# LEARNING VIA DISTRIBUTED DIALOGUE: LIVENOTES AND HANDHELD WIRELESS TECHNOLOGY

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**ABSTRACT.** This paper introduces a new learning technology for classroom 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 shared 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 through both qualitative and quantitative analyses the dialogue that developed in two classroom trials across multiple sessions. Finally, we suggest several issues that researchers can consider in designing collaborative software.

**KEYWORDS.** 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 classroom learning. Livenotes is such an exploration. Developed by Matthew Kam, Livenotes uses wireless communication and pen-based computing 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. As such, we define distributed dialogue as a non-localized, yet co-located, 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 one another 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-form

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discussion. It extends longstanding educational arguments that students learn best by actively engaging each other in conversation, and recognizes 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.

## WHAT IS LIVENOTES?

### System Description
Livenotes is a research software prototype and practice for collaborative note-taking. It is a Java program that is specially designed to run on the Clio handheld as well as regular desktop and laptop computers. We chose the Clio tablets because they are inexpensive and sufficiently portable, when folded into flat electronic tablets, to be used in any physical setting. In fact, as illustrated in Figure 1a, the lightweight nature of the Clio tablet enables it to be used even outside the classroom. For one user study, the wireless networking infrastructure was already installed in the computer science building where the study was held. For the other user study, which was conducted in a building without the necessary infrastructure, we were able to establish the network with minimal effort by bringing a portable access point to each session. The Clio, on top of supporting regular keyboard input, is also stylus-based, and hence less constraining and more low-profile in its use, since pen-based computing is generally more intuitive than keyboard input. The last key aspect of the Clio is its long battery life (eight hours under normal conditions), which is crucial for prolonged note-taking in an environment which lacks the necessary infrastructure (such as power supply) to support computer systems.

Furthermore, the Clio's Windows CE 2.11 operating system supports a Java Virtual Machine (JVM), which is essential for running Livenotes, even though the JVM incorporates only a subset of the full Java specification. This is not a constraint because the given JVM supports all of the operating system calls that Livenotes makes, including those for multithreading, networking, and a Graphical User Interface (GUI). The main limitation of the Clio platform is that the tablets are powered by a relatively slow microprocessor, but this drawback is more than made up for by having a JVM capable of running on a handheld device, which is necessary since the hardware portability afforded by Java provides us with future flexibility in the choice of Personal Digital Assistant (PDA) hardware.

Livenotes is designed to be used under a two-tier system in the classroom, such that the instructor constitutes the first tier while the students make up the second tier. These students are divided into small groups of up to seven members, since Livenotes is intended to support peer learning in small groups, as explained later. Using Livenotes, students record handwritten notes on their respective Clio tablets, such that the same notes appear in real time on the Clios of their group members who are also running the software. In this manner, students can take notes of the instructor's presentation for their personal use (first tier), as well as exchange annotations and comments with one another as the lecture proceeds concurrently (second tier). In each group, a particular student is tasked to perform the role of a scribe, and is responsible for taking notes of the lecture, while the other group members add their annotations to the scribed notes. As elaborated in greater detail later, this social practice arises due to the need for a group leader to "steer" the group discussion, so as to ensure that it remains relevant to the class lecture. A collaborative note-taking session is started by running Livenotes on all the Clios, after which one Clio is delegated to server mode and the remaining Clios set to client mode. Users of these latter clients then connect to the server using the appropriate option in Livenotes, such that these Clios are eventually connected in a client/server fashion.

