The Roles of Representations in Online Collaborations

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Introduction

Online collaborative learning intrinsically requires that learning be mediated by external representations. These representations may include discourse representations (e.g., the chat rooms and threaded discussion tools by which learners and teachers communicate in their native language (Herring, 1999), disciplinary representations such as visualizations and designed artifacts (e.g., Hundhausen & Douglas, in press; Schank & Kozma, in press), and symbolic representations of one's theories and reasoning that we will term knowledge representations (Suthers, et al., 2001). Unlike the spoken discourse of proximal collaboration, the discourse in distance collaboration takes place in a software-supported representational medium. Given the total reliance on external representations in online collaborative learning, it is appropriate to ask how these representations should be designed to facilitate collaboration. Of particular interest is coordination between the different types of representations just listed (Ainsworth, et al., 1998; Hoadley & Enyedy, 1999; Turoff, et al., 1999).

Our prior work on external representations in face-to-face collaborative learning situations has shown that differences between representational notations can translate into differences in the focus of learners' discourse and collaborative activities (Suthers & Hundhausen, 2001, 2002). In our studies, learners were asked to solve a problem in science or public health, presented as a sequence of information pages, while utilizing one of several experimentally manipulated alternate representations (text, graph, and matrix) for recording data, hypotheses, and the evidential relations between them. Differences in discourse focus were predicted according to the kinds of information that the representations prompt one to seek, and the information needs that become salient as one constructs a representation (Suthers, 2001a). We found that visually structured and constrained representations can provide guidance for collaborative learning that is not afforded by plain text. However, more guidance is not necessarily better. For example, the matrix representation prompted for consideration of irrelevant relationships as well as relevant ones. The graph representation – "evidence maps" – provided guidance without excessive prompting. Benefits of graphical evidence maps have also been observed in a classroom setting (Toth et al., in press).

In this paper we report on our first extension of this work to a study of how representations might influence collaboration in distance collaboration situations. We begin with a comparison of face-to-face and online collaboration, since we have studied the former in great detail and need to understand how online collaboration differs. This study compares Proximal (face to face) with Distal (synchronous collaboration via networked software) conditions. Although we did not make

specific predictions for the results, we considered two divergent hypotheses: (1) The influence of representations in the Distal condition could be weaker because of the lack of implicit "taken as shared" that results from working together in front of a physically shared display, and because of the greater difficulty of utilizing the representations as a resource for conversation through deixis (Clark & Brennan, 1991). (2) The influence of representations in the Distal study could be stronger because participants may rely more on them for their communication in the absence of face-to-face communication. Our results show that the distribution of activity was quite different between the Proximal and Distal groups, and that this distribution provides evidence of both predicted influences. We discuss alternate explanations for these results, and broader implications for the nature of collaborative learning with knowledge representations.

Design

The present study built on a prior study that compared three representations: Matrix, Graph, and Text (Suthers & Hundhausen, 2001, 2002). We elected to implement a synchronous distance collaboration version of the Graph condition and to compare performance of participants in this condition with those in the previous proximal (face to face) Graph condition. Both groups were given the identical task of exploring an unsolved "challenge problem," presented as a series of textual web pages, by recording data, hypotheses, and evidential relations as they encountered them.

Participants

We recruited 20 students in self-selected, same-gender pairs, out of introductory biology, chemistry, physics, and computer science courses at the University of Hawai`i. Participants were age 25 years or younger and native English speakers. Participants were paid a $25 honorarium.

Materials

Pairs of participants used one of two different versions of software for representing data, hypotheses, and evidential relations. The Proximal version is shown in Figure 1. Participants used the upper right hand window to move forward through a sequence of 15 pages that presented information relating to the cause of a mysterious neurological disease on the island of Guam. The left-hand window contained a graphical tool for constructing representations of the data, hypotheses, and evidential relations participants gleaned from the information pages on the right. The graph tool is based on Belvedere (Suthers et al, 1997), and enables one to build a graph of nodes expressing data items and hypotheses, and links labeled "+," "-," or "?" representing evidential relations.

