Lessons Learned From eClass: Assessing Automated Capture and Access in the Classroom

JASON A. BROTHERTON
University College London
and
GREGORY D. ABOWD
Georgia Institute of Technology

This article presents results from a study of an automated capture and access system, eClass, which was designed to capture the materials presented in college lectures for later review by students. In this article, we highlight the lessons learned from our three-year study focusing on the effect of capture and access on grades, attendance, and use of the captured notes and media. We then present suggestions for building future systems discussing improvements from our system in the capture, integration, and access of college lectures.

Categories and Subject Descriptors: H.5.1 [**Information Interfaces and Presentation**]: Multimedia Information Systems—*Evaluation/methodology*; *Hypertext navigation*; *Video*; H.5.4 [**Information Interfaces and Presentation**]: Hypertext/Hypermedia; K.3.1 [**Computers and Education**]: Computer Uses in Education

General Terms: Design, Experimentation, Human Factors

Additional Key Words and Phrases: Educational applications, ubiquitous computing, capture and access, evaluation, multimedia foraging and salvaging, human-computer interaction

---

This research was supported in part by National Science Foundation CAREER grant #IRI-9703384. Dr. Abowd is funded through a Faculty CAREER grant through the ITO and Interactive Systems programs within the CISE division of NSF. Dr. Abowd is funded in part by DARPA through the EDCS program (project MORALE). The work in eClass is sponsored in part by SUN Microsystems, Proxima Corporation, Xerox Liveworks, MERL, FX-PAL, Palm Computing, Apple, and the Mobility Foundation.
Authors' addresses: Jason A. Brotherton, UCLIC, University College London, 31/32 Alfred Place, London WC1E 7DP, United Kingdom; email: j.brotherton@ucl.ac.uk; Gregory D. Abowd, College of Computing, Georgia Institute of Technology, 329 Technology Square Research Building (TSRB), Atlanta, Georgia 30332-0280; email: abowd@cc.gatech.edu.

1. INTRODUCTION

Multimedia and web-enhanced learning have become increasingly attractive to schools both for financial and technological reasons. Students spend a significant portion of the day listening to and recording the events that occur in classrooms, typically by taking notes with pen and paper. As a result, the capture of classroom lectures for later access has become a popular research topic with several different approaches and contributions [Brotherton 2001].

We define the capture and access problem in the college classroom as the attempt to capture new, nonpersistent information (such as speech and the writings on a whiteboard), while integrating it with existing information (such as presentation slides) so that the new information can be successfully accessed at a later date. We consider materials 'successfully accessed' when they are found at the proper level of detail (as defined by the accessor) with minimal effort.

The impact of capture and access on students in the classroom still remains largely undocumented. This is due mostly to the difficulty involved with using these systems in an authentic setting over a sustained period of time. Although there is much research on building novel methods for capture and access in the classroom, few studies into the actual usefulness of these approaches have been conducted to identify critical factors for success.

1.1 Capture and Access in the Classroom

Our previous work [Abowd et al. 1996] introduced eClass (formerly called Classroom 2000) as an automated note taking service for college lectures and provided several preliminary qualitative results on the impact of this technology on students. At that time, we did not present data on how students actually used the online notes, leaving an important question unanswered: Is the media augmentation of captured notes is actually useful, and if so, how do students use the online notes in their study routines? The answer impacts the design of capture and access systems for not only college lectures, but also other domains such as meeting rooms and conferences.[1]

This paper shows how ubiquitous computing can help solve the capture and access problem in a specific setting, the college classroom, where success depends largely on the ability to capture and access information at a later moment. Our research is motivated by the notion that rote copying of presented materials from college lectures via traditional note taking techniques can be time consuming, difficult, and prone to error. We are not arguing against note taking in general; rather, we are trying to reduce instances of copious note taking. By automating the capture and access of lectures and by augmenting traditional notes with media, we can provide a more detailed record of a lecture than is possible with just pen and paper. We also believe that providing students with access to these notes can improve their review and study sessions.

[1]Meeting and conference capture have their own set of unique problems, but there still remains a significant overlap with the classroom, namely how to best capture the materials, and how the materials are later used in access.

1.2 Overview of Article

In Section 2, we briefly highlight previous work in capture and access and on systems designed for classroom capture. Section 3 describes eClass, our automated note taking service for college lectures, and summarizes its use. Section 4 details our evaluation goals and experimental methods. Section 5 presents our findings on the impact on students and teachers and examines the usage patterns of the online notes by students over a three-year period showing their media use characteristics, and factors contributing to online note use. We show that students both desire and use the captured notes and the media linked to them, and we describe the student access patterns of online lecture notes. We conclude with Sections 6 and 7, highlighting our 'lessons learned' and giving advice on building, using, maintaining, and evaluating automated capture and access systems.

2. BACKGROUND AND RELATED WORK

There has been considerable work on the general theme of automated capture and access for a variety of domains. While most work reports on the technological capabilities of capture and access (see review Brotherton [2001]), there are a few notable studies of the user experience. The majority of that evaluation work provides either qualitative or quantitative assessment of access behaviors, when an end user tries to review some previously captured experience. An important distinction in these studies is between short-term controlled access experiments and longer-term longitudinal studies of more authentic and less controlled access behaviors.

Filochat [Whittaker et al. 1994] and the Audio Notebook [Stifelman et al. 2001] are two examples of systems that extend traditional single person note taking with technology to allow notes to serve as an index into a recorded audio session. Filochat, based on tablet computers, was evaluated in a controlled setting to determine how the augmented note taking compared with traditional note taking and how simple memorization impacted performance (based on speed and accuracy) on post-lecture quizzes. Audio Notebook, built to resemble a traditional notebook, examined the more qualitative reaction of a small number of users in different settings (classroom and one-on-one reporter interviews) to give a better idea of what augmented note taking might be like in authentic settings. The evalutions of both systems concluded that there is a user need for note taking assistance, and that augmenting handwriting with audio is helpful.

Moran et al. [1997] presented work from the extended use of their Tivoli system but also focused on the media access characteristics of a single user whose task was to summarize technical meetings. One interesting feature of the Tivoli studies was the ability to track how the single user adapted his capture and access behavior as he developed familiarity with the system. In addition, this tracking allowed them to categorize salvaging techniques for perusing captured media. We will revisit these salvaging techniques later in the paper.

Researchers at Microsoft Research have reported on a number of controlled studies exploring summarization and skimming techniques and the impact on rapid browsing of the multimedia streams that capture and access systems promise to deliver [Bargeron et al. 1999, He et al. 1999, Li et al. 2000]. These systems explore a number of different domains from meetings to education. While we do not address 'accelerated playback' in our work, they have shown that such features, given a generalized capture system, would be desirable for access. A particular prototype system of theirs, Flatland [White et al. 1998], was targeted towards distance education, allowing everyone to be virtually present in an auditorium, but it was not studied for long-term effects on student access trends.

Other educational capture systems have been built (AutoAuditorium, [Bianchi 1998], Lecture Browser [Mukhopadhyay and Smith 1999], STREAMS [Cruz and Hill 1994], Rendezvous [Abrams et al. 2000], Author on the Fly [Bacher and Muller 1998], and DEBBIE [Berque et al. 1999], to name a few); some have been empirically evaluated, including Forum [Issacs et al. 1994] and MANIC [Padhye and Kurose 1999]. Similar in functionality to Flatland, Forum research focused on characterizing student and instructor behavior during the capture phase of a live lecture and less on access behavior after the lectures. MANIC presented some results on how students accessed manually captured lectures over the course of an entire term, but with the intent of being able to model the workload of the media server that streamed lecture content over the network.

Many functional similarities exist between eClass and other systems. This is not surprising considering the age of the project; we are not the only ones doing capture and access research, nor are we the only ones exploring capture and access in the classroom. The major difference between the work proposed in this article and all of the work we have just examined is that in eClass, the central focus of the work was to go beyond the initial implementation and technological demonstration and to understand how the introduction of technology impacted the teaching and learning experience. For a more complete treatment of background work in relation to eClass, consult Brotherton [2001].

The evaluation of eClass we present in this paper is a longitudinal study of access behavior over a three-year period of extended use of what was then a relatively novel capture service. Compared with all previous reports on capture and access, this work covers the longest period of authentic use by the largest population of users. Through a few controlled studies and longitudinal use, we characterize the access behavior that emerges as this novel service becomes a part of the everyday educational experience. We show how students actually use captured lecture notes and how the media augmentation is incorporated into study routines.

3. A BRIEF DESCRIPTION OF ECLASS

eClass began with the goal of producing a classroom environment in which electronic notes taken by students and teachers could be preserved and accessed later, augmented by audio and video recordings. eClass has since evolved into a collection of capture-enabled programs that attempt to preserve as much as possible of the lecture experience, with little or no human intervention.

To the instructor or students enrolled in a course taught using eClass, the in-class experience is not significantly different from a typical classroom equipped

Fig. 1. eClass in use. On the right, the instructor annotates PowerPoint slides or writes on a blank whiteboard. Previous slides (or overviews of more than one slide) are shown on the middle and left screens. The screens can also be used to display Web pages.

with modern presentation equipment (see Figure 1). A professor lectures from prepared slides or Web pages or writes on a blank whiteboard. Then, after class is over, a series of Web pages are automatically created, integrating the audio, video, visited Web pages, and the annotated slides. This is normally completed before the instructor leaves the room and the students can then access the lecture via the Web, choosing to replay the entire lecture, print out any slides that were created, search for related materials, or just go over a topic that was not well understood.

Figure 2 shows an example of the captured notes. In the upper left pane, students see a timeline of the class, from start to finish, decorated with significant events that happened in the class such as the instructor visiting a new slide or a Web page. Clicking on the black timeline plays back the audio and video of the class at that point in the timeline. Clicking on the slide link takes the student to that slide, and clicking on the Web link takes the student to that Web page. Below the timeline is an embedded video player. The student has the option of using an external or embedded audio/video player, both having equivalent functionality.

The right side of the interface shows all of the slides and their annotations in a single scrollable frame. This allows for scanning a lecture to find a topic quickly. For slower network connections, only one slide at a time is loaded into the frame. Clicking on any handwritten annotations will launch the video of the lecture at the time that the annotations were written.

