Livenotes: A System for Cooperative and Augmented Note-Taking in Lectures

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ABSTRACT
We describe Livenotes, a shared whiteboard system and educational practice that uses wireless communication and tablet computing to support real-time conversations within small groups of students during lectures, independent of class size. We present an interface design that enables group members to interact with one another by taking lecture notes cooperatively, as well as to augment student note-taking by providing instructor slides in the background to annotate over. Livenotes was designed to facilitate more efficient, stimulating modes of learning that other collaborative approaches do not. We report how the system impacts cooperative learning in an undergraduate class and how students interacted with background slides in the workspace. We conclude with directions for improving the system and learning practice.

Author Keywords
Augmented note-taking, Cooperative note-taking, Collaborative learning, Computer-Supported Collaborative Learning (CSCL), Cooperative Learning, Education, E-Learning, Peer Instruction, Shared whiteboard, Small group learning, Tablet PC

ACM Classification Keywords
H5.3. Group and Organization Interfaces: Collaborative computing; Computer-Supported Cooperative Work; Synchronous Interaction.

INTRODUCTION

Small groups are a key facilitator of learning [4, 6, 11]. Well-structured groups enhance student learning through shared goals, interdependence such that learners need one another in order to succeed, and social support [11, 12]. Dialogue between students in groups may facilitate learning when a learner is presented with ideas that are incompatible with his or her existing ideas [3], or when prompted to break out of cycles of negative thoughts to view events more methodically [23]. As discussed in [17, 18], there is value in students asking questions and giving explanations. Social theories of learning, such as Bakhtin's notion of dialogicality [15], argue that learning is the reconciliation of multiple perspectives, including that of the lecturer, the authors of educational resources like textbooks and class handouts (e.g. lecture slides), the learner himself, and other students in the group [4]. Small groups with shared learning and interest in an organization, named as communities of practice, have been recognized as crucial to the exchange and interpretation of information [22].

Our goal is to stimulate interaction within small teams of students in lectures in universities and schools with minimal institutional or pedagogical change. This paper describes a new cooperative learning practice *and* technology called Livenotes, which was designed to address this goal. The system uses wirelessly-networked, portable Tablet PCs to connect peers in small groups. No matter how large the class is, the size of each group is always kept small.

Livenotes uses a whiteboard interface that has undergone several design iterations in response to deployments and user feedback. This interface has features that allow students to engage in cooperative note-taking and discussion in real-time, augmented by lecture slides in the background, alongside an ongoing lecture. The interface distinguishes Livenotes from other systems for collaborative learning in small groups. The interface enables multiple perspectives on the lecture to be juxtaposed at once, through pen and keyboard input. One important interface feature is that lecture slides can be imported into the whiteboard's background for students to annotate over.

Our hypotheses are twofold:

1. The shared whiteboard interface allows students to interact with one another via cooperative note-taking and discussion, hence facilitating learning, and
2. The background slides feature augments note-taking by providing slides that students can interact with.

In this paper, we summarize the design of Livenotes and its user interface. We report a field experiment that was conducted in an undergraduate human-computer interaction (HCI) class, and analyze how Livenotes supported cooperative and augmented note-taking in this experiment. We conclude with implications for extending the system and learning practice.

MOTIVATION

Interaction in small groups is a common feature of many educational systems. The use of electronically-mediated communication during lecture review was a key element of Tutored Video Instruction (TVI) and Distributed TVI [20], which inspired our work. The Stanford TVI/DTVI experiments used video recordings of regular classroom lectures that small groups of students reviewed and discussed with a tutor. The DTVI experiments described in [21] involved over 1,000 students at many campuses and demonstrated consistent improvements averaging 0.4 standard deviations in traditional grade measures. Similarly, Mazur's peer instruction model [16] involves pausing regular lectures for short intervals of time, so as to allow for group discussion between students, and is now used in many courses in the United States.

These methods have their limitations. TVI uses normal lecture recordings but demands numerous small presentation rooms equipped for video playback. Most campuses do not have enough such rooms to accommodate all the students enrolled in large classes. Both TVI and DTVI require a live tutor in the review sessions, which is often impractical. Due to time limitation, peer instruction is typically confined to one or two short collaborative episodes per lecture.

Mindful of these institutional and resource barriers, we sought an approach to cooperative learning that required minimal changes in instructor practice or classroom design. Our solution is *both* a learning practice *and* technology called Livenotes. Using the Livenotes interface, students can engage in cooperative note-taking, namely, note-taking in which different individuals jointly take notes in real-time as part of a group effort that every group member can see simultaneously. According to Johnson et al. [12], cooperative note-taking can lead to students creating a more accurate, comprehensive account of the lecture and correcting each other's interpretation.

