Learning Via Distributed Dialogue: Livenotes and Handheld Wireless Technology

Alastair Iles, Daniel Glaser, Matthew Kam, John Canny*

(iles@nature + dcg@cs + mattkam@cs + jfc@cs).berkeley.edu

University of California at Berkeley

ABSTRACT

This paper introduces a new learning technology for in-classroom and remote learning. The system and practice is called "Livenotes" and is motivated by the empirical success of peer learning methods, and by theoretical considerations of distributed dialogue among student peers as a facilitator of learning. The technical part of Livenotes is a collaborative whiteboard running on wireless handheld computers. We describe the system and the affordances we have developed for it to support the distributed dialogue model. We then examine the interactive dialogue that resulted from two classroom trials, using transcript captures, and analyze how users developed ways to navigate between pages, organize space on screens, determine whether the system was operational, and create social rapport. Finally, we suggest several issues that researchers can consider in designing collaborative software.

keywords

Livenotes, peer learning, distributed dialogue, shared whiteboard, collaborative note-taking, wireless handheld.

INTRODUCTION

Peer discussion is one of the most potent facilitators of classroom learning. Several previous studies of collaborative learning via computer support – such as the Distributed TVI experiments at Stanford (Dutra et. al. 1999) – suggest that fostering peer dialogue through technological aids can lead to better outcomes than traditional in-class instruction. They also show that – as in a synchronous newspaper editing system (Tanikawa et. al. 1999) – groups of students can work together to solve problems more effectively through peer dialogue with ample feedback and interactions than with a single central authority directing the process. They imply that seemingly non-sequitur conversation during less structured peer dialogue can actually lead to greater attention and thought by students. In addition, there is extensive evidence that learning is facilitated in small groups (e.g. Resnick et. al 1991; Slavin 1990).

These facts motivate further exploration of distributed dialogue during in-class learning. Livenotes is such an exploration. Developed by Matthew Kam at the Department of Computer Science at the University of California at Berkeley, Livenotes uses wireless communication and handwriting to allow a real-time conversation within a small group of students during a normal lecture, independent of the number of students in the physical classroom. We have tested this software in two graduate classes – one a lecture and the other a seminar – which we report on here. The program was originally designed for small groups of students to carry on a live discussion during the course of a lecture or presentation to supplement what they were learning directly from the instructor. Later, after user testing, we noticed that the technology would be appropriate for other kinds of discussion settings. Along with our pre-designed practice, we observed the emergence of a rich new practice among the users of Livenotes as they developed ways to communicate and coordinate their note-taking.

Following an introduction to Livenotes, this paper looks at how learning depends on the development of "rules" for communication in the Livenotes medium. It also investigates how groups of both designers and users chose to adapt and think about, dialogue-supporting technology in distributed ways. As such, we define distributed dialogue as a non-localized, yet collaborative activity. Such distributed dialogue may reveal unexpected, non-text-based patterns (e.g., highlighting points or deciding where to put input on a screen) in communication between people that verbal dialogue in the context of a classroom situation may obscure. Enabling these patterns to emerge in a classroom context can ease constructive dialogue in which students can engage in different threads of conversation and help teach each other through clarifying or adding to the teacher-led discussion. In this paper we reinforce the argument that: "Learning occurs as the co-construction (or reconstruction) of social meanings from within the parameters of emergent, socially negotiated, and discursive activity" (Hicks 1996, p. 136).

Our approach of writing on multiple graphic screens linked by wireless technology is similar to other approaches looking at distributed learning environments such as chat rooms or bulletin boards since it allows for free-from discussion. It extends longstanding educational arguments that students learn best by actively engaging each other in conversation, and recognizes

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* Alastair Iles is a deaf postdoctoral fellow at the Energy and Resources Group. Daniel Glaser is an doctoral candidate in Information Design. Matthew Kam obtained his B.S and B.A. degrees from Berkeley in Spring 2001 and has enrolled in Berkeley's M.S. in Computer Science this Fall 2001. John Canny is Professor in the Department of Computer Science.

that each student has his or her own resources to contribute but may not have the opportunity to do so (e.g. as argued through Scardamaliea and Bereiter 1991). Wireless supported dialogue differs greatly from existing approaches because it not only involves people speaking by handwriting with each other in real time within a physical group situation, but also can support uncontrolled small group conversation in parallel with a broader level of controlled discussion (such as a lecture). Moreover, the wireless technology does not fully define what may be communicated and how, but allows users to develop potentially widely diverging styles of communication by themselves. In contrast, chat rooms and other similar media are heavily based on typed text, and operate via relatively centralized and fixed communication systems.