Other features of the notes that are not shown include generating a printable version of them, searching for keywords in the lecture, and editing a

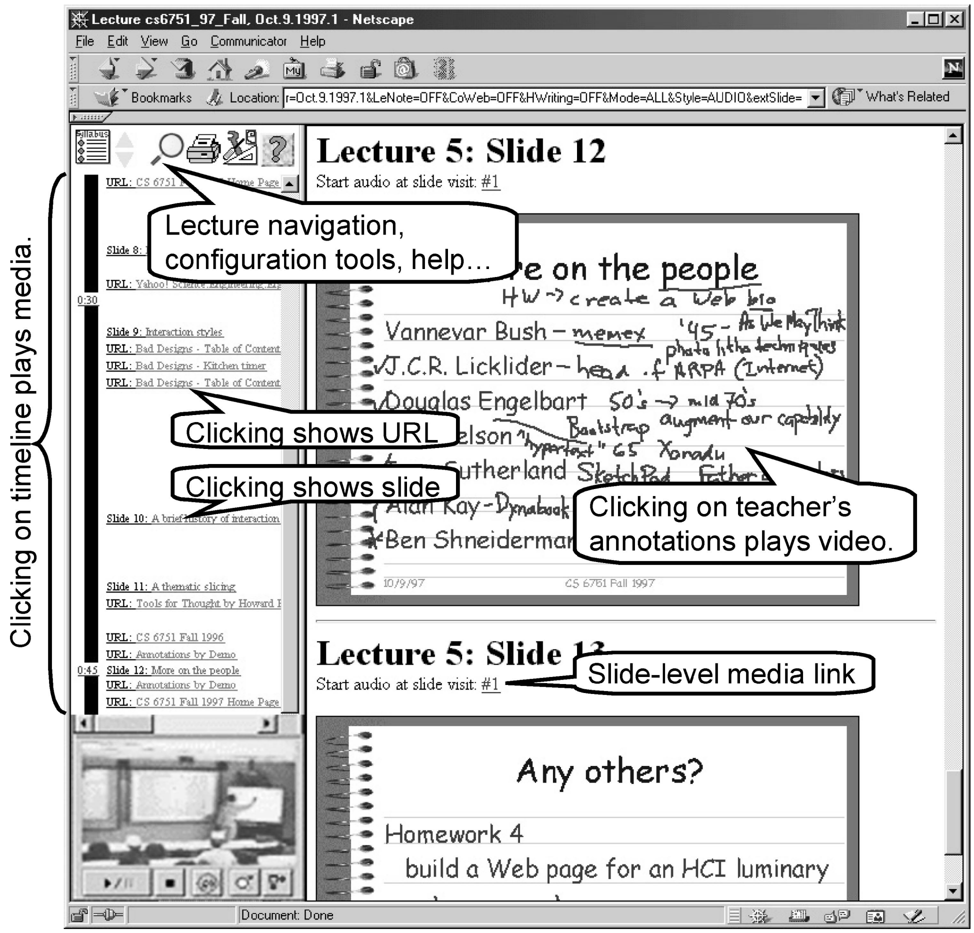

Fig. 2. An example of the notes taken by our classroom. On the left a timeline is decorated to indicate significant changes of focus, from whiteboard slides to Web pages. The frame beside the timeline contains a scrollable list of slides to facilitate browsing. Web pages are brought up in a separate browser window, as shown. Directly above the timeline is a link that allows students to bring up help on using the system.

collaborative Web page for the course. For a more thorough description of eClass (and its evolution), please see our earlier publication [Abowd et al. 1998].

3.1 Summary of Use

We started using eClass to capture classes at Georgia Tech in April 1997. Our observation period reported in this paper ended after the completion of the Spring 2000 term, for a total of 13 semesters. During that time, we captured most lectures from 98 academic courses (75 unique courses) consisting of 2,335 lectures, taught by 35 different instructors in two different classrooms.

In addition to Georgia Tech, other researchers and instructors have installed and used eClass. We have captured courses from eight courses at Kennesaw State University (Winter 1998, Spring 1998, Fall 1998, and Spring 1999), one course at McGill University (Fall 1999), and one course at Brown University (Fall 1999).

From the Spring 1997 through Spring 2000 semesters, we have identified 59,796 anonymous accesses to the lectures captured by the system (including use by other universities). This is a conservative estimate of the number of actual study sessions because we are only counting accesses for which we were able to determine a complete study session. The actual count of "Web hits" is much larger, with over 200,000 individual accesses.

4. EVALUATION GOALS AND METHOD

Our initial emphasis for eClass was simply to integrate it into everyday use. After achieving that goal, we then began the evaluation tasks. The evaluation of ubiquitous computing systems implies doing studies on real and sustained use. This is difficult to achieve using traditional HCI techniques, and due to strict humans-as-subjects rules, we were further limited in the amount of logging and personal information acquisition we could have done otherwise. Although better experiments and observations might have been possible, we feel that we have collected as much data as possible about the use of our system while allowing for maximum anonymity.

We employed four different methods for obtaining information about what material students were accessing, how they were accessing it, when they were accessing it, and why and where they were accessing it. These methods included Web-log analysis with session tracking, questionnaires, controlled experiments, and classroom observations.

4.1 Web Logging with Session Tracking

Our initial analysis plan for eClass use was to examine Web (Apache Web Server) and media (Real Networks Server) logs. Because the online notes are served through a typical Web server, we were able to look at the logs and perform coarse usage studies. However, the server logs alone were not enough to provide a useful detailed analysis of how the system was being used. For example, Web logs show when a user visits a page, but not when they exit. Also, since we provided three methods for accessing media from the captured notes, we wanted to know which method students were using as well as what portions of the recorded media were being played.

The HTML captured notes interface was instrumented to collect detailed logs about the study sessions for students and how they were using the system. For every clickable link, we embedded meta information via parameters in the URL. The parameters were named such that by looking at the logs from the Web server, we could tell what the (anonymous) user did and how they did it. In this way, we could create a "cookie crumb" trail of user-initiated events and actions.

Examining the logs from the modified interface allowed us to generate anonymous student study sessions. We defined a study session to be the activities for a single lecture viewed. A student studying multiple lectures is considered to have multiple study sessions, one for each lecture viewed.

```
startSession | Slow-Audio | cs6450 | Spring99 | 04/21/1999 | dial8.resnet.com | 04/26/1999 | 05:21:29 | 609
viewSyllabus | 0 | cs6450 | Spring99
viewSlide | 4 | 1
viewSlide | 18 | 3
viewSlide | 85 | 2
viewSlide | 130 | 4
playMedia | 138 | ink | Audio | 0:22:05 | 182
viewSlide | 218 | 3
viewSlide | 228 | 5
playMedia | 250 | ink | Audio | 0:47:20 | 260
viewSlide | 538 | 4
playMedia | 544 | ink | Audio | 0:35:13 | 65
```

Fig. 3. A sample session from our logs. Here, the user starts a study session using the one-slide-at-a-time interface with audio for cs6450_spring99, viewing a lecture taught on 4/21/1999. The study session was from a dorm room (resnet domain) and started at 5:21 in the morning on 4/26/1999. The session lasted for ten minutes (609 seconds). The student viewed slides 1–5 (the first number for subsequent log entries is the study time in seconds that the event occurred) and played three audio snippets (lasting 182, 260, and 65 seconds) by clicking on written ink.

A study session begins with a 'startSession' entry and ends at the time of the last recorded event for that IP address, or before a new 'startSession' is encountered. Sessions that have more than 30 minutes of inactivity are assumed to be terminated early, and the remaining log entries are ignored until a new 'startSession' is encountered. Figure 3 shows a log of a typical session.

4.2 Questionnaires

The server logs gave us plenty of quantitative measurements, but we also wanted to obtain input from the students using the system. At the end of each term, all students were asked to fill out (anonymously if desired) a questionnaire on their use of the system. Comments were solicited on what features of eClass they found particularly useful or distracting. We collected data from this questionnaire for classes from Georgia Tech for six terms and from Kennesaw State University classes for three semesters and from one semester at Brown University giving a total of 965 student questionnaires with more than 22,010 responses.

Our goal in administrating these student questionnaires was to obtain from a large user population the general qualitative reaction to eClass as well as self-reports on how students used (or did not use) the technology. The responses are from undergraduate and graduate students enrolled in 45 courses taught by 24 different instructors. The courses cover undergraduate and graduate level material and topics taught in Math, Computer Science, and Electrical Engineering.

We have administered five different student (and one instructor) questionnaires. For this article, we will be using data collected from our end-of-semester questionnaires for students. The actual questionnaire consisted mostly of 5-point preference scale questions (response options were Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree) with a few open-ended questions. The actual questionnaire evolved over time as we stopped asking questions that were receiving consistent and predictable answers and replaced them with new ones, and as we modified questions to receive more focused answers.

4.3 Controlled Experiments

To help answer some of the questions about the impact of eClass we conducted two controlled longitudinal experiments, each on real courses and lasting for the duration of the course. The main idea behind the experiments was to teach the same course in two different sections—one with eClass support and one without—and look for any effects related to student note taking and performance between the two sections. We were looking to quantitatively measure the impact, if any, of eClass on individual note taking styles and to see if use of the system was positively correlated to performance and attendance in the classroom. Additionally, we wanted to see if we could support the student reactions from the questionnaire and determine if there were any trends to be found between classes having captured notes and those without this support.

The first experiment was performed on two sections of an undergraduate software engineering course at Georgia Tech. Students were unaware of the experiment when registering for classes, but if their schedules permitted, they were allowed to switch sections if so desired. The course met three times a week with section A at 9 am and section B at 11 am. Both sections were taught by the same instructor and both sections used the same eClass technology even though the two sections met in different rooms. The only significant difference between the two sections was that section A was allowed access to the eClass notes whereas section B was not. In other words, section B was a normal class taught in a multimedia-enhanced classroom. The on-line notes were not processed for Section B and the notes for Section A were password protected. Section A was instructed not to give their access passwords to section B or otherwise divulge any information about the class. Section B knew about eClass and was made aware that they were not going to have access to the automatically generated notes.

The instructor (Dr. Abowd) was an expert user and researcher of eClass technology. The majority of his lectures consisted of annotating on top of already prepared PowerPoint slides that had been imported into the system. The instructor made these slides available at least 24 hours in advance of class so that the students had the option of printing them out before class and annotating on top of them. A few lectures consisted of the instructor writing on blank slides, much like a traditional class taught using a whiteboard. These lectures were discussion-driven and therefore, there were no notes prepared for the students in advance.

Anticipating that a lecture might be taught better (or worse) the second time given by the same instructor, and to reduce cross-section interference, the lecture order was reversed in the last half of the course. In the first half of the course, section B had the same lecture as the one provided for section A earlier that day. In the latter half, section B would have the first lecture on a topic and section A would have the same lecture at the next class meeting.

At the end of the course, students from both sections were provided the opportunity to turn in their entire set of notes for the course for extra credit. If a student did not take notes for a lecture, the student was to indicate this by providing a blank sheet of paper saying that they took no notes for that day. Of the 35 students in section A, 13 complete sets of notes were received, and of the 45 students in section B, 15 complete sets of notes were collected. In addition to collecting notes from students, they were also required to complete a survey (anonymously if desired) about the instructor's use and their own use of eClass.

One year later, in the Spring 1999 semester, a similar experiment was performed at KSU on an undergraduate calculus course. This time, however, the technology in the two sections was not equal. One section was taught in an eClass enhanced room; the other section was taught in a traditional room with chalkboards. The eClass enhanced room consisted of one 60-inch diagonal electronic whiteboard (a SmartBoard with no projection) and one projected non-interactive overview screen showing what was previously on the physical whiteboard. The room for the other section contained one full wall of chalkboard, approximately 20 feet, and another, 8-foot chalkboard on the left wall of the room, next to the front wall. Other than these physical differences, the experiment was nearly identical to the earlier study conducted at Georgia Tech.

We collected attendance records for the 85 enrolled students in both sections for the duration of the term. In addition, we collected grades for homework, quizzes, and exams for both sections of the course, but did not collect any notes from students or uniquely identify their study sessions. The on-line notes for the captured section were not password protected, but the students in the other section were not made aware of their presence. Lecture order was not reversed halfway through the course as it was for the Georgia Tech experiment.

The instructor was again an expert user of eClass technology. Her lectures consisted of writing the lecture notes on the whiteboard from her own personal copy of notes. The course had 11 quizzes, two projects, and three exams. The quizzes were unannounced and were always a problem previously assigned in the homework.

4.4 Attendance Observations

To help determine the impact of eClass on attendance (in addition to the attendance records from the KSU experiment), we performed a small attendance observation in the Fall 1999 semester. During a 28-day period, in the middle of the semester from October 15 to November 12, we manually took attendance from 12 courses taught in eClass equipped rooms. We did this by standing in the hallway and peeking in the classrooms to count the number of heads in a lecture. The counts were taken approximately 15 minutes after the lecture had begun. The lecture counts were taken from random days primarily in the morning and early afternoon hours. We collected attendance records from seven courses that did not use eClass to capture lectures and from five courses that did. In sum, we had 23 attendance samples from the non-captured classes and 33 from the captured classes.