Cooperative note-taking is not the only mechanism that Livenotes uses to enhance learning. Experiments on traditional note-taking [8, 14] have compared note-taking augmented by complete lecture notes from the lecturer that students could annotate, with note-taking accompanied by skeletal (i.e. partial) notes and note-taking that was not accompanied by any lecture notes. These experiments concluded that students achieve maximum retention of lecture material when they can annotate a set of skeletal lecture notes for themselves. Livenotes was therefore designed to allow lecture slides to be imported into the whiteboard's background for students to write on. With lecture slides in the background, students can replicate their habits of annotating and underlining printouts of these slides in the lecture setting.

To date, Livenotes has been deployed in 4 graduate classes and seminars [9, 10, 13]. Graduate students naturally use Livenotes as intended, with a high proportion of collaborative and discussion notes in their transcripts. However, when we first tested Livenotes in a Fall 2001 undergraduate class, we found that our undergraduate volunteers were more comfortable with being "lectured at," and were not unaccustomed to group discussion. This highlighted some of the challenges to the success of Livenotes and cooperative note-taking in undergraduate classes, and prompted the larger-scale investigation that is the focus of this paper.

Classroom Presenter [2] is an alternative Tablet PC note-taking system based on a broadcast model. The instructor can add annotations to his own slides, which are broadcast to all students. Students can also annotate their slides, and provide aggregated feedback on the instructor's slides. But there is no support for small-group student interaction. Another similar system is StuPad [21] in eClass (formerly known as Classroom 2000), which enables students to take *individual* notes on top of background slides using tablets. Notepals [5] is a system for note-taking on Personal Digital Assistants (PDAs), but collaborative review of lecture notes takes place only after the notes have been uploaded onto a "Notepals" website *following* the lecture. A recent system [19] supports live collaboration on PDAs but with a fraction of the affordances of Livenotes.

Among the few commercial systems that support cooperative note-taking, Microsoft's OneNote in its current form is not usable for our educational purposes as it lacks an appropriate integration of slides and notes, group awareness and a peer topology (it is best suited to a single large group). Finally, although Classtalk [1, 7] facilitates group discussion, it does not act as the discussion medium. Instead, students are provided with Classtalk devices to transmit their answers to a central server that aggregates these responses into a histogram display for instructor and the entire class.

DESIGN EVOLUTION

The original Livenotes system was written in Java. Back in 2000, we had chosen to develop the prototype in Java so as not to be restricted to any particular hardware platform. The basic user interface (Fig. 1) is a shared whiteboard structured into multiple pages that are ordered sequentially, based on the metaphor of a paper notebook, so as to provide an intuitive interface that the user can use to record multiple pages of lecture notes by writing or typing.

The interface has undergone three design iterations after each user study [9, 10, 13] as we gained a better understanding of how it could be improved to promote cooperative learning. First, the interface was implemented on the Clio handheld tablets from 2000 to 2002, in the form of a simple whiteboard. The Clios were a remarkable device for their time (1998), but were limited in terms of processing capability (168 MHz RISC CPU) and usability (cramped keyboard, limited screen sensitivity to pen input, and a pressure-sensitive screen that treated accidental hand contact with the screen as pen input).

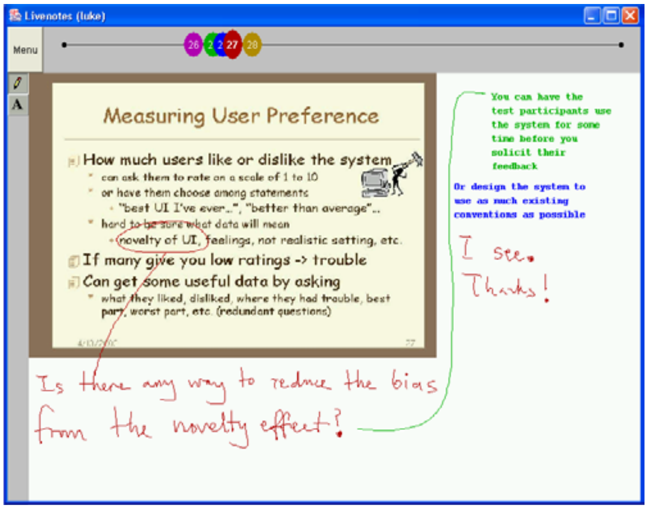

Figure 1. The Livenotes user interface for the experiment described in this paper, with the imported background slide occupying the top left-hand area of the whiteboard.

Second, the interface was overhauled in 2002 to incorporate new group awareness and to enable lecture slides to be imported. This taxed the capacity of the Clios and made it impossible to introduce Livenotes into an undergraduate class on a non-trivial scale without disruption. We therefore migrated Livenotes to laptops and found that it worked effectively with significantly greater computing power. Third, the interface was changed in 2002-2003 to include keyboard support (for laptops), not just pen input. We then migrated Livenotes to Tablet PCs when these finally became available to us in early 2003.

Making use of the paper notebook metaphor for the whiteboard interface implies the idea of the page that the user is currently viewing and allowed to edit. It also implies that we must provide functions for the user to "flip" between pages, which motivated the group awareness widget at the top of the main window. This widget indicates the current page number of each user in the current Livenotes session using an oval icon, which is displayed in the user's selected ink color, along the slider at a position relative to other users. The user moves between pages by dragging his icon along the slider. To allow for flexibility, automatic page turns are not supported and the user is responsible for advancing to the next slide.