The initial results of testing Livenotes in the two graduate classes help illuminate some of its possibilities and problems in supporting distributed dialogue. We conclude that certain simple features are fundamental to creating an infrastructure where users can develop rules for negotiation and collaboration through free form, relatively unstructured dialogue. These features, however, are related to each particular context of use and may not be the same across different groups of users. We also analyze several key "socio-technical" features of the ways in which the technology was introduced and operated, with a view to assessing its benefits in small group collaboration and improving Livenotes later in 2001.

WHAT IS LIVENOTES?

Livenotes is a research software prototype and practice for collaborative note taking. It is a Java program that runs on Clio handheld tablets connected over a wireless TCP/IP network. The tablets and software are designed to be unconstraining and low-profile in their use. They can be used in many classroom settings without the necessity for direct access to computers (Figure 1a). Students can record handwritten notes on graphic screens that appear in real time on the Clios of their group members who are also running the software. Students, then, can exchange annotations and comments in the midst of the presentation. We chose Clio tablets because they were inexpensive, sufficiently small, light and portable to be used in a classroom setting, and their Windows CE 2.11 operating system could support a Java Virtual Machine. Livenotes was implemented in Java since it supported many Application Programming Interfaces (APIs) essential to the needs of this software such as multithreading, networking, and the Abstract Windowing Toolkit. In addition, Java programs, unlike their native code counterparts, are sufficiently hardware independent to run on most platforms. This is important for future flexibility in choice of hardware. Finally, the tablets that we currently chose can run on battery power for up to eight hours, thus facilitating prolonged note-taking.

Several important design choices were made to guide the anticipated collaborative learning. The program consists of a large shared whiteboard canvas, navigation bar, and a menu with a variety of options (Figure 1b). The canvas permits users to draw directly onto the canvas, using the stylus, with differently colored inkstrokes to identify each user. The inkstrokes are updated across all Clios belonging to the session via the wireless network connections. The navigation bar uses a "page" metaphor to signify that the main drawing area is only one of many numbered, sequential canvases. This navigation structure was chosen since we felt that users may get lost with a single scrollable page and it is a common strategy for electronic whiteboards. The menu bar is used to connect machines, save and load sessions, choose colors, and also to bring up a "presence indicator" window. This window helps users identify who else is online and what page they are currently looking at. A transcript of the note-taking can be saved for future reference, and can be exported to HTML. If desired, the transcript can be "played back" by being loaded onto the handhelds, though this is currently time consuming for client tablets due to network and hardware limitations of the Clio tablets. Various design options can be added to Livenotes as users desire: connection to a TV screen for broadcast to a room, private screens for separate conversation threads, and HTML export to websites or email for use by participants as notes. Further features may be added from time to time in response to user feedback.

A collaborative session is started by delegating a server role to a particular Clio or lap-top and connecting (multiple) clients to it, thus forming a star topological network. A computer can act both as a client and a server. Data compression has been an active area of research for allowing for responsive updating among the Clios on the wireless network. Tradeoffs between a highly reduced data format, low-cost compression schemes for the microprocessor, and data integrity of the inkstrokes has led us to a 50% savings in data format. In addition, thread timing and coordination is also being explored to find a more balanced updating scheme that will not overload individual machines and the network. For one user study, the wireless bridge between the Clio handhelds was already part of the computer science building while for another we brought in a small bridge for each session.

One precedent of a collaborative system using a shared graphical space is Belvedere (Suthers et. al 1997). Like Livenotes it allows for simultaneous access to a graphical space where users are able to create arguments. It differs from Livenotes though, since participants use a toolbar to create data, hypotheses, or unspecified textual input, which can be placed at a location on the whiteboard that they determine. Aside from keyboarding text, users can also create arrows between text boxes to agree, disagree, or join statements. There also is a window for bringing up hints—either through direct interaction with the instructor, or with an intelligent system.

Other precedents include the Distributed TVI (DTVI) experiments at Stanford University. These included probably the most comprehensive evaluations of a learning technology to date, but this is under the framework of students learning and being evaluated in a traditional lecture mode. DTVI allows small groups of students and a tutor to remotely collaborate through multiple video and audio channels to learn from a videotaped lecture (Dutra et. al. 1999). Although users are free to interact through audio and voice channels, there is no notion of collaborative drawing since the viewports are separated from each other. In DTVI, students regularly discuss the material, and half the students participate in roughly half of the discussions, so there is a high degree of participation. Outcomes correlate with the amount of interaction in the group. But surprisingly, there is no significant correlation with the relevance of the dialogue to the course material. Even apparently non-sequitur conversations among students enhance their learning. A second powerful peer learning technique is peer instruction (Mazur 1995). Peer instruction employs short episodes of dialogue in groups of students in a normal lecture classroom in response to questions from the instructor. Like DTVI, peer instruction has shown improvements in outcomes across many course topics.

