poorly. This research effort contributes to the widely accepted pedagogy that feedback contributes significantly to student learning. This pedagogy is both practical and possible through in-class assessment using Classroom Presenter and Tablet PCs.

We are continuing our analysis of the current experiment and designing new experiments for the academic year 2006 and 2007. In particular, because of the small number of students involved in these initial research efforts, we plan to repeat the experiments with a larger number of students. In addition, we will focus effort on the number of in-class exercise responses that students make when using Classroom Presenter and the Tablet PC. The ability to quantify student interaction in terms of number of responses holds promise for providing a more rigorous basis for evaluating the use of technology in the classroom than has been possible to date.

In our upcoming studies, we plan to investigate student-student interactions, as well as instructor-student interactions, as there is compelling evidence that peer instruction improves learning [14]. We have made modifications to Classroom Presenter that support the formation of student groups and the transmission of ink among members of a group. We currently are designing experiments to investigate student interaction in such groups.

Finally, we plan to deploy Classroom Learning Partner, which adds ink interpretation and aggregation components to Classroom Presenter, and evaluate its use in 6.001 recitations next year. If we can validate our initial findings and replicate the results, then we will be in a position to introduce these pedagogies into much larger classrooms in the very near future.

6. ACKNOWLEDGMENTS

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