Note Taking Style	Percent
I write down what professor writes and important points he says.	41.8%
I write down everything the professor writes.	28.5%
I take few notes – just important points.	17.0%
I take no notes.	6.2%
Other	6.5%

Fig. 4. Note-taking style in classes without eClass technology.

5. EVALUATION RESULTS

In this section, we will examine how the students used the notes in their study sessions. We begin by looking at overall use of the notes, showing that eClass was used extensively, and then look at how the media augmentation features were used. Finally, we look at why students access the notes and how students are using them to study for courses.

5.1 Students Take Fewer, More Summary Style Notes

One of our main motivations for eClass was to reduce the need for mundane note copying for the students. It is not surprising then, that students report taking fewer notes than they would in a traditional classroom.

One of the ways we attempted to measure the impact of the technology on the students' notes was to have the students reflect on their note-taking practices after completion of an eClass course and noting any deviations from their normal note-taking routine. We begin by looking at the student responses to our end of the course questionnaire. In an open-ended question, we asked students to "briefly describe your note-taking practices in classes similar to this class but not using eClass technology." The response was open-ended, but we found that many students answered in similar ways, making it easy to categorize their answers. In instances where the categorization was not obvious, we labeled the answer, 'other.' Figures 4 shows the effect of captured notes on student note taking styles based on responses from Fall '97, Spring '98, and Fall '98 (323 total answers). It shows that 70% of students report that they write down at least as much as the professor writes on the board with 42% writing down what the professor says as well. We obviously expected some change in note-taking behavior because eClass records everything the professor writes and says.

We then asked students, "have your note-taking practices in this class changed as a result of eClass? If yes, briefly describe the change." Only 40% (shown in Figure 5) said that the technology did not affect them at all, whereas 55% said that they took fewer or no notes. Recall that it was not our intention for students to stop taking notes altogether, but rather that they would take more personalized notes of items not explicitly written down in the classroom. We found that capture seems to affect students differently based on their note taking style. For example, students who take few notes are less likely to be affected by capture. Students who take copious notes show a trend toward taking more summary style notes, choosing not to write down what the system will capture for them and instead writing down what the system does not capture (personal

Effect of eClass	Percent
Did not affect me at all.	39.7%
I took less notes, outlined, pay attention more to lecture.	31.3%
I took no notes.	23.8%
Other.	5.3%

Fig. 5. The effect of eClass on note taking.

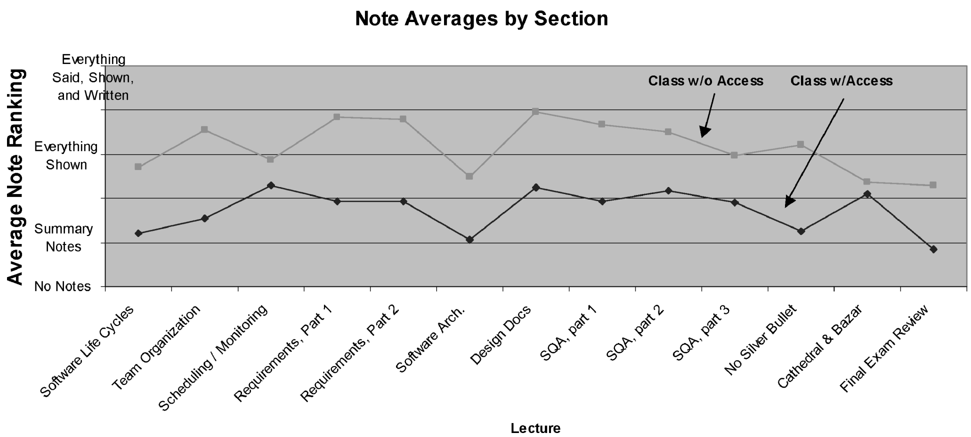

Fig. 6. Comparison of notes between students in the same course.

annotations). Students who just take notes on what is written are more likely to stop taking notes altogether because the system captures everything they would normally preserve.

Students report that they take fewer notes because of eClass, and this is also true empirically. When we collected student notes from a Spring 1998 software engineering course (taught in two sections, one with access to notes, one without) and analyzed their contents, we found that students in the section with access to the capture notes consistently took fewer personal notes (Figure 6). T-tests confirm that students with access to the captured notes took fewer notes than their counterparts ($F(1/24) = 14.02$, $p < 0.005$).

These results are best summed up by student sentiments such as: "Before taking a course equipped with eClass, I attempted to write down everything the professor does. This is sometimes distracting. When taking a course with eClass, I did not try to write down everything that was said, just parts I found interesting or important."

5.2 Notes Are Authentically Used

In our previous work [Abowd et al. 1998; Brotherton 2001], we showed through questionnaire analysis that:

- Students see classroom lectures as the most significant resource for success.
- Students use eClass for the purpose it was built: to review lectures.
- Students see eClass as a useful study tool.

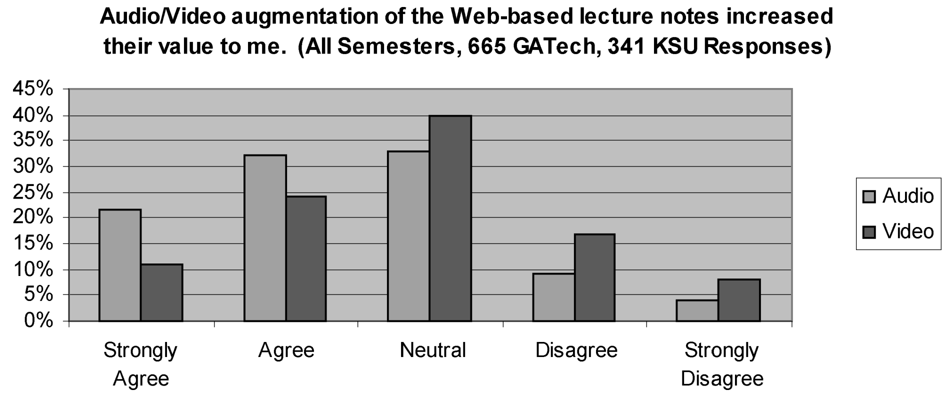

Fig. 7. Student opinion of media augmentation of captured notes.

Questionnaire responses and student opinions only tell part of the story. Recall that we were able to identify 59,796 individual access sessions. In total, there were 2,335 classroom lectures captured. If we assume that there were 25 students enrolled for each course captured, we have more accesses than if every student in every course accessed every lecture once! Of course, some students did not access the notes at all, and others probably accessed them more than their peers, but on the whole, these numbers indicate that the captured notes were frequently accessed by the students. Therefore, through questionnaire analysis and system use, we conclude that not only do students say the online notes are useful, but that they actually do use them.

We will now better characterize these usage patterns by looking at the individual access sessions. We find that the average duration for an access session is 4 minutes, 30 seconds, but this is a conservative number. Many access sessions are less than one minute, for example, when a student is simply printing the notes, or quickly scanning through lectures to find a specific topic. If we look at study sessions that are longer than two minutes, we find that the average study session jumps to just over 13 minutes.

Although 4 minutes, 30 seconds per session on average does not seem like heavy use, let us put it in perspective. If we look at all of the access sessions (that we were able to log) and treat them as one continuous session, we find that in just over 3 years of capturing lectures, the system was used for a total of just over 557 eight-hour days!

5.3 Media Augmentation of Notes Is Useful

We augmented the captured notes with audio and video using the teacher's handwriting, slide visits, and a timeline as indices into the media. Figure 7 shows that overall, 53% of students think that audio augmentation increases the value of the notes with only 13% disagreeing. The numbers for video augmentation are somewhat lower, but more people are in favor of it than are against it.

In practice, we found that the captured media were used, but not as much as we had expected. 10,612 study sessions (18% of all study sessions) accessed

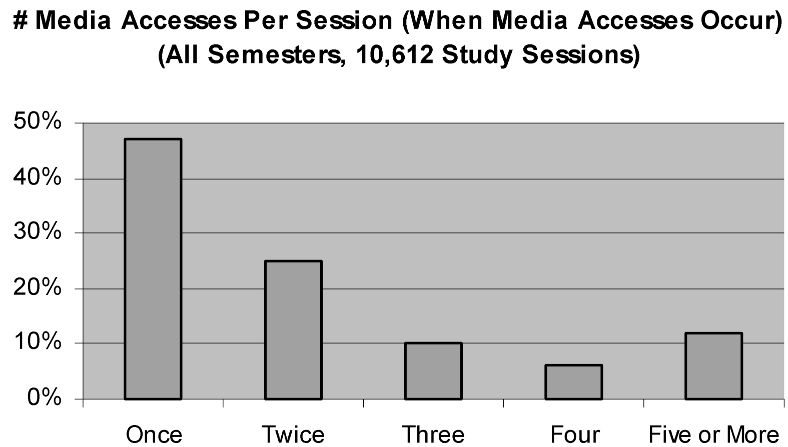

Fig. 8. Breakdown of media accesses per study session (when media access occurs).

either the audio or video associated with the lecture. When a student does access the media in a study session, they access the media an average of 2.7 times per session. However, as shown in Figure 8, almost half (47%) of the students only initiate one media playback per study session. The average number of accesses jumps to 4.1 when a student initiates more than one media access in a study session.

Recall that the average duration for an access session is 4 minutes, 30 seconds. We found that this figure varies widely based on whether or not the student accesses the captured media. Study sessions not accessing media lasted only an average of about 3 minutes, 51 seconds, while those that did access the media lasted an average of 12 minutes, 16 seconds. These results are consistent with those reported on the use of MANIC where it was found that study sessions were longer if the students accessed the captured audio [Padhye and Kurose 1999]. In our case, student study sessions that access the captured media last an average of 4 times longer than those that do not access the media.

Students play the media for an average 6 minutes and 14 seconds per study session and the average duration of each media play is 3 minutes, 18 seconds. We note in Figure 9 that the total duration of media played increases as the number of media plays increases (up to an average of 13 minutes for sessions with five or more media accesses), but the average duration of each media access decreases (down to 1 minute, 35 seconds). This indicates that the students might start to exhibit a foraging tendency when more than one media access is initiated. We discuss this observation further in the next section.

To better understand how students were using the media in their study sessions, we look at when in a study session students were most likely to access the associated media. We found that 69% of media accesses occurred within the first five minutes of a study session (Figure 10).

We used a Real Server, a third party, on-demand streaming server, so our research was not concerned with optimizing media stream delivery, but this is a topic of interest to other researchers (see Bonhomme [2001] for an overview

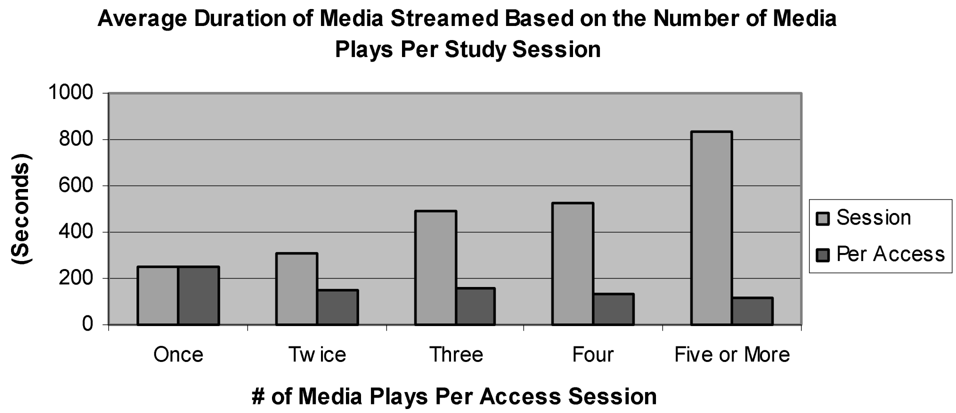

Fig. 9. Average duration of media played per session, based on the number of media plays.