DTVI and peer instruction have one feature in common: regular dialogue between a small group of students (less than seven) while the students are first encountering new material. In both cases, there is a practice to "steer" the dialogue toward the course material. In DTVI, a teaching assistant prompts students about the material, answers, and questions. In

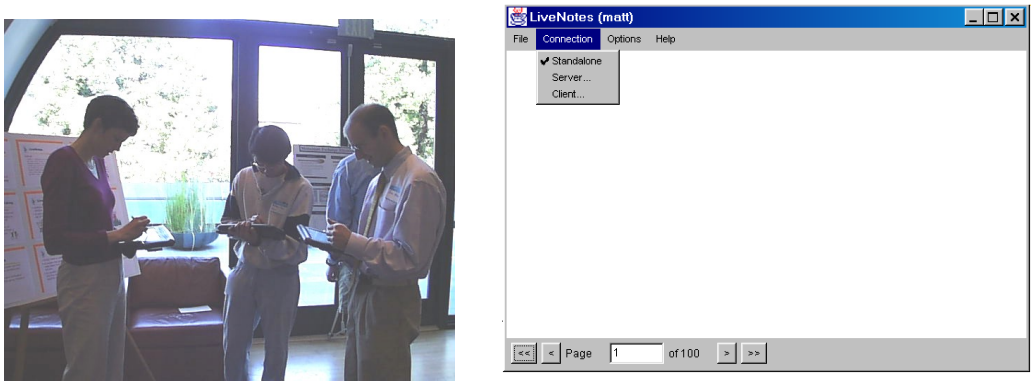

Figure 1. a) (left) A Livenotes session—three users communicating as a small group. b) (right) What a screen capture of Livenotes looks like.

peer instruction, the instructor poses specific questions that the students must address during pauses in the lecture. Livenotes differs from these precedents because it is designed to run concurrently with a larger classroom conversation and tries to move the distributed dialogue to a number of tablets simultaneously without any central screen or authority (except a server to support the interplay). Consequently, differences in user personality and user familiarity with 'rules' of communication may affect how Livenotes is used in practice. Livenotes does not provide prefixed rules of communication so users are likely to make up these rules in the course of learning to use the technology.

USER ANALYSIS

BACKGROUND

Livenotes was first deployed in a graduate seminar in Human Centered Computing (HCC) in Berkeley's College of Engineering and then in an advanced seminar in Science and Technology Studies (STS) through the Energy and Resources Group. In both cases the technology was brought in after classes began (12th week in the HCC course, 5th week in the STS seminar) and hence played a supplementary role in structuring classroom activity. The analysis for the HCC course is based upon in-classroom observations of participant interactions by three of the paper's authors* and transcript analysis. The STS course analysis was also through observations of two of the paper's authors, in class discussion of the technology, unsolicited e-mail dialogue with classmates, transcript analyses, and questionnaires.

Starting in September 2000, the focus of the HCC course was to expand the theoretical foundations for research on computers and people through social systems that are broader than what is typically offered by a graduate computer science course on human-computer interaction. The HCC class was organized such that a student would first present and summarize the reading for that session, before the instructor further developed the topic and posed questions. Then small groups of about 4 students each would be formed to work out their responses and share them with the rest of the class. There were approximately 12 students in the class and most were affiliated with the College of Engineering.

* This is an acceptable data collection for educational researchers (e.g. Ball 1993)

During the 12th week of class, Livenotes was introduced into the class. The intention was to provide a parallel communication channel for students to concurrently discuss and clarify points during the student presentation and instructor lecture while it was happening. For that session 10 students were present and each of them was provided with a Clio tablet with the Livenotes software installed. The class separated into two user groups (and client-server networks), and used the Clio tablets extensively during both the student and professor's presentations. This was not surprising since all the participants were highly familiar with computer technology and there was an expectation that Livenotes would be used at some point. As the next section illustrates, even though the lecture was instructor-led, the students used the tablets selectively to discuss the material in a distributed fashion. During face-to-face group discussion, the Livenotes software lost the attention of students since they could not keep up with this fast paced environment. Livenotes lost the students' attention because they preferred to communicate verbally, and could not easily focus on the parallel distributed dialogue. During group summaries, one team leader used the tablet to read off his ideas to the instructor. The tablets were only used for one class, and a total of 13 pages were recorded for our analysis.