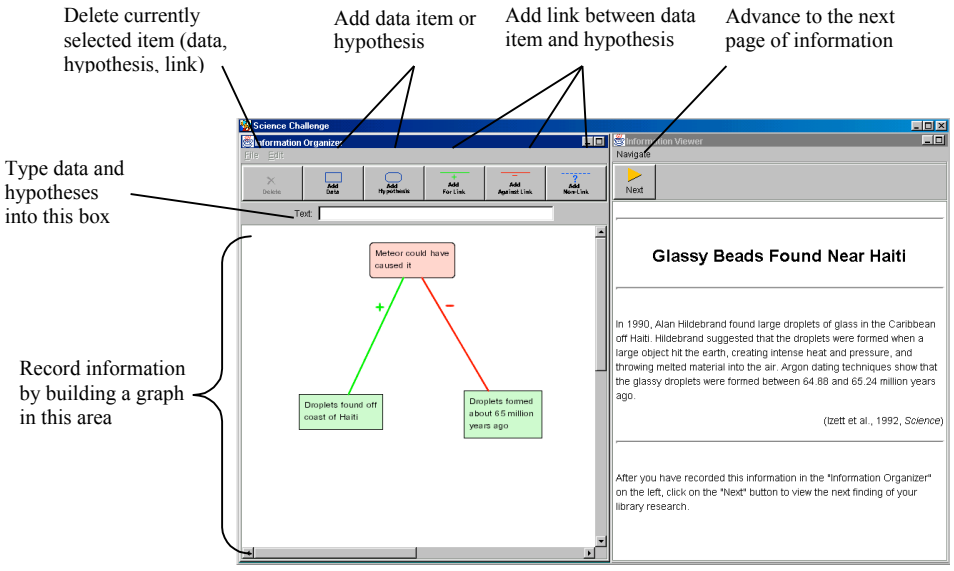

Figure 1. The Graph version of the software

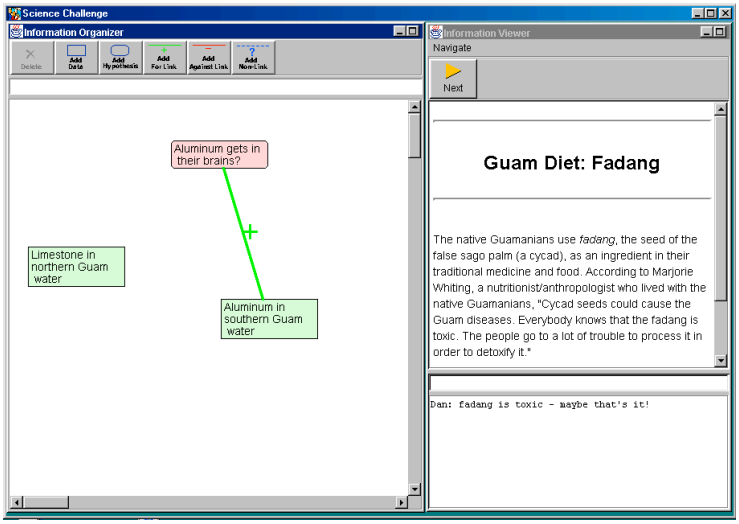

Figure 2. Addition of Chat tool in Distal

The software for the Distal condition provided a simple chat tool in an additional window in the lower right (Figure 2). Messages typed into a chat entry box were sent to both participants' shared chat displays once the message was completed and the "send" button was pressed. Both versions of the software support deixis by causing the color of objects to change when one passes the cursor over them, enhancing the deictic value of the cursor. The Distal version of the software replicated these color changes to the remote display. In this manner we attempted to enable the use of the knowledge representation as a resource during conversation in the Distal as well as Proximal condition.