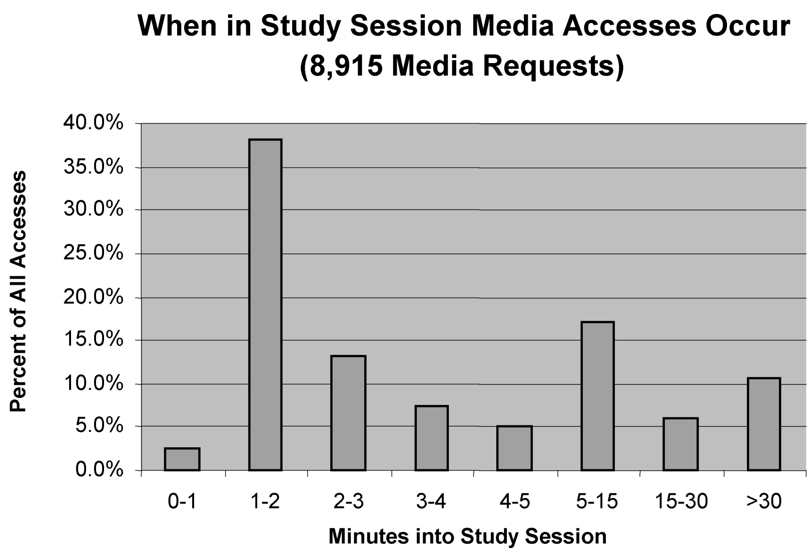

Fig. 10. Breakdown of when in the study session students are accessing media. Recall that when media is accessed at least once, the average session duration is just under 13 minutes.

of streaming video server research). We can use the data provided by these two graphs to provide suggestions for prefetching media. Since only 3% of the study sessions tried to access the media in the first minute but 69% tried in the first 5 minutes, and since nearly 1/2 of all media accesses occur in the first five minutes of the media, a reasonable prefetch policy would be to use the first minute of a study session to preload the first five minutes of the media to the client machine. But what can we say about precaching media after the first five minutes?

As expected, the longer a study session lasts, the further into the lecture accesses occur, but what is surprising is that after only 5 minutes of a study session, 40% of media accesses will refer to a point later than the first 30 minutes

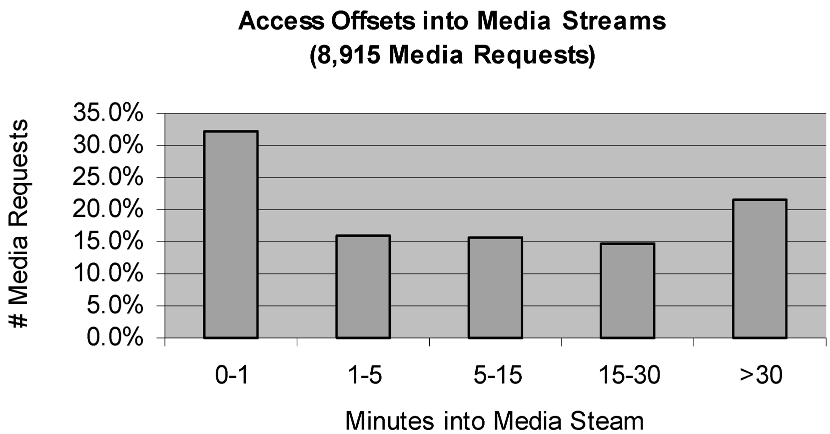

Fig. 11. Breakdown of when in the media stream students are accessing. Next, we looked at where in the lecture students are accessing the media. Figure 11 shows that nearly 4,400 accesses (47% of all media accesses) are within the first five minutes of the media.

of the lecture, indicating that students progress quickly through the captured lectures. Thus, in our limited analysis, we have shown that even though the first 5 minutes of the captured media is heavily accessed (almost 49% of accesses), accesses to the rest of the media account for the majority of accesses.

5.4 Slide-Level Media Granularity Is Most Used

The eClass interface provides three methods for playing back media streams (recall Figure 2). Students can click on the ink to hear the audio at the time the ink was written, or they can play back the audio from the time a slide was visited in class (one of possibly multiple times), or they can index into the audio by clicking on the timeline and jumping to any arbitrary point. A question we wanted to answer was which of these levels of indexing granularity (ink, slide, timeline) is most appropriate based on student use? We have found that slide-level access into the media is the most common method used by students.

Figure 12 highlights the different methods used to index into the media and their relative frequency of use. To generate this table, we looked at all media playing actions where we could identify the method of access. Not shown are access actions where the media access occurred, but the initiating method was unknown. Overall, we were surprised to see that slide-level indexing was the most used, as this method offered the fewest number of indices into the media and did not support jumping directly to a topic within a slide.

We conclude from this that although ink-level access seems like a good idea, in practice, for college lectures, it does not seem to be heavily used. We will discuss possible reasons why in the next section.

5.5 Salvaging Techniques Used During Study Sessions

Moran et al. [1997] define salvaging as “the new activity of working with captured records.” Salvaging consists of searching audio or video for key portions of a recorded event to increase understanding of that event. The Tivoli experience

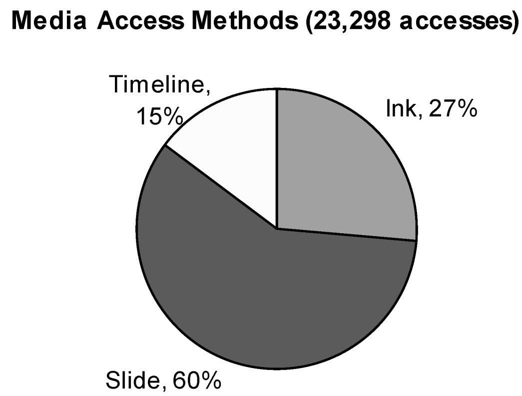

Fig. 12. Methods used to index into media (23,298 accesses).

showed that salvaging tools are valuable for dealing with free-flowing discussions of complex subject matter and for producing high-quality documentation.

Initially, we believed that students using eClass would exhibit complex salvaging activity because we felt that the captured media was useful and because we were providing many indices into the media. However, the classroom is different from a meeting, and students accessing the notes have different goals than the subject studied using Tivoli. Lectures are not so much free-flowing discussions but resemble more structured presentations. Although the subject matter may be complex, it is the job of the instructor to present it simply and clearly. Finally, the goal of a student accessing the notes is not to create a high-quality documentation of the lecture, but to increase understanding. Understanding the material might be accomplished by creating a complete record of the lecture, but as we have shown, even if students do this, their average study session durations indicate that they are probably examining in detail only small parts of the lecture.

We can gain further insight into how the media was used by examining individual access sessions. We mapped each individual student's study session to one of the five salvaging techniques presented by Moran et al.:

- StraightThrough: a study session plays media, but has no media jumps.
- StartStop: a study session has no jumps, but the media played was paused and resumed.
- SkipAhead: a study session has only forward jumps in the media
- Relisten: a study session has only backward jumps in the media
- Non-Sequential: a study session has both forward and backward jumps in the media.

Finally, we can further characterize each session by the method used to play back the media during that session. We provided three ways of initiating a media playback (ink, slide, timeline), but occasionally we were unable to identify how a student indexed into the media. This gives us five types of session characterizations; the four just discussed: ink, timeline, slide, unknown, and

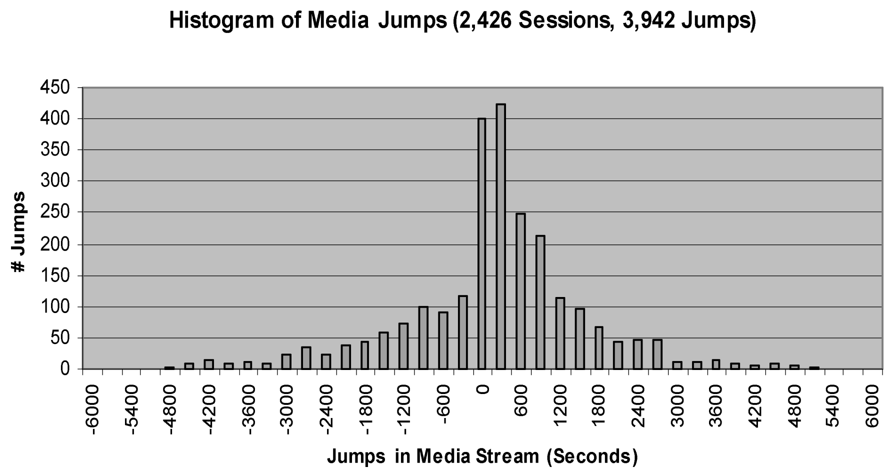

Fig. 13. Distribution of jumps in the media. Negative values indicate backward jumps.

a mixed session containing two or more methods of indexing into the media. We further detailed 'mixed' into four categories, mixed(ink), mixed(timeline), mixed(slide), and mixed(unknown), based on which was the dominant access method.

We were able to categorize the primary media access method for 4,616 access sessions. For each session we could categorize, we then determined the salvaging technique used. We start our analysis in this section by looking at the average number of media jumps per access session, and the frequency of forward and backward jumps.

Of the 4,616 access sessions, 2,426 had at least one media jump for a grand total of 3,942 media jumps. There were 2,492 forward media jumps and 1,450 backward media jumps. One in two sessions had at least one forward media jump and one in three sessions had at least one backward media jump (averaging to 0.54 forward jumps and 0.31 backward jumps per study session accessing media). For sessions with at least one media jump, these figures increased slightly to 1.8 and 1.3 respectively. MANIC found in their analysis of student access sessions that forward jumps were seven times more likely than backward jumps. Although we found forward jumps in the media to be the most common, we observed that they were only 1.7 times more likely, indicating a need for an access interface that supports both kinds of media jumps.

Figure 13 shows a histogram of media jump distances. The jump distances appear to be clustered around zero, but 53% of all media jumps are to a point more than 10 minutes forward or backward from the current point in the media. This indicates that students might be exhibiting more of a random access behavior (indicative of a salvaging behavior) instead of playing the media straight through.

To better understand the salvaging activity of the students, we now look at the distribution of media access methods for each session. As shown in Figure 14, sessions where the media is indexed at the slide level are the most

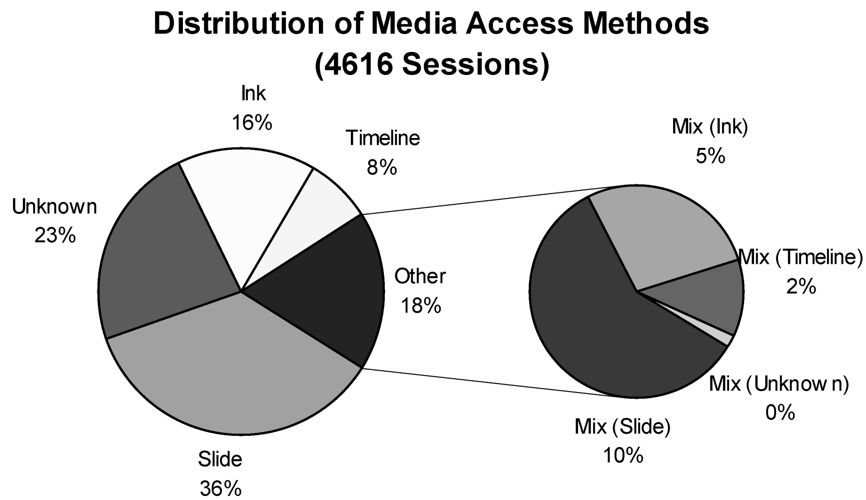

Fig. 14. Distribution of media access methods, classified by sessions.

common, and also account for nearly 60% (11% overall) of the mixed sessions. Recall in Figure 12, we listed the relative percentages for media accesses. In that figure, unknown accesses were not counted; the data shown represents individual accesses. In Figure 14, we are showing the classification of *sessions*. Though not immediately apparent, the relative percentages between ink, slide, and timeline individual accesses are nearly the same as the relative percentages between ink, slide, and timeline sessions. In other words, in both individual accesses and in session categorizations, slide-level accesses are about twice that of ink-level accesses, which are about twice that of timeline-level media accesses.