The STS seminar in Spring 2001 brought participants from a diverse set of disciplines together to discuss science as social and cultural practices. This was a high-level research seminar of 10-12 participants who engaged in extensive face-to-face interaction throughout. Participants came from a variety of disciplinary backgrounds (energy and environmental policy, medical sociology, political science, and education) and had different levels of familiarity with the subjects discussed. In each seminar session, participants took turns to present 3-4 readings each week, with another class member providing commentary, before opening the meeting up to discussion of several research questions posed by the leader. The aim was to generate input into each participant's dissertation or research project. One aspect of the seminar was taking notes for a deaf post-doctoral fellow who relied on peer note-taking to follow class discussion. Prior to the introduction of Livenotes, this note-taking took the form of recording by pen and paper, with the responsibility of being the scribe rotating between individual participants each week.

In the 5th week, Livenotes was introduced. The tablets were used for three classes, which generated 26, 34, and 28 pages of transcripts respectively that we could analyze. In contrast to the HCC class, many participants were unfamiliar with wireless computer technology. Additionally, not every seminar participant used Livenotes; some participants observed how their peers were using Livenotes but did not attempt to use Livenotes themselves. In the first class, three Clios were used, with two people taking notes for the deaf participant. In the second class, different people performed this note-taking role, but also engaged in distributed discussion. In the third class, the deaf participant was the session presenter and sought to make Livenotes a central part of the discussion. Five people participated actively, with four others observing passively for most of the time. We noticed that some people also joined the network by looking over a user's shoulder.

THE PROCESS OF INTRODUCING LIVENOTES

In both cases, the decision to introduce Livenotes into the class was top-down, made by the professor in cooperation with one or two students interested in the technology. There was little discussion of whether participants wished to try Livenotes out, or of what Livenotes might contribute to their classroom experiences. This may have affected the responses of the participants, in that some people—particularly in the STS seminar—expressed concern about the lack of discussion regarding the deployment of Livenotes. For them, the tablets simply appeared mysteriously in a meeting, without explanation as to why they were being used. In fact, one of the professors was worried that the way in which Livenotes was introduced may have influenced the seminar's social dynamics adversely.

KEY USAGE ISSUES

We observed many interesting phenomena during the trials, but choose to discuss three examples that bear particularly on future design considerations of Livenotes that may better support collaborative learning. We will refer to both trials because similar issues were raised by both seminar and lecture formats, and as such, may be relevant to any usage of Livenotes in general.

CONNECTING UP AND GETTING ON THE SAME PAGE

When starting Livenotes for the first time in a session, participants did not know whether Livenotes was operational. They did not know who were participating. The whiteboard canvas by itself could not indicate whether the network was working or if everyone was receiving and sending any handwritten messages. Additionally, throughout a session, people were repeatedly uncertain, on moving to a new page, whether others had also advanced to the page, or were still looking at earlier pages. It was possible for participants to open the "presence indicator" window to check if the individual Clio was connected to the server, who else were on-line, as well as the pages that these individuals were currently looking at. However, it was difficult for participants not already aware of this option to make use of this window.

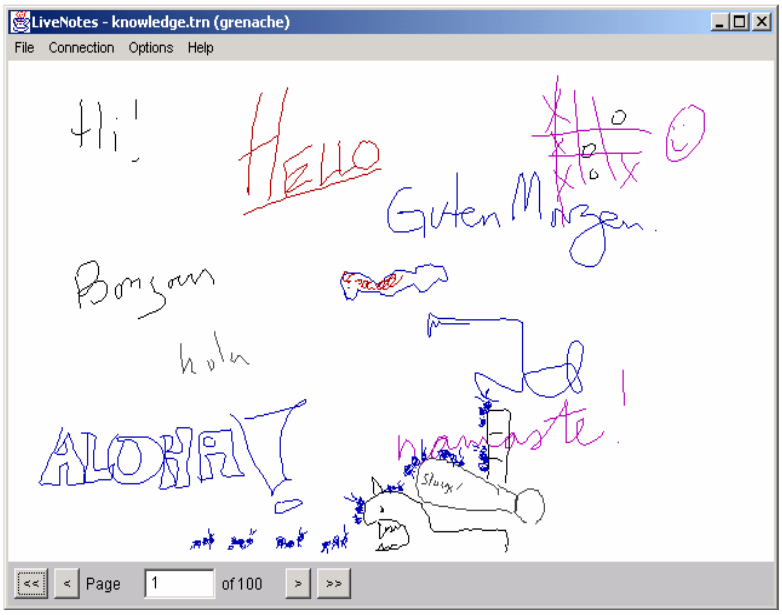

Figure 2. Greetings dominated the first page of each session.