A menu of options can be accessed using the "Menu" button at the top right-hand corner of the main window. These options enable the user to import a set of PowerPoint slides into the whiteboard's background, to save the current set of notes, and to set up the Livenotes peer group. More specifically, in any Livenotes group, one student selects the menu option to set his Livenotes to server mode, while other users connect to this machine as clients. This process usually takes under 2 minutes. The tablet running in server mode provides a unique communication "end-point" for each group, allowing other users to join the same group. After users join a group, there is no difference in interface or functionality for members in the same group. Each user can only join one group at a time in the current design.

The whiteboard provides a public view of the local user's current page, such that every user's writing or keyboard input on that page can be seen by other members in the same group. For simplicity, space management was not implemented in the piloted version, that is, users may write on top of another user's notes. To ensure adequate space for note-taking, however, slides imported into the whiteboard's background occupy only two-thirds of the top left-hand whiteboard area.

EXPERIMENT

In the middle of Spring 2003, we received a grant of 40 Toshiba Protégé 3500 Tablet PCs from Microsoft Corporation. Each Tablet PC has a Pentium III 1.3G CPU, 512M RAM, built-in 802.11b wireless adapter and runs Windows XP Tablet PC edition. This quantity of relatively more powerful hardware allowed us to attempt a deployment in an undergraduate class on a significantly larger scale than the above Fall 2001 study, while permitting us to observe the use of background slides at the same time. Due to the difficulty in obtaining instructor consent when the semester is underway, we decided to conduct the study in the Computer Science 160 class in which John Canny and Matthew Kam were the instructor and head TA respectively. This is the upper-division HCI class that meets 3 hours per week in lectures and 1 hour per week in discussion sections. There were 48 students in the class, with 36 majoring in computer science and the remainder majoring in cognitive science. Students worked as a team on a semester-long project of their choice, with the semester's theme being user interfaces for mobile phones and PDAs. Students were also graded on their individual assignments, midterm and final exam.

Livenotes was deployed during the last 4 weeks of the class, spanning a total of 7 lectures. 21 students volunteered for the study. To avoid selection effects and to create a finer comparison, volunteers were randomly partitioned into two subsets in each session: one used Livenotes collaboratively in small groups of 2 to 4 students while the other subset used Livenotes individually.[1] Collaborative note-takers remained in the same groups within each lecture session. But students were randomly chosen as collaborative note-takers and assigned to groups, so groups may change across lectures. This randomized design reduced the influence of individual

[1] We partitioned the volunteers starting from the third session. All volunteers used Livenotes to take notes cooperatively during the first two sessions because we had to train all of them in this new practice -- in previous deployments, we observed that users initially struggled to take notes cooperatively and pay attention to the instructor at the same time.

student ability and familiarity from belonging to the same project team. We also designed the slides for each lecture as a set of skeletal lecture notes, which we loaded onto the Tablet PCs before every lecture.

Based on our former experience with the above small-scale deployment in Fall 2001, we believe that undergraduates need to be trained to use an in-class communication system effectively for question-asking and constructive critique. We coached students to engage in lecture-related group discussion by carrying out Mazur's peer instruction in class, in that we paused each lecture for up to two times to pose questions for students to discuss with their neighbors and/or group members (if using Livenotes). But we did not provide coaching in augmented note-taking because it is fairly widespread even in traditional individual note-taking.

METHODS

Our analysis comprised both qualitative and quantitative methods. To obtain open-ended feedback from users, we conducted qualitative interviews with 3 students after the semester, together with informal interviews with other users during "idle" times, such as while waiting for class to start. We also handed out survey questionnaires during the first week of deployment (~38% response rate), and again at the end of the semester (~29% response rate). Lastly, we pored through the lecture notes that the users took using Livenotes (~1581 pages) and observed the group interactions and critical incidents that took place on the lecture transcripts.

To enhance the above transcript analysis with quantitative measurements, we refined an existing analytical framework that we had previously used in [9]. To summarize, our basic unit of analysis is the "mark," which is a spatio-temporally contiguous segment of pen-strokes or keyboard entries by one user to express a single logical idea. For example, the statement "This lecture is very interesting" written on the whiteboard interface by a student would constitute one mark, and not five separate marks. We next performed a quantitative analysis by hand-coding the marks into categories, and then tabulating and graphing the counts for each category according to student group and lecture. The eventual learning categories that we used were:

- *Note-taking*: someone taking notes on the lecture.
- *Commentary*: someone making a statement, as opposed to recording notes.
- *Question*: someone soliciting a response.
- *Answer*: answer to a question or clarification to some confusion.
- *Reinforcement*: someone's encouragement or response to others' comments.