We expected to find different salvaging techniques depending on the method of media access. Accessing the media at the slide level does not offer as many indices as accessing the media from the ink level, hence we would expect to see fewer jumps, and less salvaging activity from slide-level accesses.

Surprisingly, over 62% of the media access sessions overall exhibited the StraightThrough salvage technique (see Figure 15 for a breakdown of these percentages). It is interesting to note that StraightThrough was dominant regardless of the primary media indexing method. However, looking at sessions that used mixed media accessing methods shows that students in these sessions were more likely to jump around in the media stream. (It is not possible to have a StraightThrough session with mixed media accesses because by definition, mixed access means more than one media play.)

We concluded earlier that the indices provided at the slide-level granularity are sufficient for most student study sessions. When students use only one media access method, they generally just play the media straight through without much jumping around. However, if a student uses different media access methods in the same study session, we find a tendency toward a non-sequential salvaging technique during the study session. We do not know if a particular salvaging technique is 'better' than another for student learning.

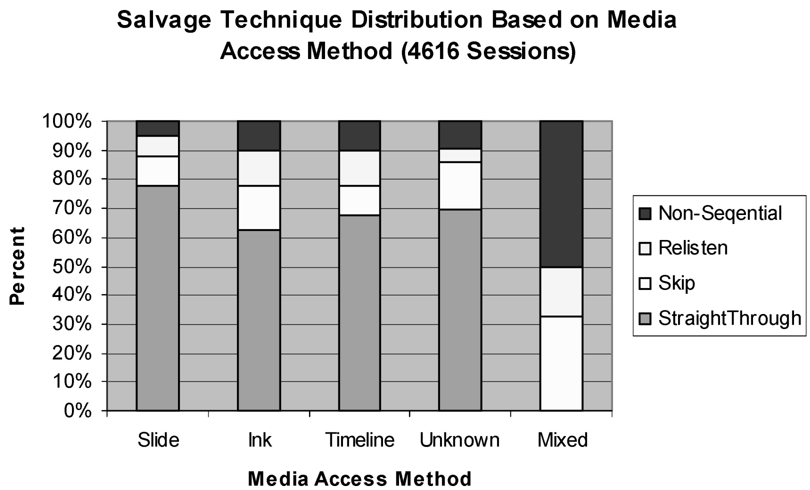

Fig. 15. Distribution of salvage techniques based on media access methods used.

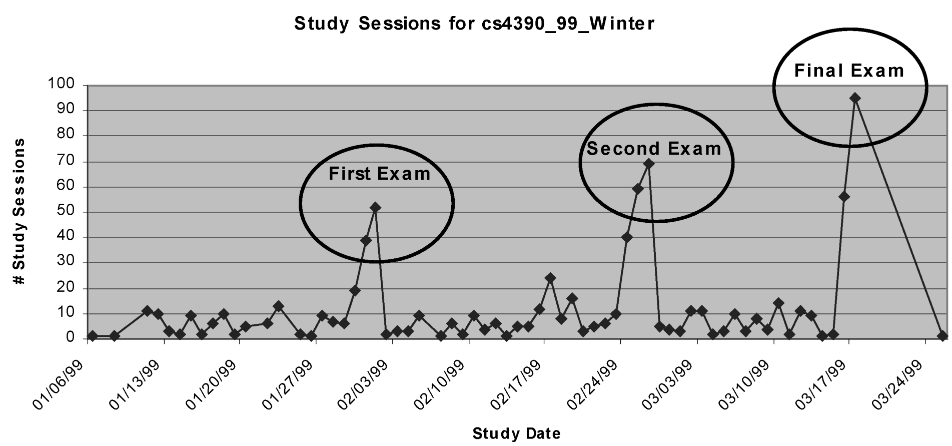

Fig. 16. Access sessions for a typical course from the beginning to the end of the course.

5.6 eClass Is Used for Exam Cramming . . . and More

Now that we have looked at how students access the media augmented notes, we turn our attention to factors that contribute to note accesses. Figure 16 shows a summary of session distributions for a typical course throughout the entire quarter. Overall, for this course, the number of accesses is fairly stable, about 30 per week. The low points on the graph correspond to weekends where accesses are typically lower. The three sharp peaks in access occur around exam dates (two general exams and one final exam). Not surprisingly, as most students cram for exams, the system gets the most use around the time of exams.

What is also significant about this graph is that there are multiple peaks. The first peak shows that the students used the system as a study aid for exams. The second and third peaks provide evidence suggesting that the students found

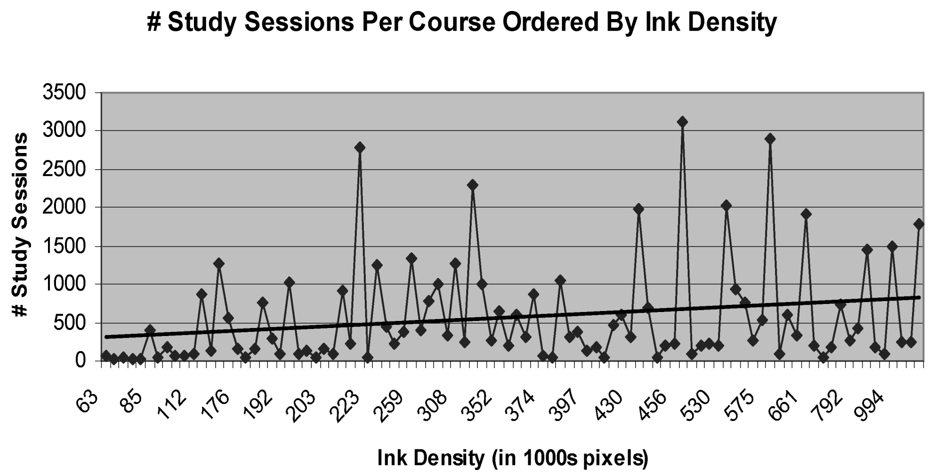

Fig. 17. The number of study sessions increases gradually as the ink density for a course increases.

the system useful as a study aid for the first exam and that they want to use it to help study for the upcoming exams. If the students did not feel like they received much benefit from the system, the second and third peaks should not be as pronounced.

The study session profile for this course is not atypical. In fact, ANOVA tests show that the time between an exam date for a course and the date of a study session is one of the strongest predictors of note access ($F(1/659) = 29.68$, $p < 0.005$) with 43% of all accesses for a course occurring within a week of an exam for that course.

We have looked for other correlations for note accesses as well. Among them are the amount of ink written for a course or for a lecture, the instructor's experience with eClass, the student's experience with eClass, student opinions of eClass, if a course uses PowerPoint slides, and the nearness of the lecture to the study session time.

We thought that the amount of ink written for a course (measured in number of pixels) might be a predictor of how many times the notes for that course were accessed. The data looked promising, and on first glance appeared to support this claim (Figure 17). Regression tests indicate that although we have failed to show any statistically significant correlation at our confidence level ($F(1/92) = 3.60$, $p = 0.061$), the data suggests that some correlation might exist. We then thought that perhaps the correlation might hold at the lecture level; a lecture with lots of ink might be accessed more than a lecture with little ink. At the lecture level, we were unable to find any correlation ($F(1/398) = 1.07$, $p = 0.30$).

It seems likely that courses containing students who have a high opinion of eClass might have more accesses than other courses. We looked at courses whose students rated eClass favorably on the questionnaires and compared their accesses to those courses whose students were not as positive in apprais-ing the value of eClass. We used responses from two questions to gauge stu-dent opinions. The first question was whether eClass made the lectures more engaging, and the second question was whether eClass helped them pay more

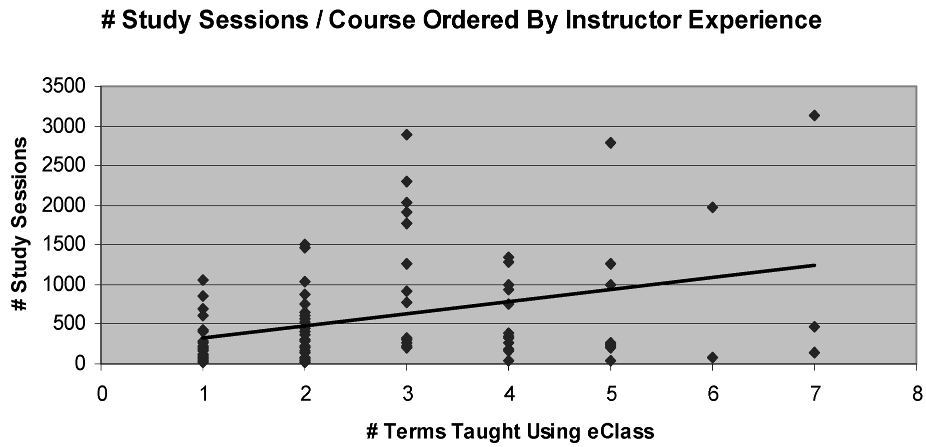

Fig. 18. As instructor use increases, so does the number of study sessions.

attention to the lectures. We were unable to find any correlation between student opinions of eClass (based on these two questions) and the amount of note accesses ($F(1/27) = 0.62$, $p = 0.435$ and $F(1/45) = 0.03$, $p = 0.851$).

We were also unable to find any correlations between accesses and student experience with eClass, but we could establish a correlation between accesses and the instructor's experience with eClass. Figure 18 shows that as the number of semesters an instructor used eClass increased, so did the number of accesses for the courses they taught ($F(1/93) = 14.86$, $p < 0.005$). It is unclear why this trend exists, but we think it might be related to more effective use of the capture capabilities that comes with extended experience with the system. As a result, instructors with prior use might see the benefits of students using the system and therefore, make sure that the students use it more.

We also noted that overall student impressions of eClass increased as students gained exposure over consecutive terms, also suggesting that it takes time for students to determine how to effectively incorporate such a novel service into their educational routine.

Courses with prepared PowerPoint slides had more accesses than courses that did not use them. Specifically, as the percentage of slides using PowerPoint increased, so did the number of access sessions to those lectures ($F(1/51) = 8.33$, $p = 0.006$). This is most likely because as the instructor uses more prepared information, it is easier for the students to access it on the Web than it is for them to copy down the slides.

Finally, we also discovered that accesses to a lecture are more likely to occur within a week of that lecture ($F(1/912) = 121.98$, $p < 0.005$). In fact, as Figure 19 shows, nearly 1/3 of all accesses to a lecture occur within a week of the date the lecture was given.

To recap, we found four factors that determine online note accesses. The first two are the nearness to the lecture being accessed and nearness to the exam for the course. Additionally, instructor experience correlates positively with accesses, as does having prepared slides for a lecture presentation.