In both the lecture and seminar meetings, it was observed that many participants wrote brief messages to determine whether or not the wireless connection was transmitting these messages to the rest of the user group. Such opening messages included: "Can you receive?", "Hi", "Is this working?", or "Namaste". Sometimes, especially in the seminar, certain individuals would make little drawings to see if others could, or would, declare their presence by adding to the images. When moving between pages, individual users might write: "Is this page current?" or "Can anyone read this!?" The important observation is that users were able to create rules to decide whether or not the network was operational, based on their communication, rather than on the technology per se. Figure 2 illustrates the first page of one such session.

NAVIGATION AND SPACE MANAGEMENT

Two of the most pressing communication challenges that Livenotes poses are the distributed decision-making involved in navigating between and within pages, as well as in dividing up a page so that more than one user can participate. We found that although many different conversations and topics were jumbled together on the one page, users were nonetheless mostly able to coordinate how they would share their space and to work out ways to distinguish between the various conversation threads to a reasonable extent. Two observations were especially important.

First, people sitting far apart in the classroom often did not know whether or when they should move to a new page. However, they tested various symbols to either signal the need to change pages, or to ask if other people had changed pages. For example, in the 2nd seminar session, people used "Now we go to a new page", "page 4→", "p5?", "→", or "I got it!" in one corner of the page to communicate in this way. One user drew little arrows at the base of the page as if it was a continuous scrolling page.

Second, people did not always know whether or not others were paying attention to their input, or whether what they wrote was visible in the jumble of writing to the others. They could not rely on the kinds of cues that verbal, face-to-face communication can often provide. The conversation threads might not be easy to connect together. This differs from trying to find out if participants are all "on the same page", in that specific people may be concerned that their contribution is not being read or evaluated by the group. The social context matters greatly for how users resolve this issue.

We observed that a seminar session that was primarily note-taking by one or two people was fairly simple: the users would

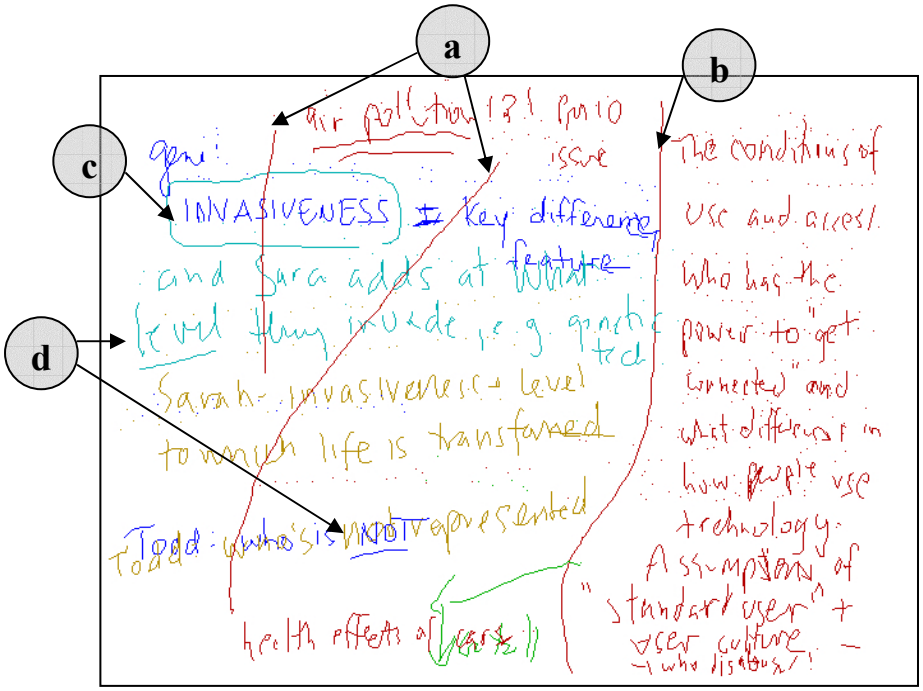

Figure 3. A screen capture showing a variety of elements including (a) linking together disjoint spaces of conversation (b) marking territory (c) highlighting someone else's points (d) highlighting one's own points for attention.