On the systems level, several important design choices were made to facilitate the anticipated collaborative learning. The user interface 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. Any inkstroke made is subsequently updated across all other Clios belonging to the same group of users 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, so that users can locate their fellow users on the electronic medium. A transcript of the note-taking can be saved for future reference, and can also 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 hardware limitations of the Clio tablets.
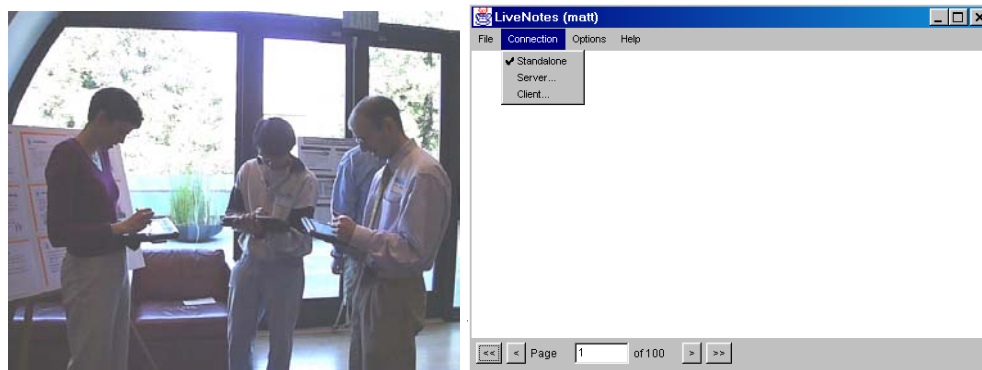


**Figure 1**. a) (left) A Livenotes session—three users communicating as a small group.
b) (right) What a screen capture of Livenotes looks like.

Data compression is employed to some extent to reduce storage requirements and to speed up the transmission of data among Clios on the wireless network. Tradeoffs between tighter compression and quality of the inkstrokes (we are using lossy compression) has led us to a 50% savings in space requirement. In addition, thread prioritizing and time-slice allocation are also being explored to find a more balanced scheduling scheme that will yield a better performance on individual machines and the network.

**Related Research**

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 rely on a toolbar for structuring keyboard input into various categories. Also, users are provided with arrow primitives to draw between text boxes to agree, disagree, or join statements. There is also support for direct interaction with the instructor or with an intelligent system.

Other technological 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.

The intended practice in Livenotes is motivated by peer instruction, which is a powerful learning technique (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 share the similarity that they support regular dialogue between a small group of students (less than seven) while they first encounter 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 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).

## USER ANALYSIS

### Background
Livenotes was first deployed in a graduate class 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 a qualitative transcript analysis. The STS course analysis was also drawn from the observations of two of the paper's authors, but the transcript analysis was much more detailed and quantitative. Also in the STS course there was class discussion of the technology and unsolicited e-mail dialogue from the users.

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.

During the 12th week of class, Livenotes was introduced into this 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. Students did not use Livenotes since 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. Supplementing this infrastructure was a major motivation for introducing Livenotes.

In the 5$^{th}$ week, Livenotes was introduced. The tablets were used for three classes, which generated 26, 34, and 28 pages of transcripts respectively for analysis. 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. Seven people participated at different activity levels while others joined the network by looking over a user's shoulder. After the last class was over, we heard that the few people who did not have visual access to a tablet felt excluded. This was in contrast with the first two classes where fewer people used Livenotes.

## 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.

## Qualitative Analysis
We observed many interesting phenomena during the trials, but choose to discuss four issues 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.