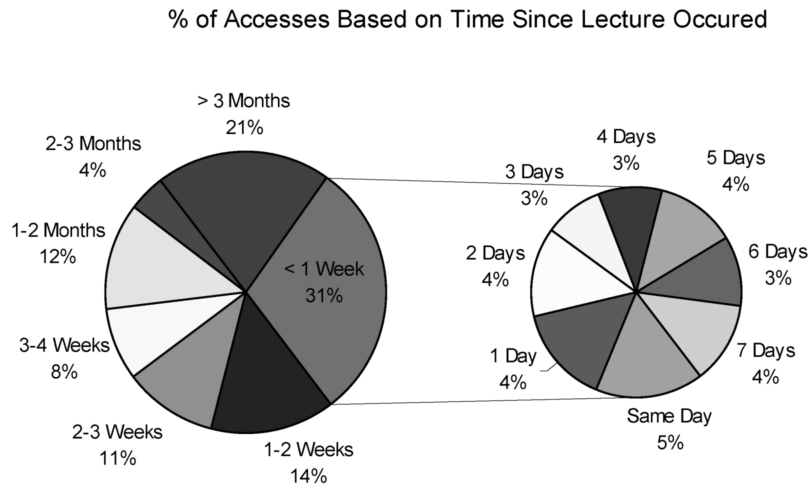

Fig. 19. Distribution of accesses to a lecture.

5.7 Attendance and Performance

We end by answering two questions we are always asked about eClass:

- Does eClass encourage students to skip class?
- Do students using eClass achieve higher grades?

5.7.1 *eClass Does Not Encourage Skipping.* One of the biggest concerns that we are often asked about eClass is whether its use encourages students to skip classes. The reasoning is that if the lecture experience is available on-line, then students will not be motivated to join in the live class and instead just watch it from home at their leisure. On the surface, this seems like a reasonable concern, but we have always maintained that the service provided by eClass was designed to be a supplement for a lecture—not a replacement for it. We believe there are some key aspects of the lecture experience that eClass does not preserve or enable, such as remote interactivity, and that without the benefit of actually being there, the on-line notes are not valuable enough to serve as a substitute for attending lectures.

Since Fall 1997, on the end of the term surveys, we have asked students if they feel whether eClass encourages students to skip class. Figure 20 shows the summary from student responses at Georgia Tech and Kennesaw State. These figures include 757 responses, (563 from Tech, 194 from KSU) and cover all terms of use at both institutions. It turns out that, as a whole, students are evenly divided as to whether or not they think it encourages students to skip classes with 30% agreeing, 35% disagreeing, and 35% having no strong feelings either way.

If we segregate the responses from students by term and for each school, we see that these figures represent a stable response since student responses to this question have not changed significantly over the years (χ^2 (16) = 19.17, p = 0.263 for GT, and χ^2 (12) = 10.87, p = 0.542 for KSU). Additionally, students from both Georgia Tech and Kennesaw State do not answer the question differently (χ^2 (4) = 1.42, p = 0.843).

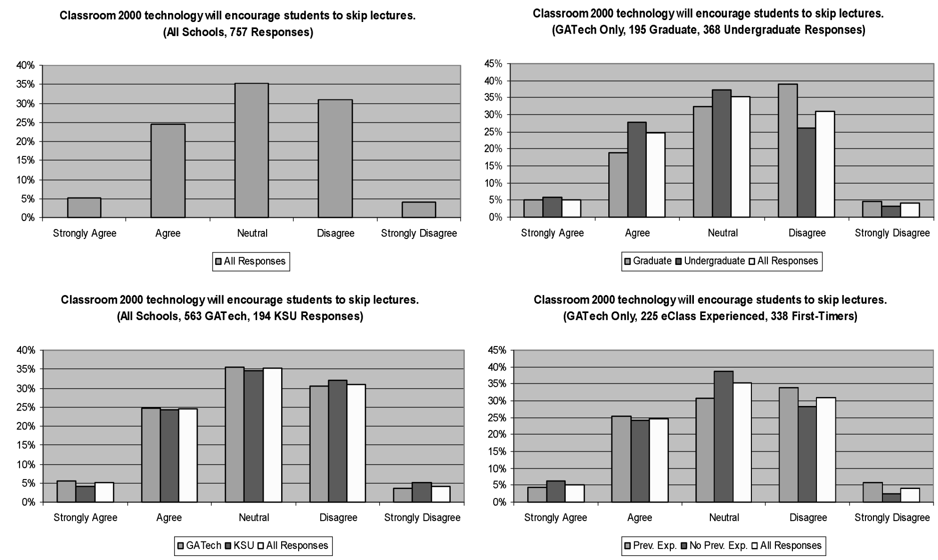

Fig. 20. Student opinions on whether eClass encourages skipping class.

Interestingly, graduate and undergraduate students answered this question differently. Graduate students were more inclined to say that eClass doesn't encourage students to skip while undergraduate students were more likely to feel that eClass encourages skipping (χ^2 (4) = 12.67, p = 0.013). This might be because undergraduate classes are more structured and tend to more closely follow the reading, slightly diminishing the importance of attending lectures. Graduate classes, on the other hand, tend to be more discussion based and cover material not present in the readings. Alternatively, graduate students may simply be more mature students and as such, would be less likely to miss a lecture under any circumstance.

A related question is whether students feel that eClass makes them personally feel less worried about missing a class if they need to. Figure 21 shows the results from 760 student responses (565 from Tech, 195 from KSU). Overall, students feel somewhat more strongly that it does make them less worried about missing with 49% agreeing, 30% disagreeing, and 21% having no opinion.

The questionnaire data seems to indicate that while eClass does not encourage skipping, it does relieve students of some of the worry of missing a class when they must. In general, compared to asking if eClass encourages skipping, students were more likely to have a non-neutral opinion on eClass relieving the worry of missing a lecture.

We found several factors in determining how students answered this question. Overall, KSU students were more likely to strongly disagree instead of agree (χ^2 (4) = 20.00, p < 0.005) compared to their GT counterparts. Again, this is probably reflective of Tech students being more comfortable (and more trusting) with technology in general than their KSU counterparts.

Once again, graduate and undergraduate students answered this question differently. Graduate students were more likely to strongly agree and agree

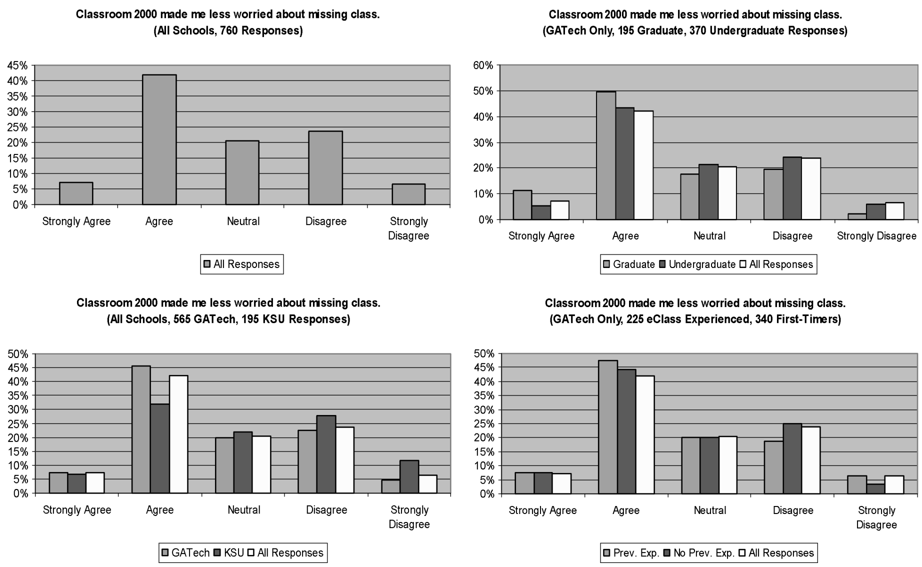

Fig. 21. Student opinions on whether Classroom lessened the worry of missing a class.

while undergraduates were more likely to be neutral or disagree (χ^2 (4) = 17.57, p < 0.005). Additionally, students in courses that utilized PowerPoint slides were more likely to strongly agree and agree while students in courses without PowerPoint slides were more likely to be neutral. Because eClass does a better job of capturing prepared slides than it does handwritten slides (handwriting is often sloppy and occasionally unreadable), this might cause student in courses with prepared slides to feel more strongly that the system will capture the presented information if they have to miss class.

Of course, questionnaires do not tell the whole story. To get a more quantitative answer, we examined two sets of actual attendance records: one set from the Kennesaw State University controlled experiment, and one set from observations at Georgia Tech.

Figure 22 shows a summary of the random mid-semester attendance samples for captured and non-captured classes taught at Georgia Tech along with a linear regression analysis trend for both types of classes.

Figure 22 reveals two interesting points. First, the trend lines indicate that the attendance in captured classes is around 5% lower than in non-captured classes. Second, the trend lines suggest that attendance dropped off slightly for both captured and non-captured classes as the semester continued.

To determine whether use of eClass indeed had a negative impact on attendance we first checked to see if the decline in attendance for either captured or non-captured classes was statistically significant. For this data, a linear regression analysis on the trends turned out not to be significant (F (1/32) = 0.25, p = 0.62 and F(1/22) = 0.16, 0.68 respectively).

We then examined the average attendance values for each type of class: 78% for non-captured courses and 72% for captured courses, indicating that eClass might again have a slight effect on attendance. However t-tests reveal that the

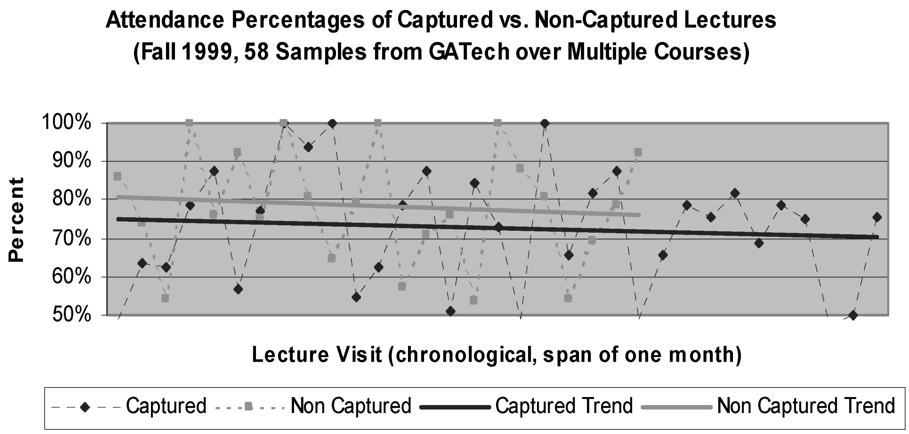

Fig. 22. Graph of GATech attendance percentages for captured and non-captured courses.

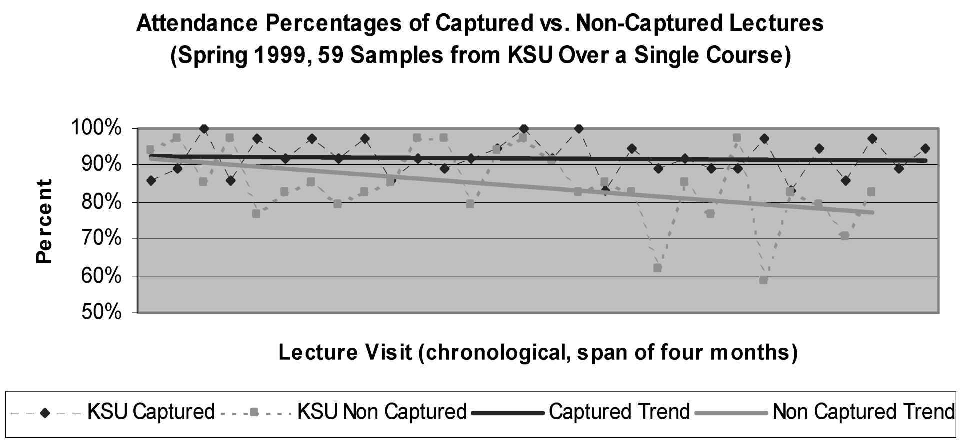

Fig. 23. KSU attendance percentages for two sections of a course, one captured and one not.

difference in attendance means is not statistically significant ($F(54) = 1.40$, $p = 0.168$) so we can conclude that the attendance data collected from Georgia Tech does not support the notion that use of eClass results in lower attendance.