write in temporal sequence down the page in "sentences", with the inkstroke colors distinguishing between scribes. It was easy to follow the conversation thread, because there was just one, sometimes with little annotations by the deaf participant at the side. But when the sessions turned into a distributed discussion involving up to five people, space management changed markedly and new rules began to emerge. People would write phrases all over the page. They often highlighted specific parts of the page by drawing boxes or circles around their input (Figure 3a). In doing so, they tried to mark off territory for their input (Figure 3b). Quite commonly, participants underlined phrases to emphasize points (Figure 3c). Occasionally, a user would simply draw lines under two different contributions. Moreover, people often drew arrows or lines across the page to connect up widely scattered phrases to continue the thread and to pick up what they were saying because someone else was writing in the space (Figure 3d). Or they might put in a series of numbers next to phrases. These non-textual inputs help make Livenotes quite different from most other technologies for collaborative learning.

DISCUSSION, PLAY AND DRAWING

The kinds of communication that Livenotes enables can be multi-layered and reflect mutual teaching and clarification of points. We observed that users in the seminar would sometimes engage in overlapping dialogue: taking summary notes of the presentation (Figure 4a), commenting on issues raised by the presentation and perhaps "training" people less familiar with the topic (Figure 4b), engaging in "side" conversation unrelated to the topic (Figure 4c), or making humorous contributions (Figure 4d). However, it could be difficult for participants to determine whether or not a given input was related to the topic. Sometimes, users would identify a speaker by name to suggest that the reference was part of the group discussion. Nevertheless, even when a point followed the larger class discussion, there was a risk that it would not be resolved within the same time period and depth as the larger discussion. For example a user asked to clarify a small lecture point "can somebody give me an example of some 'organizational knowledge' that differs from individual knowledge?", while no less than seven responses over three full pages were provided. At the end of this heated exchange while turning back to the relatively laconic lecture a user unsurprisingly asked "so is anyone else having trouble listening & writing?".

Simultaneously, Livenotes can also provide a space for drawings and playfulness that do not necessarily follow the lecture or presentation, but that allow users to add a social dimension to their writing. People sometimes drew images on the page

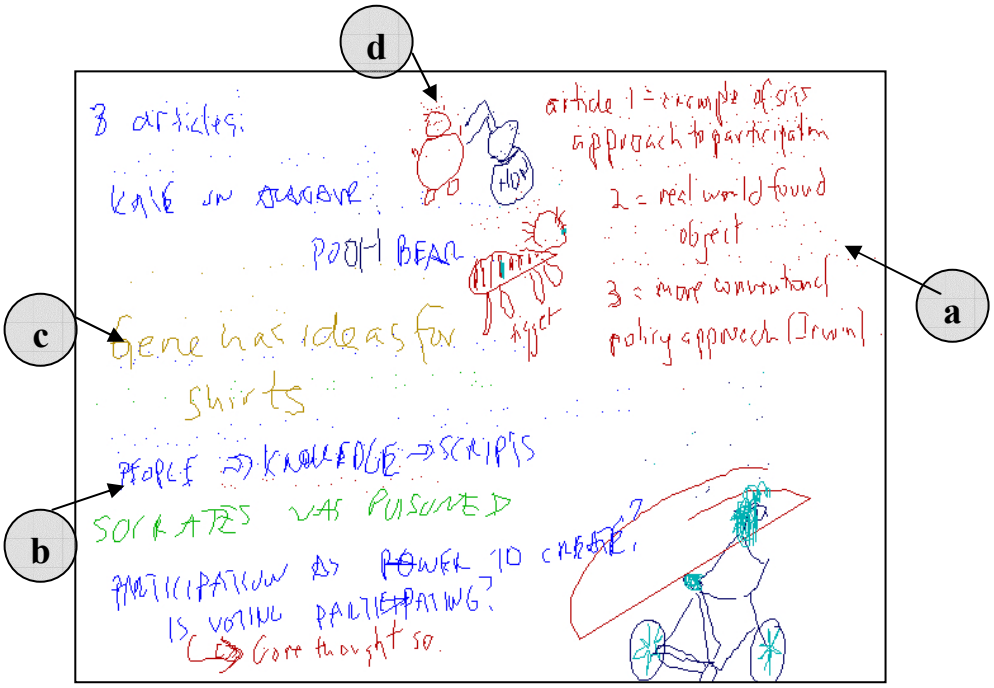

Figure 4. Transcript showing (a) summing up the lecture, (b) expanding on or developing lecture themes (c) an unrelated topic and (d) humorous interludes and drawings

alongside the textual discussion. These images could be humorous interludes or surprisingly novel attempts at clarification of discussion points. For example, an instructor in the STS seminar drew an egg representing a technical norm, while another less familiar with the literature in contempt of the idea drew Sigourney Weaver attacking the egg (as an alien), and the first participant responded, "the larva is in you" referring back to the topic of embodied knowledge. Similarly, Figure 4 shows drawings associated with Pooh the Bear (Figure 4d) while Figure 2 shows how participants in the HCC class drew ants creeping across the page and being devoured by a monster.