### *Group awareness*
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.
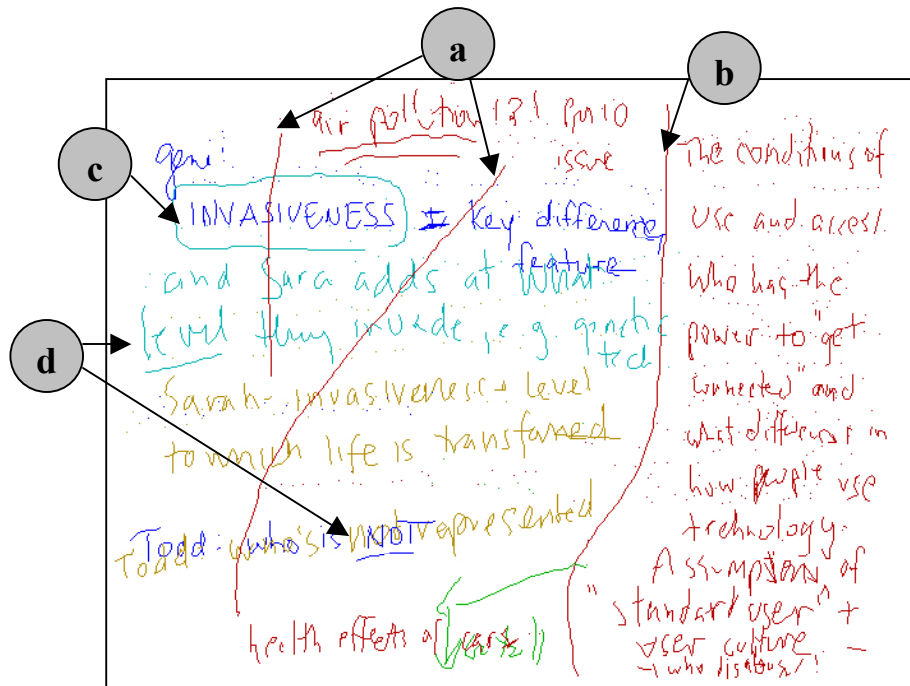


**Figure 3**. A screen capture showing a variety of elements including (a) linking together disjoint spaces of conversation (b) marking territory (c) highlighting someone else's points (d) highlighting one's own points for attention.

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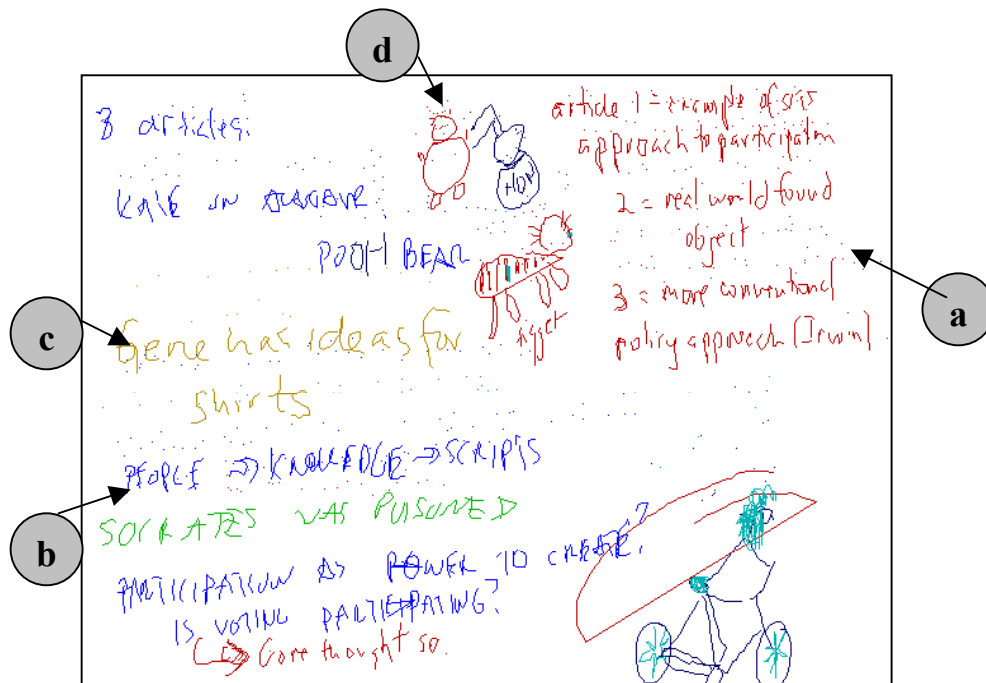


**Figure 4**. Transcript showing (a) summing up the lecture, (b) expanding on or developing lecture themes (c) an unrelated topic and (d) humorous interludes and drawings

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.

*Disruptions 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 disruptions 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.

## Quantitative Analysis

We performed an initial quantitative analysis of all three STS sessions 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 for both classes, 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). The number of drawing errors were also recorded. 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.

Table 1 shows a complete coding of the second STS Livenotes Session. In this seminar, there were four users, including two of the authors and two others we will call Greg and Kim. They took 26 pages of notes during a three hour session, only interrupted near page 17 for a small 15 minute class break (the dashed horizontal line). The first four sub-categories of management and content correspond to the marks identified in Figures 3 and 4 respectively. A fifth sub-category is used for both management (marks relating to navigation like "p.2" and greetings "hello, is anyone here") and content (talk about Livenotes). They are labeled "e" in the respective areas of table. Drawing errors for each user are also recorded in a column labeled "ε".