Procedure

At the beginning of the learning session, participants were given a brief (10-minute) introduction to the software they would be using. So that they could become acquainted with the software and the information-recording process, participants then worked on a warm-up problem (on mass extinctions) that was unrelated to the main problem. After 15 minutes, participants were instructed to stop work on the warm-up problem, and to move on to the main problem (on the neurological disease). Participants were given as much time as they needed to explore all 15 pages on the main problem in linear order (one could not go back to previous pages). Following the learning session, participants were given 20 minutes to individually complete a multiple-choice post-test, and 30 minutes to collaboratively write an essay that discussed their hypotheses and the evidence for and against them.

Results

Posttests of memory for factual information showed no significant difference between Proximal and Distal groups, an expected finding due to the short treatment period. We are currently analyzing the essays. In this paper we focus on a categorical analysis of the verbal and representational acts of the participants.

Analysis process

Video/audiotape of the proximal sessions were transcribed by hand. The software generated transcripts of the distal sessions automatically. Transcripts were divided into "segments," each consisting of a verbal or typed utterance (multi-propositional utterances were divided into individual segments) or a change to the representation. See Suthers & Hundhausen (2001) for details of coding. Then we performed a content analysis of participants' learning processes by coding all segments in the 20 transcripts into the following mutually exclusive "topic" categories:

- *Evidential relation*. These segments consider whether data and hypotheses are consistent, that is, whether a data item supports or conflicts with a hypothesis. For example, the segment "That's for the genetics hypothesis" would be coded as evidential relation—consistency.
- *Epistemic classification*. These segments classify information as either empirical or theoretical—that is, as either data or hypothesis. For example, the segment "Let's make a hypothesis about toxic drinking water" would be coded as epistemic classification. Likewise, in the Graph software, the action of clicking on the "create data" button would be coded as epistemic classification.
- *Hypothesis statement*. This coding was applied when participants stated a hypothesis concerning a possible explanation for the disease without labeling it as a hypothesis (e.g., "Might be a combination of both").
- *Metacognitive*. In these segments, participants step back and either assess what they know so far (e.g., "We know that they used the drinking water for the fadang, to prepare the seeds"), or identify information that is needed but lacking (e.g., "See, but it doesn't say that these admission records are patients that have the disease").
- *Warrant*. These segments provide justification for an evidential relation previously cited. For example the second half of, "That supports the aluminum hypothesis, because Irian Jaya was

found to have higher than normal levels of aluminum in the soil" would be classified as a warrant.

- *Tool talk*. These segments discuss some aspect of the software. Participants might, for example, ask how to complete some specific task with the software (e.g., "How do you get this out of the way?"); they might complain about the software (e.g., "Oh my, what's wrong with this thing?"), or they might share their emerging understandings of how the software works (e.g., "If we click on this we can see it").
- *Domain talk*. These segments discuss the domain of the science problem that participants are exploring. Since this is the loosest of the Topic categories, it had the lowest precedence; we coded segments into this category only if they could not be coded into one of the five categories above. For example, "Northern Guam is a low limestone plateau" would be coded as domain talk.
- *On-task*. These segments did not fall into any of the first six categories, but could still be considered on-task. For example, "Let's go to the next page" would be coded as on-task.
- *Off-task*. These segments were deemed to be unrelated to participants' learning task. For example, "What did you do last night?" would be considered off-task.

In addition, we coded topic segments with "modifier" categories, according to whether they were

- *Verbal* or *representational*—spoken or expressed in the chat tool, versus represented using the software;
- *Recited* or *non-recited*—quoted verbatim from the information pages, or not quoted;
- *Introduced* or *repeated*—the first occurrence of an idea within a given conversation, or a reintroduction of an idea already brought up within a given conversation.

The third author coded all of the data, while the second author coded 20% of the data. Overall agreement between the two coders ranged from 89% for the Proximal data to 95% for the Distal data, with kappa statistic values ranging from .0.86 (Proximal) to 0.94 (Distal).