Strikingly, these drawings did not appear in the session where only one or two members were taking notes for the deaf participant. Usually, the humorous episodes were at the start or end of a session, so people may have been implicitly using these drawings as a means of getting accustomed to the wireless technology and to creating a rapport without necessarily talking verbally to each other. This illustrates how some participants may use drawings or play as a way to facilitate social interaction and to attract the attention of each other. Livenotes has the capacity to support this kind of activity because of its graphics-based interface, which permits free-form and informal expressions, whereas text-based interfaces are unlikely to permit it. However, we observed that some participants seemed to see such drawing and playfulness as detracting from the session's verbal dialogue, without considering how jokes may form part of this conversation.

In all these cases, participants actively created (or negotiated) solutions in the form of "rules", symbols, and governance of exchanges to be distributed across the participants. These solutions were based on communication and social norm-making that substituted for technical features not already built into Livenotes or the Clios. Interestingly, the behavior observed was

often similar to the conventions generated by the deaf participant in his written conversations, in that he used arrows, underlining, circling, and other space management features.

QUANTITATIVE ANALYSIS

We performed an initial quantitative analysis of the third STS session transcript to start developing indicators of learning and user activity for our future research. First, we developed units of analysis based on our observations of user behavior, as described above. We counted the number of stylus marks that each user made on each canvas page, relying on pen colors. Next, we distributed these marks into two categories: management (how users control dialogue on the canvas) and content (what users say in relation to the classroom presentation). We then allocated the marks to the specific sub-categories that we created in analyzing the examples above, distinguishing between marks according to our judgment of how they fit into the overall dialogue. Our major conclusions were that:

- Management marks were almost as many as content marks (46.82% compared to 53.18%), suggesting that users not only discussed the lecture but also worked to manage their dialogue;
- The vast majority of content marks (83%) related directly to the lecture in some way, with only 12% of marks being on unrelated topics and humorous interludes, implying that Livenotes did facilitate in-group discussion, and that perceptions of Livenotes as dominated by play were ungrounded;
- One person (the presenter of the session: 45%) was expertly managing the dialogue – through linking points and marking territory – with the assistance of two other persons (who acted as notetakers for the presenters: 20% and 12% respectively), suggesting that Livenotes dialogue can be structured, and also that some users control whiteboard space more than others;
- In contrast, the same three users were more even in the number of their highlighting marks (31%, 28% and 28% respectively), yet produced far more such marks than other users, suggesting that highlighting is not only used more by some users but also differs from marking territory as a way to make dialogue clearer to other users;
- Two people out of six users produced almost all the drawing errors (74%), implying that they differed markedly in their ease with the technology from the others; and
- The vast majority of humorous interludes and drawings came in the first four pages of the transcript and one person accounted for 41%, suggesting that these not only are dependent on personality factors but also on the context (whether dialogue is starting, or is underway).

Breakdowns in use

We noticed several types of breakdowns in the usage of Livenotes — from the most basic technical failure of hardwire and wireless signals, to more socially contingent examples like users disengaging from the technology when they become overwhelmed in keeping up with the verbal and distributed whiteboard forms of discourse during classes. These breakdowns and, in some cases, recovery methods include:

- *Temporary technical disruptions:* Users experienced a number of interruptions including slow whiteboard responses to stylus inputs and server lag. Although it is often slower to write on the wireless tablets than with paper and pencil, some users took advantage of parallel note-taking—namely two or more people could write at once to track fast moving conversation. They could fill in information gaps side by side.
- *Multiple tasks and finite concentration:* People had various degrees of trouble following the discussion in the Livenotes user group Livenotes and the instructor-led discussion in the classroom. For some people, one means of coping with this was to abandon Livenotes altogether. Other users, however, appeared to be comfortable with switching between Livenotes and verbal conversations.
- *Frustration at the play witnessed:* Non-participants sometimes complained that the occasional smiles or laughter by the Livenotes users were at their expense. The sense of parallel conversations, which were often perceived as being unrelated to the session's topic, contributed to the tension between users and non-users of Livenotes. Non-users who had many users in their field of view but could not see the contents of the tablets were more critical than non-users who could share or look over a shoulder of a user to see the proceedings of the conversation within a Livenotes group.