In addition, even though the survey questionnaires included open-ended questions, they also contained questions whose standardized responses could be numerically aggregated. Finally, even though the sample size was somewhat small, we nonetheless attempted a learning assessment using quiz grades. At the beginning of each lecture, we conducted a short quiz lasting up to 10 minutes which tested every student on his or her recall and comprehension of the previous lecture's material. The grades for the 4 quizzes were not counted in the final grades, however.

RESULTS AND DISCUSSION

Cooperative Note-Taking

Cooperative note-taking is note-taking in which different individuals jointly take notes in real-time as part of a group effort that every member can see simultaneously. They can add new notes while other members are transcribing earlier lecture statements, overcoming finite individual cognitive capacity to remember and reproduce information through shared work. They can also take turns to note things down, allowing others to attend to the lecture more closely. They can seek explanation of the lecture if they are confused or think they have missed something. Cooperative note-taking therefore differs markedly as a practice from individual note-taking.

Since cooperative note-taking during lectures is a novel practice, we observed how students' use and familiarity with the shared whiteboard interface evolved over the experiment. In the first week of deployment, volunteers who responded to our survey rated "running Livenotes during class distracting?" as 2.6 out of 5 (1=extremely distracting, 5=not distracting at all). 25% of the respondents explained that the distraction was due to unfamiliarity with the system and that "the nifty [Tablet PC] notebooks are cool to play with." Another 25% of the respondents explained that the distraction arose from the ability to communicate with other students.

In contrast, in reply to the same question in the post-deployment survey, respondents rated Livenotes to be distracting at 3.83 on the same 5-point scale (1=extremely distracting, 5=not distracting at all). Students had become more adept at coping with both the lecture and on-tablet group interaction simultaneously as the experiment progressed. More importantly, users can quickly (< 4 weeks) become accustomed to cooperative note-taking. Nevertheless, during an interview, one student said that despite becoming comfortable with this novel practice, one drawback is that she could not employ her personal note-taking notations to take notes more speedily, for fear that group members could not decipher them. However, we expect that this usability problem can be overcome with a non-randomized group assignment (e.g. usage of Livenotes in an actual class for non-experimental purposes), in which students have ample opportunities to learn the note-taking habits of their group members.

We found that the Livenotes interface generated significant cooperative note-taking benefits. First, cooperative note-taking led to a more comprehensive coverage of lecture information compared to individual note-taking because students were empowered to assemble lecture notes more efficiently. Surveying the students yielded these comments:

- “Someone else might note something that I missed or hadn’t realized.”
- “I was mixed about this [taking notes collaboratively]. Sometimes, [I] wanted to do it separately and compare notes later. But at the same time, if we did [take notes] together, the others could catch what [I] missed, which was really cool. So I think I like collaborative [note-taking] better.”
- “I liked how note-taking became a cooperative effort… someone can take over if another user is still inputing some notes, but the prof [had] moved on already.”

Quantitatively, over 66% of the students who responded to the post-deployment survey agreed that it is much more useful to take notes collaboratively. One of them, however, qualified that cooperative note-taking is feasible only with group members willing to contribute their share.

There is, however, substantial overhead involved in keeping aware of what other group members are writing when one is *also* taking notes. One user felt: “It is much less distracting working alone because you also have to be aware of whether or not others in the group are writing the exact same notes you are – having repetition is not a bad thing, but if all the members of the group write the same thing they could be missing something else from the lecture that may be important.” Several groups eventually devised a means to balance the need for completeness in their notes with the overhead in maintaining awareness about what other users are writing. Users in those groups took turns to scribe lecture notes, such that only one person is writing on the shared whiteboard at any time while other users look on. An onlooker is expected to “jump in” and scribe a new thread if the lecturer proceeds to another point before the current scribe has finished recording the current point. We call this behavior *synchronized, turn-based note-taking*.

Second, cooperative note-taking generated a far richer variety of whiteboard activity than individual note-taking, implying a powerful effect on small group interaction. As the “individual note-takers” bar in Fig. 2a shows, 92.4% of an average individual note-taker’s whiteboard activity revolved around note-taking, with a little commentary (5.5%) and questions for personal reference (2.3%). In contrast, the “cooperative note-takers” bar in Fig. 2a shows that a significantly greater proportion of whiteboard activity in cooperative note-taking groups took the form of commentary (21.8%), questions posed to elicit responses from group members (11.8%), answers to questions (7.0%), and reinforcements of on-tablet dialogue threads (5.6%). Evidently, cooperative note-takers did take advantage of the shared whiteboard interface to engage with one another, and such interactions extended beyond cooperative note-taking to include discussions on the ongoing lecture topic.