Next, we examined the attendance logs from KSU. Figure 23 shows a summary of the attendances for captured and non-captured classes along with a linear regression analysis trend for both types of classes. T-tests indicate that students in the captured class are more likely to attend class than their counterparts in the non-captured class ($F(56) = -3.61$, $p < 0.005$). Further, regression analysis on the data from KSU indicates that students in the non-captured classes had an attendance decline as the semester progressed ($F(1/27) = 0.10$, $p = 0.02$) while those in the captured class did not ($F(1/29) = 5.86$, $p = 0.75$).

It seems then, that use of eClass actually improved attendance at KSU. Again, these results are from the same instructor teaching the same material at the same time of day (9 a.m., Monday and Wednesday for section 1, the non-captured class, 9 a.m., Tuesday and Thursday for section 2, the captured class).

School	Section	Exam 1	Exam 2	inal Exam
GATech	Access	81.5 (stdev = 7.5)	80.3 (stdev = 15.3)	N/A
	No-Access	79.5 (stdev = 13.1)	79.0 (stdev = 14.6)	N/A
KSU	Access	77.3 (stdev = 13.5)	78.1 (stdev = 12.1)	122.3 (stdev = 16.2)
	No-Access	80.4 (stdev = 13.7)	76.7 (stdev = 11.6)	124.1 (stdev = 19.5)

Fig. 24. Summary of exam performances, shown as raw scores (100 max points for Exams 1 and 2, 150 max points for the Final Exam.)

Thus, using data from our two experiments, we failed to find any proof that eClass has a negative impact on attendance either at Georgia Tech or KSU. Therefore, we conclude that overall, through student questionnaires, surveys, and attendance logs, use of eClass does not negatively affect attendance. We imagine that other attendance factors—such as the time of day of the class, the lecture topic, or the engagement level of the professor—might dominate.

As we stated at the beginning of this section, we did not think eClass was a substitute for attending lectures. However, we feel that with the addition of remote interactivity tools, eClass might start to encourage students to view the lectures wherever it is more convenient. The level of disruption that this would cause in the classroom would need to be outweighed by the benefits of having remote participants.

5.7.2 *Performance Not Impacted.* At the conclusion of our controlled experiments at KSU and GATech, we were unable to find any significant difference in exam grades based on availability of captured lecture notes. At GATech, we found that students in the traditional section performed better (but not significantly) than their eClass counterparts on the midterm exam, but that the eClass section did better (but again, not significantly) on the final exam. The results from KSU were the opposite, with eClass students doing better on the midterm and worse on the final (but not significantly in either case). The grades from both schools are summarized in Figure 24.

What does this imply? It means that at the least, eClass does not result in decreased exam performance. In other words, we do not seem to be disrupting the classroom with our research. Of course we do not seem to be helping much in terms of grades either. But what about other factors related to studying? Figure 25 shows what students reported as answers to how eClass helps them.

We see that students are overall, split evenly among using eClass for help with exams, homework, and projects—all activities that are used for assessment. It could be that although eClass does not directly help exam scores, it does help in other areas where grading is a factor. In any case, it does not seem to hurt.

We considered that while eClass might not result in higher exam performances, maybe it helps students study more efficiently, allowing them to

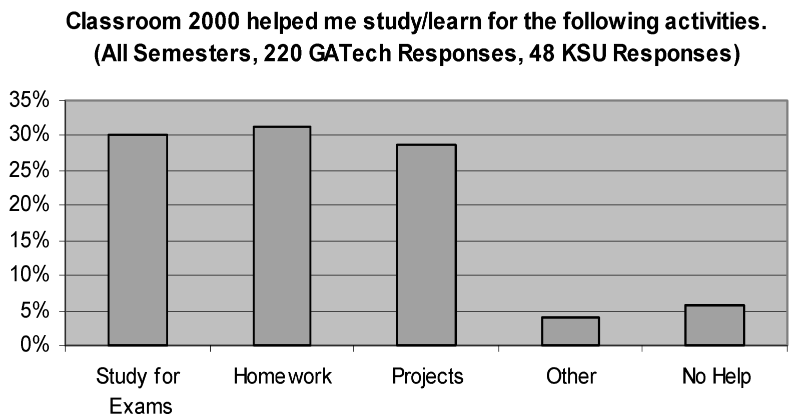

Fig. 25. Ways in which eClass helped students.

achieve the same level of performance with less work. When we asked students (through questionnaires) if this was in fact the case, we found that of 124 GATech students, 54% felt that eClass enabled them to study more efficiently with only 19% disagreeing. This was indeed encouraging, and when we asked these same students if they studied more, less, or about the same when using eClass (again, via questionnaires), we found that 74% said they studied the same amount, with 6% reporting an increase and 19% indicating a decrease.

In the end, we cannot empirically say whether eClass has a positive or negative impact on student performance on exams. We know that students use eClass to help with many different assessment activities, and after using the system for years, we have plenty of anecdotal evidence that eClass does help.[2] It is a great source of pride for the author that many students have directly said that they would not have passed a course without the help of eClass, so we do feel that we are making a positive contribution.

5.8 Impact on Instructors

Until now we have been focusing on the impact of capture and access on students. In this section, we focus briefly on the effect we have observed on instructors. Note that in this section, we are only presenting advice based on our experience and are not presenting scientific results. Nonetheless, we still feel this is useful information for the reader.

From the beginning, we felt strongly that if we required significant changes from the instructor then our system would not be widely used. As a general rule, instructors tend to eschew technology and they do not want to change their teaching styles or habits, so our challenge was to enable lecture capture while keeping the status quo. We observed that most instructors taught either by showing PowerPoint slides or simply writing on a blank whiteboard, so this is the style of teaching we supported. We felt that if we let instructors do what

[2]During the study, the authors personally received many emails per semester thanking them for building the system, usually stating that the student felt s/he would not have passed the course without the use of eClass.

they would do normally, then they would have few objections to using eClass, and this assumption has turned out to be valid. While we have been criticized for supporting a didactic model of teaching, we feel that had we required a different pedagogy, use of eClass would have been minimal. We assumed that instructors want to teach in a way that is most effective for them and for their students, and we did not want to *force* a particular style of teaching with our system, but rather to *enable* them. This has turned out to be a good idea, and one that we feel should underlie any electronic classroom design.

Therefore, to use eClass, a professor who normally walks into the room and starts writing on a blank whiteboard does just that. Of course, the 'whiteboard' is electronic, but it was always running our software and only requires the instructor to log in; something that takes just a few seconds. Instructors using PowerPoint slides, had the additional burden of uploading the slides to the system, but this did not seem like too much work if an instructor was already going to the trouble of creating a presentation. To further ease the work, instructors could upload the presentation from their office before class or from the whiteboard at the start of class. We worked hard to build a system that "just worked." This turned out to be the most critical design decision because on the occasions where the system didn't "just work," it was generally not used. Instructors do not like to troubleshoot during class time. As a result, instructors were generally very favorable to the system since in their eyes, the students got the captured notes "for free."

We had very few privacy issues with instructors—they were not worried about the lecture being recorded. Occasionally, we would get a request to blank a few seconds of audio from a lecture when something critical was said of another colleague or researcher, but these requests were rare. However, it suggests that a useful feature would be the ability to go back and edit a captured lecture, or to provide a 'mute' button during capture. We did not implement this functionality; however in hindsight, we feel that we should have.

Surprisingly, we found that instructors also accessed the captured lectures and for a variety of reasons. Many instructors checked the notes often just to make sure everything was captured properly or to see what they looked like, and for most instructors, this was the extent of their use of the notes. A few instructors have remarked that they looked at another instructor's set of notes when they were scheduled to teach a course they hadn't taught before (but one that was captured via eClass). Their intent was to get an idea of how the course was taught so that they could present consistent material and teach it in a similar fashion. Other instructors have said they used the system to review lectures captured during their absence, such as when attending a conference. The system allowed them to be aware of the materials covered while they were away.

The most creative uses of the lecture notes by instructors have been when they encouraged their students to use the whiteboard during class. One instructor would have his students write their name on the whiteboard and introduce themselves to the class. Later, if the instructor's memory of a student was fuzzy, they could go back to that captured lecture and review what the student said and what the student looked like. Other instances of this type of behavior occurred in project-based classes. The instructor would have students give their presentations using the system and then later go back and review the class when it came time to provide detailed comments about the presentation. While this use is relatively minor, it demonstrates that the technology not only supports traditional styles of teaching, it also encourages new uses of the technology—ones that would not normally have been implemented due to the overhead costs of doing it without eClass.

In closing, instructors have been fond of the technology and have generally encouraged its use. In those situations where the instructor is completely against this kind of technology, nothing was required; eClass only captured lectures when the instructor explicitly logged into the whiteboard. A similar opt-out behavior should be present in any public capture system.

6. DISCUSSION

We began our work as researchers trying to use ubiquitous computing to help what we perceived to be a problem for students in college level courses—the preservation of college lectures for later review. Over the course of our work, we have done formative and summative studies, and conducted controlled experiments on the use of our system. We have shown a need for the services we provided, both among college students and professors, and in this section, we will highlight some lessons learned through our evaluation.

6.1 Implications for Future Design

We are currently investigating how we can rebuild eClass, learning from our initial prototype. Here is a list of features we hope to incorporate into the next version of eClass, features that we think any similar system should possess.

We have shown that students do not view the captured lecture materials as a substitute for attending class. On the one hand, this is a good thing because students cited this deficiency as a reason not to skip class, but it also potentially limits the usefulness of the notes by not capturing some of the details on the actual lecture environment.

Part of the reason for our impoverished experience is that our focus was on capturing materials automatically, with no human intervention. That is to say, our capture occurs in a classroom with only a teacher and students—we do not have access to a film and production crew. What we lack in capture quality however, we make up for in volume. By removing the human from the capture loop (other than the students and instructor) we enable all courses taught in a set of rooms the option of lecture capture. We avoid the costs of bringing people into the classroom to produce a lecture.

6.1.1 *Improved Capture.* But we can do a better job in automated capture. What is missing in our system is the ability to capture any lecture presentation, whether it is with a whiteboard, PowerPoint, Web-based, acetate slides, or simulation program with a truly zero start-up time. We also want to provide high-quality video and audio augmentation for the notes. Despite mixed reviews in our work and mixed reports on the use of video, we still firmly believe that video was not used as heavily in our studies because of the poor recording quality and the amount of bandwidth required to view it. As DSL and cable modems are becoming standard, we hope to revisit this issue. Additionally, we can make use of color- and people-tracking cameras (or build one) to provide a better view of the instructor and her movements in the classroom.

The ability for students (possibly remote) to collaborate with the class and professor is sorely lacking from our system. We have had limited success with building student note taking units [Truong et al. 1999], but now that laptop computers and wireless systems are becoming more common, it might be time to revisit this topic. Also, collaboration will allow us to bring outsiders into the classroom with full discussion privileges—something that has stopped us from using eClass as a synchronous distance learning tool.

6.1.2 *Improved Access.* We want to provide a better access interface for the students (and instructors). Our current access interface is good, but it can be improved by taking advantage of Web technology (Java-enabled devices, Flash, etc) that wasn't in general use when we were building our system. We caution however, against using 'bleeding-edge' technology. Our first interface relied too much on emerging technology and it wasn't until we catered to the lowest common denominator (static HTML notes) that we achieved widespread use of the notes.