Distribution of Categories

The distribution of the codes across treatment groups is shown in Table 1. There were many more segments in Proximal than in Distal, this difference being attributable to larger counts in most categories, particularly in Domain Talk and other On Task talk, although Distal participants engaged in more Epistemic Classification and Hypothesis Statement acts.

The percentages of each category relative to the total count for each group are shown in Figure 3. We performed statistical tests on the percentages rather than the raw counts to control for differences in verbosity between groups, although raw counts will be consulted in our interpretation of the results (next section). The most striking differences in the percentages are in Domain Talk, Epistemological Classification and (to a lesser degree) Evidential Relation. The Proximal participants engaged in a greater percentage of Domain Talk, which is reflected in the raw counts as well. Distal participants engaged in a greater percentage of Epistemological Classification, Evidential Relation and Hypothesis Statements. The raw counts for Evidential Relation are actually very similar.

Table 1. Distribution of codes by raw count

	Proximal	Distal
Evidential Relation	569	561
Epistemic Classification	439	644
Metacognitive	37	28
Warrant	31	5
Tool Talk	268	85
Domain Talk	1618	368
Hypothesis Statement	38	76
On Task	1639	987
Off Task	159	144
Totals	4798	2898

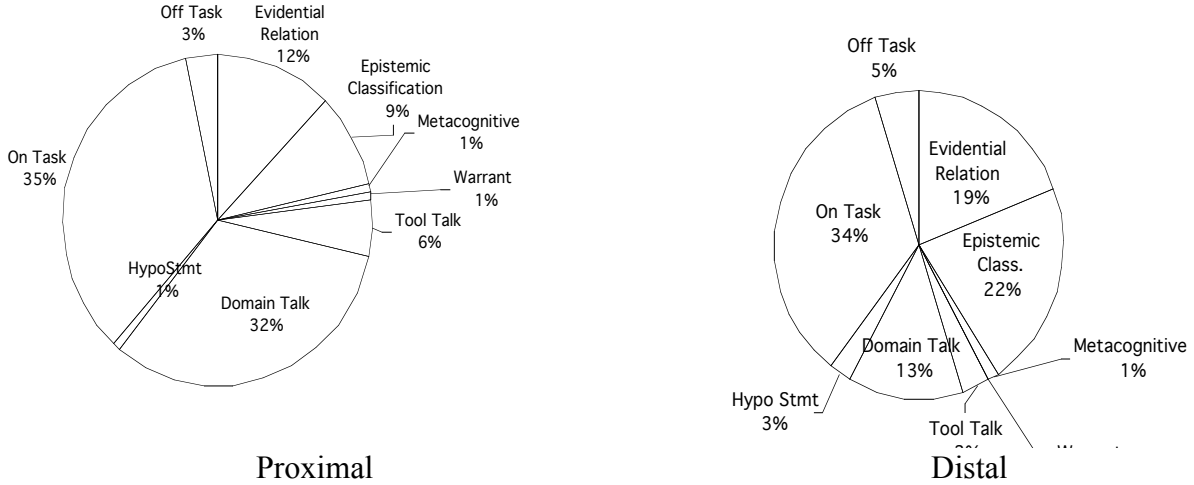

Figure 3. Percentages of each category compared

For the purposes of this study, "Verbal" means spoken in the Proximal condition and use of the Chat tool in the Distal condition; while "Representational" means use of the Graph tool in both conditions. Table 2 shows Verbal and Representational breakdowns of the Evidential Relation and Epistemological Classification categories, which are those categories we focused on in the previous study. The table shows both raw counts and percentages of On-Task, Non-Recited segments (therefore the percentages differ slightly from those in Figure 3, which are of the total number of segments).