It can be seen on page 1 that this session starts with familiar greetings (Management E), and a fair amount of play (by Greg and Alastair). By page 3, Daniel and Greg begin to share scribing responsibilities for Alastair. This is reflected by the large number of Content A (summary) marks they record. Alastair reciprocates with a number of marks in the Content B (expansion of themes) categories. After a couple of marks Kim soon rejects using the tablets until late in the session. Throughout the session, both experienced users show a high degree of managing the discourse (44% of Daniel's and 45% of Alastair's total marks) through highlighting, linking, marking, and coordinating navigation. Similar to the start of the session, as the transcript gets closer to the break time there are more instances of unrelated topics and humor (pages 16-17).

| # | \| Daniel mgmt a | b | c | d | e | ε | Daniel content a | b | c | d | e | \| Alastair mgmt a | b | c | d | e | ε | Alastair content a | b | c | d | e | \| Greg mgmt a | b | c | d | e | ε | Greg content a | b | c | d | e | \| Kim mgmt a | b | c | d | e | ε | Kim content a | b | c | d | e |
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| **totals** | 155 | | | | | | | | | | | 137 | | | | | | | | | | | | 98 | | | | | | | | | | | 10 | | | | | | | | | | |
| | 68 | | | | | **ε** | 87 | | | | | 61 | | | | | | **ε** | 76 | | | | | 36 | | | | | | **ε** | 62 | | | | | 4 | | | | | | **ε** | 6 | | | | |
| | 12 | 23 | 5 | 9 | 19 | 21 | 59 | 9 | 5 | 5 | 9 | 24 | 10 | 8 | 10 | 9 | | 14 | 0 | 51 | 13 | 8 | 4 | 12 | 5 | 5 | 9 | 5 | | 13 | 19 | 6 | 12 | 23 | 2 | 2 | 0 | 0 | 1 | 1 | | 0 | 1 | 0 | 1 | 1 | 3 |
| | mgmt | | | | | ε | content | | | | | mgmt | | | | | | ε | content | | | | | mgmt | | | | | | ε | content | | | | | mgmt | | | | | | ε | content | | | | |
| | a | b | c | d | e | ε | a | b | c | d | e | a | b | c | d | e | ε | a | b | c | d | e | a | b | c | d | e | ε | a | b | c | d | e | a | b | c | d | e | ε | a | b | c | d | e |
| 1 | | 2 | | 1 | | 1 | | | 1 | | | | | | | 3 | | | | | 1 | 1 | | | | | 2 | | | | | | 3 | | | | | | | | | | | | |
| 2 | | | | 4 | | | | | | | 2 | | | | | 1 | | | | 1 | | | | | | | 2 | | 3 | | 1 | | | | | | | | | | | | | 1 | |
| 3 | | | | | | | 1 | | | | | 1 | | | | | | | | 1 | | | | | | 2 | | | | 1 | | 2 | | | | | | | | | | | | |
| 4 | | | | | | | 1 | | | | 1 | | | | | | | | | | | 1 | 2 | | | | | 3 | | 2 | | | | | 1 | | 1 | | | | | | | 2 |