Our questionnaires have shown that students use the captured notes primarily for two reasons: to review lectures (attended and missed) and to study for exams. However, students also reported viewing the notes to get help with homework or projects and for learning more about interesting topics discussed in class not directly related to the course. Our current interface does not do much to support these activities (other than providing the captured notes).

We also want to provide a collaborative set of notes; one where students and instructors can edit the materials presented in the classroom. Our previous work in this area [Abowd et al. 1999] has shown it to be useful, but adding it to eClass was troublesome because eClass did not have the proper infrastructure to easily support collaborative editing. More than just providing a discussion forum is needed however; we would like to truly enable a Web presence for courses that facilitate the spreading of ideas and discussion (and integration) of lecture topics.

We designed the on-line notes interface to be used more as a 'table of contents' to facilitate easy indexing into a particular portion of the lecture rather than as a general replay tool. The lack of a mechanism for the automated replay of a lecture means the task of replaying a lecture is more complicated than just watching a video. A better random-access method for viewing the course media is needed with a better coupling between the media and the notes. We would like to take advantage of research in skimming recorded content to provide for a more VCR-like method to review recorded lectures or use automated summaries of the lectures [He et al. 1999]. Additionally, we would like to provide for the playback of streams other than audio/video. For example, the slides and ink can be dynamically presented [Brotherton et al. 1999] to give the flow of the lecture rather than simply presenting the final product.

Finally, students in a class are not the only consumers of the notes. We have found that professors, students outside of a course, and people who have previously taken a course all access the notes. The access interface should support the activities of these different groups. For example, instructors sometimes use the notes to see how a course was taught the year before, or to get a better idea of how to teach a specific topic. Students sometimes look at previously taught courses to see if they want to enroll in the same course. Our general interface has allowed these various activities, but we are not directly supporting these uses.

6.1.3 *Improved Integration.* Recall that slide-level media accesses were most used over ink and random access despite the latter two methods providing for more precise indexing into the media. We have two theories as to why this might be so. First, our system forced the 'slide' concept on the instructors, and this in turn may have influenced their presentation so that slide-level integration was adequate. Second, we note that our system captured the exact time ink was written on the board. What would have been better is if the system captured the time of the beginning of the topic to which the ink refers.

For example, many instructors would write down a comment after discussing it, as a way of wrapping up that topic. In this case, clicking on the ink would not play the media in the desired location, but rather at the end of the material. Because not all instructors were consistent (some would write before they spoke, others after), and because some Real Player clients did not allow users to go before the point in a media stream from when it was started, we think that students found it easier just to start the media at the point the slide was shown, and then just listen from there or skip forward.

An obvious improvement of our system then, would be to predict when the ink written on a slide refers to something that was just discussed or is about to be discussed, rather than always assume that it refers to something that is about to be discussed. Stifelman's work [Stifelman 1997] adjusted ink indices based on an analysis of the audio stream and this might be a good first step toward making the ink in our interface more usable. Our work leads us to conclude that providing higher indexing granularity is not as important as providing more predictably meaningful integration between presentation artifacts (slides and ink) and captured media. The problem is that different instructors have different preferences between speaking before writing and speaking after writing and many instructors are not consistent in their preferences during the same lecture.

6.1.4 *Privacy.* Although privacy concerns in eClass have been minimal, we would like to address them more fully in our next version. This involves making the capture system more visible to the users so that they know exactly what is (and what is not) being recorded and when it is (and is not) occurring. We also need to provide for opt-out methods, such as temporarily stopping the capture, or enabling privacy zones where audio/video is not being recorded thereby allowing students the option of being able to ask questions without having their voice recorded.

7. CONCLUSION AND FUTURE WORK

In this article, we presented some of the results from a longitudinal study of the impact of automated capture in a classroom lecture setting. We presented results of a three-year study of the eClass system used at Georgia Tech and elsewhere. We showed that:

- eClass did not have a negative impact on attendance.
- eClass did not have a measurable impact on performance (based on grades), but seems to encourage review activities that are considered helpful for performance.
- The online notes generated from automated capture of college lectures are desired and used, and media augmentation is also desired and useful, though actual use is not as strong as one would expect based on student surveys.
- Based on media use characteristics of access sessions, students do not typically exhibit the same salvaging strategies as reported for meeting records.
- The captured notes are mostly used to review lectures shortly after they occurred and for exam cramming. Other factors that influence how much the notes for a course are accessed include the instructor's experience and whether the course uses prepared slides.

Based on these results, we presented our suggestions for future capture and access systems in and outside of the classroom by focusing on improvements in the capture, integration, and access phases. In the capture phase, a system needs to support generalized capture of lecture materials with no extra instructor effort. The quality of the captured materials needs to be of the same fidelity as presented, and the taking of collaborative student notes should be supported. The integration needs to be smarter; either by providing automated summaries of a lecture, or by providing a more semantic linking of the notes. In other words, simply merging media streams based on their time provides for minimal, not optimal integration. Finally, the access of captured materials needs to support generalized replay rather than just showing the static, end result of a slide. Collaboration and editing of captured notes during access increased their value; the access interface needs to support more than just lecture review as the notes are used by instructors and students with different goals and motivations.

ACKNOWLEDGMENTS

We thank our sponsors for their continued support, both financial and otherwise. Finally, we would like to thank the many students and faculty within the Future Computing Environments Group for their strong support and energetic enthusiasm over the past four years as well as the College of Computing at Georgia Tech, Kennesaw State University, Brown University, and McGill University for their acceptance and use of eClass.

REFERENCES

ABOWD, G. D., ATKESON, C. G., BROTHERTON, J. A., ENQVIST, T., GULLEY, P., AND LEMON, J. 1998. Investigating the capture, integration and access problem of ubiquitous computing in an educational setting. In *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI '98)*. Los Angeles, CA, May, 440–447.

ABOWD, G. D., ATKESON, C. G., FEINSTEIN, A., HMELO, C., KOOPER, R., LONG, S., SAWHNEY, N., AND TANIET, M. 1996. Teaching and learning as multimedia authoring: the Classroom 2000 project. In *Proceedings of the Fourth ACM International Conference on Multimedia*. Boston, MA, February, 187–198.

ABOWD, G. D., PIMENTEL, P., ISHIGURO, Y., KERIMBAEV, B. AND GUZDIAL, M. 1999. Anchoring discussions in lecture: An approach to collaboratively extending classroom digital media. In *the Proceedings of the Computer Support for Collaborative Learning (CSCL '99).* Palo Alto, CA, December, 11–19.

ABRAMS, G., ALSPECTOR, J., HAEFNER, J. AND WILCOX, S., JR. 2000. Learning at a Distance from a Traditional Classroom: A Win-Win Proposition. In *Proceedings of the 13th International Conference on Technology in Collegiate Mathematics*, Atlanta, GA, November, Addison Wesley publishers, 1–5.

BACHER, C. AND MULLER, R. 1998. Generalized Replay of Multi-Streamed Authored Documents. *In Proceedings of ED-Media*, Freiburg.

BARGERON, D., GUPTA, A., SANOCKI, E., AND GRUDIN, J. 1999. Annotations for Streaming Video on the Web: System Design and Usage Studies, 1998. *Computer Networks: Intl. J. Comput. Telecom. Netw. 31*, 11–16 (May), 1139–1153.

BERQUE, D., HUTCHESON, A., JOHNSON, D., JOVANOVIC, L., MOORE, K., SINGER, C., AND SLATTERY, K. 1999. Using a Variation of the WYSIWIS Shared Drawing Surface Paradigm to Support Electronic Classrooms. In *Proceedings of Human Computer Interaction '99: The 8th International Conference on Human Computer Interaction*, Munich, Germany, August, 22–27.

BIANCHI, M. 1998. AutoAuditorium: A Fully Automatic, Multi-Camera System to Televise Auditorium Presentations. In *Joint DARPA/NIST Smart Spaces Workshop*, Gaithersburg, MD, July.

BONHOMME, A. 2001. "Survey of Video Servers," *hyperlinked resource page, including bibliography,* http://www.ens-lyon.fr/~abonhomm/video/survey.html.

BROTHERTON, J. A., ABOWD, G. D., AND TRUONG, K. 1999. Supporting Capture and Access Interfaces for Informal and Opportunistic Meetings. GVU Center, Georgia Institute of Technology, Tech. Rep. GIT-GVU-99-06. January.

BROTHERTON, J. A. 2001. eClass: Building, Observing and Understanding the Impact of Capture and Access in an Educational Setting. Ph.D. Thesis, College of Computing, Georgia Institute of Technology, Atlanta, GA, December.

CRUZ, G. AND HILL, R. 1994. Capturing and Playing Multimedia Events with STREAMS. In *Proceedings of ACM Multimedia*, San Francisco, CA, October, 193–200.

HE, L., SANOCKI, E., GUPTA, A., AND GRUDIN, J. 1999. Auto-Summarization of Audio-Video Presentations. 1999. In *Proceedings of ACM Multimedia*, Orlando, FL, November, 489–498.

ISAACS, E. A., MORRIS, T., AND RODRIQUEZ, T. K. 1994. A Forum for Supporting Interactive Presentations to Distributed Audiences. In *Proceedings of the ACM Conference on Computer Supported Cooperative Work (CSCW'94)*, Chapel Hill, NC, October, 405–416.

LI, F. C., GUPTA, A., SANOCKI, E., HE, L., AND RUI, Y. 2000. Browsing Digital Video. In *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI '00)*, Hague, Amsterdam, April, 169–176.

MORAN, T., PALEN, L., HARRISON, S., CHIU, P., KIMBER, D., MINNEMAN, S., VAN MELLE, W., ZELLWEGER, P. 1997. I'll Get That off the Audio: A Case Study of Salvaging Multimedia Meeting Records. In *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI '97),* Atlanta, GA, March, 202–209.

MUKHOPADHYAY, S. AND SMITH, B. 1999. Passive Capture and Structuring of Lectures. In *Proceedings of the ACM Conference on Multimedia '99*, Orlando, Florida, October, 477–487.

PADHYE, J. AND KUROSE, J. 1999. An Empirical Study of Client Interactions with a Continuous-Media Courseware Server, In *Proceedings of the 8th International Workshop on Network and Operating System Support for Digital Audio and Video (NOSSDAV '98)*, Cambridge, UK, July.

STIFELMAN, L. 1997. The Audio Notebook, Ph.D. Thesis, Media Arts and Sciences, Massachusetts Institute of Technology, Boston, MA.

STIFELMAN, L., ARONS, B., AND SCHMANDT, C. 2001. The Audio Notebook (Paper and Pen Interaction with Structured Speech). In *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI '01)*, Seattle, WA, April, 182–189.

TRUONG, K. N., ABOWD, G. D., AND BROTHERTON, J. A. 1999. Personalizing the Capture of Public Experiences. In *Proceedings of the ACM Conference on User Interface Software and Technology (UIST '99)*, Asheville, NC, November, 121–130.

WHITE, S., GUPTA, A., GRUDIN, J., CHESLEY, H., KIMBERLY, G., AND SANOCKI, E. 1998. A Software System for Education at a Distance: Case Study Results. In *Proceedings of the Hawaii International Conference on System Sciences (HICSS)*, Maui, Hawaii.

WHITTAKER, S., HYLAND, P., AND WILEY, M. 1994. Filochat: Handwritten Notes Provide Access to Recorded Conversations. In *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI '94),* Boston, MA, April, 271–277.

Received June 2002; revised October 2003, December 2003; accepted December 2003
Accepted by Joelle Coutaz