To test for statistically significant differences, we compared each Proximal/Distal pair of percentages using a Kruskal-Wallis ANOVA. As indicated in Table 2, differences between all of the values shown except for the last row are statistically significant at levels ranging from p=.0001 to .05. The overall pattern is as follows. The Proximal participants engaged in a greater number of on-task, non-recited acts overall, with most of these being spoken. Distal participants engaged in a greater percentage (although approximately the same raw count) of acts concerned with relations of evidence. These acts occurred more in the Verbal (spoken) medium in Proximal, and in the Representational (graph) medium in Distal. Similarly, Distal participants engaged in a greater

percentage of epistemological classification acts, these being primarily in the Representational medium (as opposed to the Chat tool).

Table 2. Breakdowns of Evidential and Epistemological Classification Acts

		Total Counts		*Percentage of On-Task, Non-Recited, and p levels*		
Code		**Proximal**	**Distal**	**Proximal**	**Distal**	**p**
On-Task, Non-Recited		4530	2724			
	Verbal	3646	1590			
	Representational	884	616			
Evidential Relations		569	561	12.56	20.15	.0155
	Verbal	314	35	6.93	1.28	.0001
	Representational	255	514	5.63	18.87	.0002
Epistemological Classification		439	644	9.69	22.83	.0007
	Verbal	120	24	2.65	0.88	.0050
	Representational	319	598	7.04	21.95	.0004
Domain Talk		1618	368	35.72	13.53	.0002
	Verbal	1311	367	28.94	13.50	.0005
	Representational	307	1	6.78	0.04	.0001
Hypothesis Statement		38	76	0.84	2.80	.0409
	Verbal	38	75	0.84	2.76	.0409
	Representational	0	1	0.00	0.04	.3173

Discussion

A greater percentage of acts in the Distal condition were concerned with categories provided by the representations (Epistemological Classification and Evidential Relations). In the case of Evidential Relations, the counts were similar, so this reflects a difference in the denominator: perhaps the same amount of evidential thinking is taking place in the context of less overall talk. However, a greater number of the Distal Evidential relation acts are classified as "Introduced," that is, as a reintroduction of the topic of evidence rather than as a continuation of an ongoing discussion of evidence. Given that many of these acts are representational, Distal participants may be using the Graph medium to propose evidential relations, resulting in less overall talk but many representational introductions of Evidential Relations. Thus, the representational medium becomes part of the conversational medium, a point to which we will return.

Both numerically and in percentage, there were many more Epistemological Classifications in Distal. This result would also be consistent with the interpretation that new objects are being created in the Graph representation to propose ideas, as each object creation event is also coded as a classification event.

A split in emphasis between Verbal and Representational is seen across Proximal and Distal. Participants in the Distal study represented the Epistemological Classification and Evidential Relation categories over two times more than Proximal participants. However, Proximal participants discussed Epistemological Classification nearly five times more than Distal participants, and Evidential Relation categories over nine times more than Distal participants.

The Proximal condition discussed more Domain Talk. Indeed, domain talk made up nearly five times more of the total utterances than did Distal domain talk.. Perhaps this difference is due to the extra work required to type in Chat; concepts and more complex propositions of an unfamiliar domain may have been most subject to this resistance of the discourse medium. We also observed that segments in the Hypothesis Statement category, in which participants proposed hypotheses without classifying them as such, occurred twice as often in Distal discourse. One reason for this could be that more Distal discussion tends to occur after the last page, when participants are asked to come to a final conclusion. This discussion consists largely of hypothesis statements, which are by definition conclusions not classified or represented as hypotheses (e.g., "I think it's the water").

Below we discuss and give examples of some of the major factors that may be responsible for the differences observed both in the numerical analyses and our informal observations during the studies.

Discourse Mode

Discourse mode (the main treatment variable) could explain the higher percentage of representations, as well as the nearly doubled total session time for Distal participants. Written discourse is inherently more time-consuming than verbal discourse when identical statements are compared. In addition, participants with less skill in touch-typing may have chosen to save time and effort by focusing on adding representations rather than discussing domain issues or negotiating agreement using the chat tool.