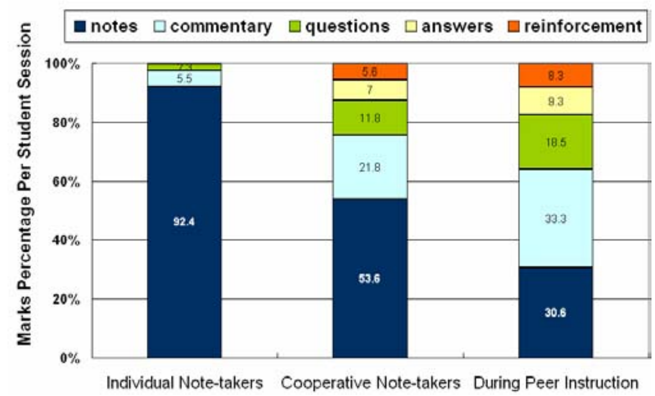

Figure 2a. Relative breakdown of marks, averaged over all sessions and groups.[2]

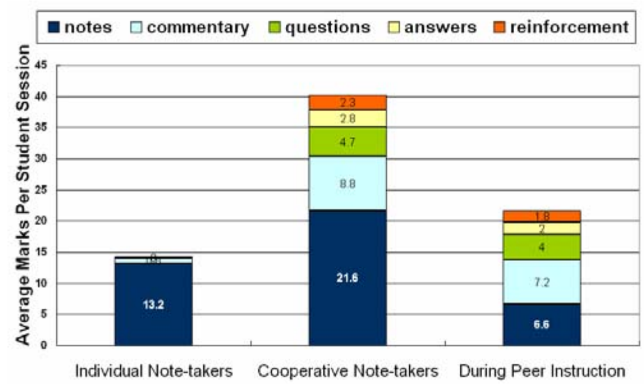

Figure 2b. Absolute breakdown of marks, averaged over all sessions and groups.

In absolute terms, the average cooperative note-taking group took more than twice as much notes as an individual note-taker, as shown in Fig. 2b. More importantly, the former made more questioning (4.7), answering (2.8) and reinforcement (2.3) marks. Nevertheless, even as cooperative note-takers, students indicated that they could not engage in as much group discussion as they would have liked. This was due to the lecture’s relatively fast pace, which compelled users to keep advancing to the next slide to keep up with the instructor. We observed several instances from the shared notes in which a group member asked a question, only to receive such a response from another member: “Lecture going to[o] fast to answer question. Heh.”

The above finding implies that cooperative note-takers are more likely to engage in discussions when the lecture slows down or pauses completely, such as during peer instruction interludes. The “during peer instruction” bar in Fig. 2a, which indicates average proportion of marks within collaborative note-taking groups during peer instruction, shows increased questioning (18.5%), answering (9.3%) and reinforcement (8.3%) behaviors, compared to the lecture at its regular pace (i.e. the “cooperative note-takers” bar in Fig. 2a). In absolute terms, the average quantity of notes taken by

[2] Here, a “group” also includes an individual student taking notes alone.

a collaborative group during peer instruction (i.e. the "during peer instruction" bar in Fig. 2b) comprised a substantial fraction of the notes scribed by such a group during an entire typical lecture (i.e. the "cooperative note-takers" bar in Fig. 2b), especially for marks in the questions (4 out of 4.7), answers (2 out of 2.8) and reinforcement (1.8 out of 2.3) learning categories.

Furthermore, some questions remained unanswered, but it was not due to lack of time for group interaction. Instead, no group members knew the answers. For example, we learned when reviewing the students' notes that some of those questions pertained to background material in the assigned readings. Students admitted in their on-tablet dialogue that they have not read them, while the instructor had assumed the material to be too basic to cover in lecture.

Third, cooperative note-taking groups yielded higher quality notes compared to individual note-taking. Note-taking is not entirely about recording the lecture verbatim. Instead, much note-taking involved a substantial amount of personal reflection and internalization of the lecture material presented. From the notes taken by students during the last lecture, for instance, we observe that on average, such internalizations were reflected on 32% (cooperative note-takers) and 22% (individual note-takers) of the slides where note-taking took place. Students noted the:

- Design implication of a HCI concept;
- Motivation for a HCI concept;
- Context of a HCI technique;
- Design pitfalls to avoid from empirical findings; and
- Advantages and disadvantages of a HCI technique,

Note-takers were also careful, at times, to clarify that their notes restate what the professor said (using direct or indirect quotes or parentheses); students appear to find it important to explicitly distinguish whiteboard content between professor statements and personal thoughts.

In addition to the above feedback, there were also findings about usability issues. First, several students felt that ink editing features such as ink deletion, ink drag-and-drop, etc. were necessary to keep students' notes well organized. Second, as will be elaborated further below, some students felt that the lecturer was too fast, and wanted an anonymous, real-time lecture feedback mechanism to inform him to slow down.

Augmented Note-Taking

Significant augmented note-taking, that is, note-taking in tandem with content already in the background, occurred. The interface enables augmented note-taking by providing lecture slides as part of the background. Students are able to use the lecture slides as a starting point for their note-taking or discussion, rather than simply engaging in note-taking from a blank slate. Very little research exists regarding the ways in which students use and interact with PowerPoint slides in an interface to meet their learning goals. Our experiment is therefore a starting point.