| 5 | | | | | | | 1 | 1 | | | | 1 | 1 | | | | | | | 1 | | 1 | | 1 | | | | | | | 1 | | 1 | | | | | | | | | | | |
| 6 | | 1 | 1 | | | | 3 | | | | | 2 | 1 | | | | | | | 3 | | | | 1 | 2 | | 3 | 1 | | 3 | 1 | | | | | | | | | | | | | |
| 7 | | | | 1 | | | 1 | | 1 | | | | | | | 2 | 1 | | | 2 | 2 | | | 1 | | | | | 2 | 1 | | 2 | | | | | | | | | | | | |
| 8 | 1 | 1 | | | | 1 | 3 | | | | | | | 4 | 2 | | 1 | | | 3 | | | 1 | | | 4 | | | | 1 | | 4 | | | | | | | | | | | | |
| 9 | | 2 | 1 | | 1 | 1 | 2 | 1 | | | | 1 | | | | | 3 | | | 3 | 1 | | | 2 | | 1 | | | | | | | 2 | | | | | | | | | | | |
| 10 | 1 | | | 2 | | | 3 | | | | 3 | 1 | | 1 | 1 | | 1 | | | 1 | | | | 1 | | | | | | 2 | 2 | | | | | | | | | | | | | |
| 11 | | 2 | | 1 | | 1 | 4 | 1 | | | | | | 2 | | | | | | 2 | | | 1 | 1 | | | | | | | 2 | | | | | | | | | | | | | |
| 12 | 1 | 1 | | 1 | | 1 | 4 | | | | | 2 | 2 | | | | | | | 5 | | | | | | | | | | | | | | | | | | | | | | | | |
| 13 | | 3 | | 1 | 1 | 4 | 4 | | | | | 3 | | 2 | | | | | | 6 | 2 | | | 3 | 2 | | | | | 1 | | 1 | | | | | | | | | | | | |
| 14 | 1 | 2 | | 2 | | | 3 | 1 | | | | | | | | | 1 | | | | | | | 1 | 1 | | | | 1 | 2 | | 1 | | | | | | | | | | | | |
| 15 | | 2 | | 1 | 1 | 3 | 2 | 2 | | | | 1 | 2 | | | | 1 | | | 2 | | | | | | | | | 1 | | | 1 | | | | | | | | | | | | |
| 16 | | | 1 | | 1 | | | 1 | | | | | | 1 | 1 | 1 | | | | 4 | 1 | | | | | | | | 1 | | | 3 | 2 | 1 | 1 | | | | | | 1 | | 1 | 1 |
| 17 | | | | | | | 2 | | 1 | | | 1 | | 2 | | | 2 | | | | 1 | 3 | | | | | 1 | | | 1 | | 2 | 3 | | | | | | | | | | | |
| 18 | 1 | | | | | | 3 | | | | | | | | | | | | | 3 | | | | 1 | | | 2 | 1 | | 2 | | | | | | | | | | | | | | |
| 19 | | | | | | 2 | 2 | | 1 | 1 | 1 | 1 | 1 | | | 1 | 1 | | | 2 | 2 | | | | | | | | | 1 | | | | | | | | | | | | | | 1 |
| 20 | | 4 | | | | 2 | 2 | | 2 | | | 2 | 1 | | | | | | | | | 3 | | | | | | | | | | | | | | | | | | | | | | |
| 21 | | 1 | 1 | | 1 | 2 | | | | | 3 | | | | | | 2 | | 1 | | 1 | | | | | | | 1 | | | | | 8 | | | | | | | | | | | |
| 22 | 4 | | 1 | | 1 | | 3 | 2 | | | | 5 | 1 | | 1 | | | | | 5 | | | | | | | | | | 1 | | | | | | | | | | | | | | |
| 23 | | | | 3 | 1 | | 6 | 1 | | | | 1 | | | 1 | | | | | 2 | | | | | | 1 | | | | | | 1 | 1 | | | | | | | | | | | |
| 24 | 1 | | | | 1 | | 6 | | | | | 1 | 1 | | | | | | | 2 | | | | | | | | | | | | | | | | | | | | | | | | |
| 25 | 2 | 3 | | | 2 | 2 | 4 | | | | 1 | 1 | | | | | 1 | | | 2 | 1 | | | | | | | | | 2 | 1 | | | | | | | | | | | | | |
| 26 | | | | | | 1 | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