The Distal discourse representation may have also affected communication on the receiving end. Because chat messages appeared in small black lettering in the bottom corner of a screen dominated by colorful graphics, effort was required to check regularly for new chat messages.

This slower and more complex "chat" discourse mode, combined with its lack of visibility on the screen, may have discouraged Distal participants from discussing the problem or checking for agreement before posting items as much as Proximal participants. These factors may have also encouraged Distal participants to bend the rules a bit to get their messages across. Several pairs used the data and hypothesis bubbles to post messages to each other, possibly to make them more visible. For instance, one pair posted off-task banter such as "Audrey is a dweeb" and later removed it. Another pair posted on-task questions, such as "What should we do now?" and "I don't know what the answer is." Still another pair posted domain questions such as, "What is causing this disease?" and linked them up with legitimate data and hypothesis bubbles. (We adjusted our statistical counts of epistemic classifications and relations so that they do not include such items).

Social Factors

Social factors may have also played a role in the results, although this could not be substantiated without personal interviews of the participants. Physical distance may have lessened the social pressure for agreement that often accompanies verbal collaboration. Distal participants may have felt they could "get away" with adding items to the graph without discussing them as much, since their partners might not immediately notice changes to the diagrams, nor take the time to type out challenges to the representations.

The illusion of privacy suggested by the Distal discourse chat tool seemed to encourage Distal participants to engage in more off-task discussion. Although a research monitor was in the main room for both studies, chat was not reviewed until after the students had left. Distal discourse was peppered with "chat slang" and email jargon popular in a recreational context. Participants often used the chat tool to send off-task jokes, laughs and emotive faces. Off task banter made up

5% of the total communication in the Distal condition, compared to 3% in the Proximal condition. (Although some emotives could relate to the problem, such as a sad face indicating disapproval with a represented item, these emotives weren't coded, to avoid drawing unwarranted assumptions about their meaning).

Physical proximity may have also influenced the number of data and hypothesis items added and later removed. Distal pairs often posted items independently without negotiating first. As a result, they sometimesended up with duplicate data and hypotheses. Similar items were later deleted, and negotiation to determine which partner's item would remain on the diagram was a frequent focus of discourse, as in the following segment of Session 2 below:

```
*P2.2
D51 ADDED:  BOAA: cause of disorder and similar chemistry of BMAA
*P2.1
D52 ADDED: BOAA(unusual amino acid) isolated from green peas by
   researchers in India and Britian- cause of disorder
CHAT      Hahaha, shall we keep yours?
*P2.2
CHAT     :) No matter
*P2.1  CHAT  Aites keep urs? [Let's keep yours?]
*P2.2  CHAT  Yours has more info. We can weed it out laters
D51  DELETED:  BOAA: cause of disorder and similar chemistry of BMAA
*P2.1
CHAT  Aites [right]
CHAT  Where does it link to
*P2.2
D52--D50 ADDED  FOR
*P2.1
CHAT    Acks actually we coulda kept yours. I'll just retype it
*P2.2
CHAT    Okies
```

Because each duplicated item counted as two introduced representations, and each deletion counted as a continuation of one representation, counts of Distal representations increased with these duplicates.