Background slides powerfully structure the whiteboard and have both positive and negative implications on cooperative and individual note-taking. This structure in turn facilitates the user in switching between pages to be "on the same slide" as the instructor. When it comes to providing group members with group awareness about other members and their status, slides enable students to know which page they should all be viewing at any moment, based on the instructor's current slide. In this way, each group member can be on the same page to engage in a truly shared dialogue. On the other hand, several students in collaborative groups did not respond to other members' questions because the person who asked the question had already moved to the next page and was thought not to be interested in the reply. Similarly, slides enable group members to identify laggards in their group. For example, from the notes, we observed a user lagging behind on slide 17, and another group member moving to this page to alert him: "Yo wake up! Go to slide 23. ☺"

We made many observations of how students used the slides, based on an examination of the transcripts. Students engaged in a remarkable range of activities associated with the lecture slides, going far beyond simply repeating bullet points (on the slides) or the lecture content, to "work off" the slides. These activities took place in both collaborative and individual note-taking groups, and included:

- Summarizing the entire slide;
- Posing questions to provocative bullet points;
- Answering questions framed as bullet points;
- Appending items to a list of sub-bullet points;
- Annotating specific bullet points;
- Listing additional ideas, examples, and issues in response to bullet points;
- Raising objections and alternative reasoning;
- Critiquing the choice of images or examples in slides;
- Explaining what abbreviations represent; and
- Complaining that the proposed design steps in a slide do not apply to a problem at hand, and correcting these

Moreover, students clarified bullet points, possibly to make them more comprehensible. Students also added new details to bullet points, especially when these contained examples.

Fig. 3 gives some examples of these "work-offs". The individual note-taker tried to answer the "Well-matched to iterative design. Why?" question in a bullet point using several specific explanations and examples. He concluded that design patterns are inherently iterative. He next annotated the first bullet with comments and opined that it is difficult but rewarding to use design patterns. These marks are much richer than scribing the lecture blindly, and may not have been made without skeletal notes to stimulate the user.

In terms of how slides were designed to foster augmented note-taking, what stood out most was that bullet points framed as questions attracted significant attention. For instance, the question in Fig. 3's slide elicited responses from over 50% of the cooperative and individual note-taking groups. People replied to such questions even when taking notes individually. Our explanation is that these questions seemingly highlighted what students ought to know for the final exam, and students wanted to be sure that they could answer them. On average, each bullet point question received a response from 36% of the cooperative and individual note-taking groups, while each cooperative and individual note-taking group responded to 35% of all bullet point questions. In particular, students were not told that such questions would appear on the exam.

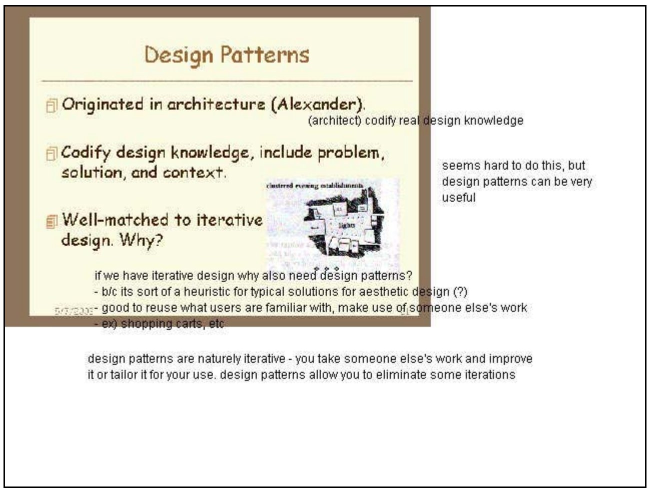

Figure3. An individual note-taker attempted to answer a question posted on the slide.

While users were provided slides to annotate over, slides were useful only to the extent that students have time to read and comprehend their content given the lecture's pace. Still, slides can help facilitate cooperative dialogue by highlighting when students make a mark on the whiteboard. One student answered on the questionnaire: "I always look at other people's comments just because it stands out from the rest of the slide." Another student added that it was the keywords in the bullet points that attracted his attention, suggesting that judicious use of keywords could help draw student attention to relevant parts of the slides.

The introduction of lecture slides into the whiteboard interface created new space management issues [9] by making the screen denser in terms of the information presented. But students resolved this issue by annotating mostly on the slide portion of the whiteboard, while using the non-slide portion for other types of cooperative dialogue. A plausible explanation for this behavior is that annotations, which supplement the skeletal lecture slides, were made near the original bullet points to provide some context to help the scribe and his or her group members attribute meaning to these marks.

To conclude, augmented note-taking can be a powerful indicator of how interface design can change the nature and quantity of cooperative dialogue. In the earlier deployment of Livenotes in the same undergraduate class offered in Fall 2001, lecture slides were not available as part of the interface. Transcripts reveal impoverished, limited responses to the lecture material. Indeed, the students in that class focused on the verbal lecture instead of on the Livenotes dialogue. In contrast, we observe a completely different set of interactions in this class, highlighting the role of augmented note-taking.