These breakdowns further imply that the ability of the participants to engage in negotiations of the rules and symbols to facilitate the use of Livenotes is crucial in helping make the technology workable. This ability is affected by several variables that we plan to investigate in future trials and which we were not able to resolve through the few, yet varied, STS survey respondents. For example, one person described the stylus as being "completely too slow… uncomfortable" while another "liked it". A respondent wrote: "It was too hard to try to write coherently … I was always mentally very behind the discussion" while another "didn't think it was a problem [coordinating both conversations]". Nevertheless, there was some agreement where they did not like the idea of private notes since it would splinter the group even more.

DISCUSSION AND CONCLUSIONS

We conclude that, through Livenotes and handheld wireless screens, students can learn from each other during the course of a lecture or seminar in distributed and "horizontal" ways otherwise not possible. They can actively engage in discussion and commentary on lectures or presentations as these occur, thus enhancing their comprehension and ability to participate. Livenotes differs markedly from existing approaches to distributed learning that rely on typed text and relatively fixed technical and communication modalities. It is interactive dialogue that is distributed across a number of people, can take place in real time, can have many threads that can appear or vanish within a session, and can readily change in response to user participation. Wireless-supported dialogue allows much greater control over content and communication features to be given to users, instead of being imposed and moderated from the top-down.

This dialogue – as seen in Figure 4 for example – is often multi-layered, with people taking notes of the session, more experienced members explaining ideas to other, less knowledgeable people, and members engaging in what may seem to be peripheral conversation that nevertheless helps illuminate session topics. Even if students make erroneous statements of knowledge, they can be immediately corrected by other users or by teachers who may be involved, and their dialogue can be posted in various forms (email, web, or print) for further distributed comment and scrutiny. The inherent flexibility and whiteboard nature of Livenotes enables such free form, mutually correcting dialogue. In contrast, the enhanced, but text-based, DVTI system appears to be primarily based on lecture summaries instead of interactive dialogue (according to published transcripts available from www.sun.com/research.ics.notes.html). It is easier to maintain control over content through centralized and text-based systems, but this may inhibit the emergence of dialogue in small groups such as those that we observed.

In turn, we conclude that users can generate significant non-technical modifications to systems through engaging in the communication and social interaction enabled by Livenotes. We have found the effectiveness of the technology is highly contingent on the social context that it is being used in. In particular, users appear to generate social "rules", symbols, and conventions (often expressed in graphical or text-graphical forms) that fill in for missing or inaccessible technical features, and that enable communication to take place effectively. Livenotes allows this process of generation to occur because it is not "finished", depends on free form whiteboards, and has great flexibility built in. We have also realized that the ways in which deaf people engage in written conversations can provide valuable insight into how Livenotes might work in settings where hearing users write on handheld whiteboards and as a media for comparative purposes with the current development of Livenotes.

Designers of learning support systems, then, can gain much fruitful insight from studying how users work with technology. Drawing on the insights of the two trials to date, we recommend that, to make further advances in developing collaborative learning systems, designers consider the following:

- Systems need to be designed with flexibility and "unfinished" (comparatively unspecified) features to allow users to develop modifications through their communication activities. This facilitates negotiations between users in each particular context or use setting.
- Because some users became frustrated with the tablets since they demanded too much attention, different features should be added so that the user can participate at different levels of engagement. For example, their collaborative whiteboard could simply be tied to a group leader so that they do not need to worry about keeping up with navigation.
- Systems need to be designed to take account of how users may rely on communication and negotiation to deal with issues such as navigation between pages, space management on pages with multiple conversation threads and jumbled writing, and working out if users are "on the same page".

Finally, we are developing evaluation metrics for both adaptation and learning benefits of using Livenotes. This will include a typology of users, development of a protocol analysis to capture the multi-modal interactions with this media, and assessments on the utility of Livenotes in learning. Some of these indicators can be seen in our initial quantitative analysis. From our first trials, we identified familiarity with computer technology, preferences for typing versus handwriting, and the personality and multi-task capabilities as relevant user dimensions. Although we were able to make comparisons between the verbal and Livenotes conversations in section 3 of this paper, we are planning to set up video cameras to record classroom dialogue (with and without the use of Livenotes), to augment the data logs captured by Livenotes (e.g., to provide time logs of when users write on the canvas) with contextual information, and to interview participants before and after the introduction of Livenotes. We plan to cross-check these data sources against each other according to the timeline of the transcripts. We will also develop software tools to automate this analysis to some extent. These technical developments will play an important role in developing evaluation metrics with teachers on the effectiveness of Livenotes in the classroom.

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