Roles of Representations in Discourse

Although further analysis is needed to determine whether representations influenced discourse and learning more in one mode than the other, it is already apparent that the timing and purpose of discourse related to representations differed considerably. For Proximal participants, Graph representations seemed to function as a stimulus to discourse, focusing discussion both before and after they were created.. Collaboration and agreement tended to be forged before representations were made, so the representations may be seen as an external product of the discourse:

```
*L: Actually, you can't say that this goes to that, though. <points to D5 & H1>
*R: Why?
*L: Because other people drink from the water too, yeah?
*R: Like who?
*L: The navy people.
*R: Maybe they, maybe they got their stuff from somewhere else.
*L: And then this will go against the idea of this. <points to D7 and H1>
*R: Except when they get here, though. <cursor at D9>
```

```
*L: But then this will go with this, you know what I'm saying? <points to H1 and
D9>
*R: Yeah, but this would make this whole thing go with it, though.
<sweeps cursor from D9 to H1 across right hand row of boxes>
Because the seeds are soaked in the water, it makes the seeds  part of the water
hypothesis.
If they weren't soaked in the water, then it would be <inaudible>.
*L: This lady thinks it could be just from the seeds, though. <points to D8>
<DOMAIN>
*R: I know, but like a dragon could have farted on them and caused the disease!
<laughs>
10:42:42    D07--D06   ADDED: FOR
10:42:48    D08--D07   ADDED: FOR
10:42:54    D09--D08   ADDED: FOR
10:44:00    H01--D05   CHANGEDTO: QUESTION
I mean, like this one, what naval people was it? Was it American naval?
*L: Because, this just says that Guam is part of U.S. territory.
*R: America, but I mean, like, do they have their own navy or something?
*L: No.
*R: Well, then if it's American naval, then maybe they have their water source
or something. I'm sure they don't drink water out of the stream. They probably
clean, I'm sure they go through a cleaning process if they live on a naval base.
*L: What about the other people?  Guam isn't…If it's part of the U.S. territory,
I would think that they would have enough, at least adequate facilities to treat
water.
*R: I don't know.
*L: Go to the next one.
```

For Distal participants, in contrast, the Graph representation served multiple purposes. As in the Proximal condition, Graphs functioned as a stimulus to and product of discourse, but they also were used as part of the discourse medium itself. In the Distal condition, discourse often took place within the graphs in two ways: (1) participants often proposed new items or relations by creating them in the graph medium, whereupon chat focused on approval or disapproval; and (2) participants used the graphical representation in place of the chat tool to send a message that was deleted. The Graph was also used in a manner peripheral to discourse, when a participant independently modified the graph amidst unrelated chat discussion. This created a need for the removal of duplicate or similar items created independently by each partner, and some discourse focused on the negotiation of whose item would be removed.

The following example contains most of these typical characteristics of Distal discourse. Instead of using discourse to decide what to add to their graph collaboratively, the pair proposes new items or relations by first representing them independently of one another in the graph medium. Chat then focuses on short comments of approval or disapproval with what is added, as well as the negotiation of removing duplicates:

```
*P6.1
Changed to page 1:  Northern Guam
H01 ADDED:       [Blank]
*P6.2
D01 ADDED:  Water collects calcium as it seeps through limestone
*P6.1
H02  ADDED:  Limestone may be the cause of the disease ALS-PD
D01--H02  ADDED:    FOR
H01   DELETED:          [Blank]
```

```
*P6.2
Changed to page 2: Southern Guam
*P6.1
D02  ADDED the drinking water in Guam is collected from wells that have water
that seeps through  limestone
D02--H02  ADDED:   FOR
Changed to page 2: Southern Guam
*P6.2
D01  DELETED:   Water collects calcium as it seeps through limestone
*P6.1
CHAT   Why did you delete it. didn't think it was relevant?
*P6.2
CHAT    Its the same thing you just said
*P6.1
CHAT    K
*P6.2
CHAT    Except for the calcium part
D03   ADDED:   The water collects calcium as it seeps through limestone
*P6.1
D04   ADDED:   Drinking water contains high levels of aluminum from streams
D04--H02  ADDED:    AGAINST
H03  ADDED:   Aluminum in drinking water is cause of ALS-PD
H03--D04  ADDED:    FOR
*P6.2
H04   ADDED:      ALS-PD is a form of mineral poisoning
D04--H04   ADDED:           FOR
*P6.1
D02--H04  ADDED:           FOR
CHAT            Does that look alright
*P6.2
CHAT            Ya i guess so
*P6.1
CHAT            Moving on
Changed to page 3: Hospital Records
```