Student Learning

On average, cooperative note-takers scored below individual note-takers on all four quizzes that we conducted (Table 1). This result does not necessarily imply that cooperative note-taking is inferior as a learning practice, because differences in quiz scores were not statistically significant under an ANOVA test. More importantly, this result is inconclusive because of the small sample size – a volunteer was included in our quiz dataset only if he was present in a session to use Livenotes *and* be present in the next session to take the quiz for the former session. Unfortunately, we did not anticipate volunteer attendance to be inconsistent between sessions when class attendance began to decline at the end of the semester.

	Quiz 1		Quiz 2		Quiz 3		Quiz 4	
	C[3]	I[4]	C	I	C	I	C	I
Mean Score[5]	63.9	66.0	71.2	75.0	58.5	67.4	53.2	55.7
Std. Dev.	9.2	7.3	12.1	n/a	9.5	11.5	8.6	24.4
Sample size	8	4	9	1	9	4	7	4
P-value	0.702		0.771		0.168		0.810	

Table 1. Scores of cooperative and individual note-takers on all four quizzes

Notwithstanding the above quantitative results, other quantitative and qualitative results from the survey questionnaires suggest that some learning benefits arose from using Livenotes. When asked "how did Livenotes, if at all, assist your learning in lecture?", 75% and 83% of the students who responded to the start-of-deployment and post-deployment surveys respectively gave a positive reply.

36% of the students who responded affirmatively attributed the learning benefit to the social aspect of cooperative note-taking. For instance, one student explained that cooperative note-taking "helped me to focus more in lecture. Often I fall asleep/lose attention in lecture. Having group members to respond to kept me better on track." Students in groups were able to attend much better to the lecture. Another student explained that the cooperative nature of the note-taking reduced the duplication incurred when each person had to take identical notes. Cooperative note-taking was also collegial in that in at least three different groups, we observed

[3] Collaborative note-takers.

[4] Individual note-takers.

[5] Quiz scores presented in this table are normalized on a scale of 100.

one member doing most of the note-taking while other members cheered him on. One of these scribes thought that he understood the lecture, because he wrote a message to his teammates saying, "I am getting an A for the day." Users also expressed sentiments like "good working with you all" at the end of lectures.

On the other hand, as one student put it, the opportunity to engage in group conversations led him to "stop paying attention and start socializing." We believe that the impact of group conversation on learning is far more complex than it appears, and depends on several factors, including the personality of other group members: "I actually preferred individual [note-taking] the first time I did it. The first group I was with didn't concentrate. But with a good group, group [note-taking] was superior." Consistent with our observations from previous user studies, the most serious form of distraction in cooperative note-taking stemmed from the need to keep up with both the lecture and on-tablet conversation at the same time. One student summed it up succinctly: "It is helpful to be able to discuss questions. However, this does take attention away from the lecture if you are focusing on answering/asking a question."

More significantly, a larger proportion (55%) of the students who self-reported learning benefits attributed them to augmented note-taking, compared to cooperative note-taking (36%). Half of the former subgroup indicated that having slides at hand, without having to print them ahead of the lecture, so that they could take notes in a single workspace in conjunction with bullet points in background slides helped learning. One respondent added that the background slide was an artifact that engaged his attention, although he was not clear on how it did so: "being able to write and interact with notes helps someone stay attentive and learn more."

Finally, when reviewing the students' notes, it was usually possible to determine, based on the quality of notes taken, which individual students understood the lectures better. Of course, such an analysis cannot be complete, because some students can take very sparse or no notes since they had already understood the material very well. Nonetheless, the superficial (or even incorrect) notes taken by some students alerted us, as the instructional staff, to possible learning difficulties. Individual student comprehension did not appear to differ markedly between collaborative and individual note-takers.

Incorrect notes were few and were occasionally corrected by other group members. It was not clear, however, if these errors were not rectified more frequently due to the lecture's pace or students' inadequate grasp of the material. But we observed that several high-quality notes in collaborative and individual note-taking groups had resulted from their authors "working off" bullet points on background slides. It appeared that bullets were effective in attracting students' attention, after which students annotated these bullets by paying closer attention to the lecturer's coverage of related topics.

IMPLICATIONS

The above results are encouraging in terms of student learning, and more importantly, show how the design of the Livenotes interface and practice had both positive and negative influence on students' ability to use it effectively as a group learning tool. Since the experiment in this paper was concluded, we have began to implement the next iteration of the Livenotes software prototype and to incorporate some of the lessons learned into this version. For this iteration, we chose to switch from Java to the Microsoft .NET platform in order to take better advantage of the Tablet PC's native capabilities.

The reported experiment yielded some insights on how the user interface and practice for learner-centered tools could be potentially improved to foster small-group student interaction and learning. First, cooperative note-taking and group dialogue appeared to have an inherent limitation, in that questions raised by students could not always be resolved by other students due to the lack of knowledge about the course material or time. Such educational systems need to enable students to bring the instructor into the loop whenever necessary, such as when learning difficulties surface that students cannot resolve on their own. One solution is to enhance the interface to support student-instructor interaction. For instance, the latest iteration of Livenotes allows the user to transmit specific questions directly to the instructor during a lecture.