**Table 1**. The coded second session of 26 pages of notes for four users. The coding for *management* marks were subclassified into (a) linking disjoint spaces (b) marking territory (c) highlighting someone else (d) self-highlighting and (e) page hello/navigation. *Content* marks were (a) summary points (b) expansion of themes (c) unrelated topics (d) humor and (e) talking about Livenotes. *Errors* for each user were recorded in the column labeled ε.

By comparing the three coded sessions, we can make some general remarks about the use of Livenotes:

- Livenotes can facilitate lecture discussion even in groups of growing sizes (with the largest group of 7 users during the third STS session, 83% of the marks related directly to the lecture).
- Notetaking took different forms—in the first session, it was split between two people at 70%/30%; the second at 75%/25%, while the third at 50%/25%/13%/10%/2%.
- New and continuing users behave differently (as users became more experienced, their errors rates decreased; new users did not make many management marks; veteran users played less).
- Livenotes dialogue can be structured, and also that some users control whiteboard space more than others (as shown by a disproportionate number of management marks by veteran users).

- There was a wide variance in user abilities to create marks. For example, two people out of seven users produced almost all the drawing errors (74%) in one session, implying that they differed markedly in their ease with the technology from the others.
- Perceptions of Livenotes as dominated by play were not well grounded since they were limited to periods near breaks in the session, and only accounted for 16% of all total marks.

## DISCUSSION AND CONCLUSIONS

We conclude that, through Livenotes and handheld wireless tablets, 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 conversational threads that appear or vanish over a session, and can readily be adapted in response to user participation. Wirelessly-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 less knowledgeable people, and members engaging in what may seem to be peripheral conversations that nevertheless help 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 shared whiteboard nature of Livenotes enables such free-form and 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 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 communication and social interaction enabled by Livenotes. We have found that 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 these improvisations enable communication to take place effectively. Livenotes allows this process of adaptation to occur because it is not "finished," depends on free-form whiteboards, and has great flexibility built into it. We have also realized that the ways in which deaf people engage in written conversations can provide valuable insights 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 which are more in tune with 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."

In the case of Livenotes, we are in the process of changing the navigation structure and integrating information sources from outside the tablets. For example, the presence indicator window has become more prominently

displayed on the toolbar. In addition, private notes are being developed to add another dimension of flexibility which we anticipate can both reduce attention demands for some users and provide self-dialogue for others. We are also developing links to incorporate external data sources to focus user attention without prohibitive restrictions on its use.

Finally, we are refining our methodology for coding and evaluating data, so as to better measure the adaptation and learning benefits of using Livenotes. From our first trials, we identified familiarity with computer technology, preferences for typing versus handwriting, personality, and multi-task capabilities as relevant user dimensions. We will better develop these dimensions in future studies. For learning, we are also refining our methods for data collection and analysis. For example, we are planning to set up a video camera to record classroom dialogue to see how the on-tablet is interwoven with the off-tablet conversation. This will be supplemented with improved data logging facilities to coordinate the video and transcript data sources. We are in the preliminary stages of developing a software tool to automate the simultaneous analysis of video and log data. We are also planning on interviewing users and teachers (although the categories have not been exclusive) to assess the educational value of Livenotes.

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## REFERENCES
Dutra, J. Gibbons, J., Pannoni, R., Sipusic, M., Smith, R., Sutherland, W. (1999), "Virtual Collaborative Learning: A Comparison between Face-to-Face Tutored Video Instruction (TVI) and Distributed Tutored Video Instruction (DTVI)" Sun Microsystems Research Technical Report TR-99-72.

Hicks, D. (1996) Contextual inquiries: A discourse-oriented study of classroom learning. In D. Hicks (Ed.), Discourse, Learning, and Schooling (pp. 104-141). New York: Cambridge University Press.

Mazur, E., (1997) "Peer Instruction: A User's Manual", Prentice Hall, Upper Saddle River, NJ.

Resnick, L. B., Levine, J. M., Teasley, S. D. (Eds.) (1991), Perspectives on socially shared cognition. Washington, DC: American Psychological Association.

Scardamalia, M., Bereiter, C. (1991) "Higher levels of agency for children in knowledge building. A challenge for the design of new knowledge media". The Journal of the Learning Sciences, **1**:37-68.

Slavin R.(1990) "Cooperative Learning: Theory, Research, and Practice", Prentice Hall, Englewood Cliffs, NJ.

Suthers, D., Toth, E., Weiner, A. (1997), "An Integrated Approach to Implementing Collaborative Inquiry in the Classroom", CSCL '97 Proceedings.

Yukiko Tanikawa, Hideyuki Suzuki, Hiroshi Kato (1999) A Synchronous Collaborative Editing System for Learning to Write. In C. M. Hoadley and J. Roschelle (Eds.), Proceedings of the Computer Support for Collaborative Learning (CSCL) 1999 Conference (pp. 621-630). Palo Alto, CA: Stanford University.