Distal discourse related to the problem was often concentrated on the last page, after all representations had been made and participants were urged to come to a final conclusion. The nature of this discourse differs from the concluding discussions of Proximal participants. Much of the concluding discussion of Distal participants consists of Hypothesis Statements, which are general statements of hypothesis without classification or representation. This may explain the higher counts for this code in the Distal condition.

```
*P3.1
Changed to page 16: Final
CHAT     Okay
*P3.2
CHAT     K tell her we are pau [done]…
*P3.1
CHAT      Wait we're going to have to write a paper on this
*P3.2
CHAT       Ummm yeah
*P3.1
CHAT       So whats ur conclusion…
CHAT       I think it was started by the medicine
*P3.2
```

```
CHAT        The disease was not genetic
CHAT        But through the soil? Like aluminum poisoning?
*P3.1
CHAT         Yea there wasn't info on genetic
*P3.2
CHAT         Yea...ok
*P3.1
CHAT         Maybe it was what was in the medicine that was toxic.
*P3.2
CHAT         Ya…
*P3.1
CHAT        And probably the water too dirty that's why
*P3.2
CHAT         Ok  now where's that chick?
```

Referencing Representations

The referencing of knowledge representations was another issue affected by discourse mode. Coordination between discourse mode and diagrammatic media was easier for Proximal participants because they could non-verbally reference items for clarity. They simply pointed to an item on the screen or clicked their cursor when determining a relationship or discussing an issue. Because both Proximal partners could determine more easily whether they were looking at the same parts of the screen, they could use expressions such as "On the top right," "Up! No, further!" etc. to direct the person holding the mouse to the correct item. This ability to easily reference items and determine that they were both focusing on the same items may have allowed them to discuss more items and relationships.

Distal participants, on the other hand, rarely referenced items that had been previously represented, except for those that had just been added. In that case, discourse often involved simple agreements with the change in statements, such as "That's fine." An analysis of how often items from previously viewed pages are reintroduced into the conversation has already been conducted for the Proximal study. A similar analysis for the Distal group (presently underway) will help determine whether representations also remind their users of previously encountered information in an online context.

Conclusions

We began this study hoping to learn more about the differences between proximal and online synchronous collaboration. Our future work will focus primarily on asynchronous rather than synchronous online collaboration. This study has helped form a bridge to that work.
Two competing hypotheses were considered:

(1) that visual knowledge representations would play less of a role in guiding discourse because without co-presence they do not as easily function to convey "taken as shared" information or to support deixis;

(2) that visual knowledge representations would play a greater role in supporting discourse because participants would make use of them to make up for the reduced bandwidth of the verbal modes of interaction.

Paradoxically, both of these seem to be supported by the study. The first hypothesis is difficult to address without a *comparative* study involving Matrix and Text representations (as we did in the Proximal study), to see whether the pattern of results changed. However, we have evidence for this hypothesis in the form of observed disconnects between the activity in the workspace and the

verbal activity in the chat. Many uses of the knowledge representations as such are not as tightly coupled with verbal discourse as in the proximal case, so we would expect that their influence on verbal discourse would be weaker. We feel we have good evidence for the second hypothesis. There was a clear shift to a greater number of communicative acts being undertaken in the representational medium in the Distal condition, where the knowledge representations were used for transient negotiation normally undertaken verbally in the proximal case, such as proposing new hypotheses or relations.

We were also interested in how patterns of categories of talk analyzed in our original study comparing different representations would differ in the distal case. The frequency of categories supported by the knowledge representation software (evidential relation and epistemological classification) increased online, while Domain talk, not directly supported by the software so requiring the verbal medium, was greatly reduced in the Distal condition.

With respect to the design of software for on-line learning, perhaps the major conclusion to be drawn from this is that close attention must be paid to the coordination (both in the design and in use) between multiple representations, in cases in which multiple representations are used. If users are able to modify more than one type of representation, the discourse process will not be confined to the medium provided for discourse: it will be distributed across all mutable representations. Therefore the software should support fluid crosstalk between all representations by making the relationships between different representations and between acts on those representations clear (Suthers, 2001b).

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