Second, designers for educational systems should recognize that classes need to progress at an appropriate pace for learners, and more importantly, that such a pace result from negotiation between students and instructor. Interfaces can be designed to facilitate such social processes. For the latest Livenotes, we have extended the interface to enable anonymous, real-time feedback by students about the ongoing lecture, including feedback that the lecture is going too quickly or slowly. Such feedback is transmitted from each student's Tablet and aggregated by a central server that displays the results in the form of a histogram for the instructor in real-time. We believe that this mechanism will enable class time, which is a scarce resource, to be used more efficiently

Third, certain aspects of collaborative note-taking and dialogue are related to social expectations and norms. For instance, some groups seemingly broke down when one or two members were not contributing to the shared note-taking and discussion. Sometimes, members were not paying attention to the class, without understanding how their actions had an adverse impact on other members. These incidents demonstrate that group interaction is very dependent on the norms within electronically-mediated learning communities, and that the effective use of these collaborative tools entails thinking about how to develop and preserve appropriate norms.

Next, even though augmented note-taking could be carried out over paper-based, printed background slides, the above lessons on augmented note-taking offer some directions for research that lie at the intersection of HCI and educational technology. These research could potentially explore how to take advantage of electronic interfaces to make a greater impact on education.

First, augmented note-taking appeared to raise student attention by helping students to focus their attention on appropriate portions of the lecture, such as through the use of keywords, bullet points, etc. Further investigation can be carried out on how to better design background slides in terms of content and presentation to help students look out for important points during the lecture presentation, while not requiring undue attention to refer to the slides.

Second, since students appeared to interact spontaneously with background slides without prompting, one promising way to scaffold higher-order interaction is to insert prompts such as "Motivation?", "Pros", "Cons", etc. appropriately throughout slides, with blank spaces for students to fill in. In this way, instructors could make use of augmented note-taking interfaces to develop more effective note-taking habits among students.

Third, the most interesting direction arises from the same observation that students answered questions found on slides, without prompting, whether they are individual or collaborative note-takers. This suggests that slides can be enhanced to support more sophisticated user interfaces. For example, electronic forms can be hosted on background slides, such that questions can be posed and student responses aggregated electronically. This is a *lightweight* means of conducting peer instruction, and while not all questions are appropriate to be asked in this manner, it holds the promise that valuable questions can nonetheless be asked without having to pause the lecture completely. As another example, survey questions can be included every few slides that ask students to rate their understanding of the last topic covered in lecture, so as to provide the instructor with real-time feedback about how well the lecture was understood.

CONCLUSIONS AND FUTURE WORK

Livenotes was designed with an interface to facilitate cooperative and augmented note-taking during lectures. Participatory design using student feedback has played a critical role in the evolution of the system and interface. For example, the group awareness feature was added in 2002 as a result of student experiences with the old Clio interface. We will continue to use student experiences to develop the Livenotes interface further.

From the experiment reported in this paper, we found that when compared to individual note-taking, cooperative note-taking enabled students to collectively compose a more comprehensive set of lecture notes, as well as engage in a greater degree of group dialogue. In addition, the resulting set of notes reflected a higher degree of internalization of the lecture presentation.

Next, augmented note-taking appeared to prompt users into making notes that "work off" skeletal notes provided by the instructor. Examples included the user reacting rhetorically to provocative statements in bullet points, answering questions in bullet points (even for individual note-takers), and appending items to sub-bullet points conceptually organized as lists. Augmented note-taking is a new area for HCI research, and this study has shown that student interactions with lecture slides alone are much broader and richer than simply regurgitating lecture points.

Such reactions from students to background slides suggest that augmented note-taking is likely to aid cooperative learning greatly. Artifacts present in the electronic workspace, such as slides, can provide learning objects that invite students to interact with them. Slides are also a more lightweight means of carrying out peer instruction since there is no need to pause the lecture. We intend to explore how question-styled bullet points can further engage students with the lecture. We also plan to investigate how other types of artifacts can be inserted into the whiteboard to facilitate augmented note-taking. These could include webpage links; interactive tools; calculators; and demonstrations using Java applets.

Similarly, since background slides appeared to introduce discontinuities into the electronic workspace by partitioning it according to lecture topics, we plan to look into ways of overcoming this limitation. A potential approach is to provide an Instant Messaging feature that maintains conversational history across slides. This feature also may enrich cooperative learning by being more intuitive, and by providing new social superstructure to regulate note-taking practices alongside lecture note-taking.

On the analytical end, we plan to develop a framework to quantitatively evaluate how students use and engage with lecture slides as artifacts in the workspace. Doing so will enable us to more effectively evaluate the practice of augmented note-taking in lecture classrooms.

As a student commented in the survey, not all classes are suited to PowerPoint slides. We plan soon to evaluate Livenotes in classes in other subjects than computer science. We also plan larger scale deployments to overcome the small sample effect encountered in statistical analysis.

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