Comparing the Roles of Representations in Face to Face and Online Computer Supported Collaborative Learning

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Abstract

We report an empirical study comparing the role of discourse and knowledge representations (graphical evidence mapping) in face to face versus distance collaborative learning. Our prior work comparing alternate knowledge 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. The study reported in this paper compares Proximal (face to face) with Distal (synchronous collaboration via networked software) conditions. We considered two divergent hypotheses: (1) The influence of knowledge representations in the Distal condition could be weaker because of the lack of shared awareness and meaning 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 gestural deixis. (2) The influence of knowledge representations in the Distal study could be stronger because participants must rely more on them to compensate for the absence of face-to-face modes of communication. Our results showed that the distribution of activity was quite different between the Proximal and Distal groups. The quantitative data on interactive processes largely support the second hypothesis. There was greater consideration of categories supported by the knowledge representation software. However, essay quality and other observations provide indirect support for the first hypothesis. We discuss explanations for these results, and implications for the design of online collaborative learning environments.

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 a natural 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.

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, to appear). 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 (Graph, Matrix, and Text) 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 that becomes 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. Specifically, users of the Matrix representation discussed and represented issues of evidence more than users of other representations; while users of visually structured representations (Graph, Matrix) revisited previously discussed ideas more often than users of text. However, we also found that representational prompting could lead users of the representations astray. For example, the Matrix representation prompted for consideration of irrelevant relationships as well as relevant ones, leading to excessive consideration of weak or ambivalent evidence. Although an expert would not have been misled in this manner, the Graph representation provided the most appropriate guidance for the initial investigations of novice participants. Benefits of graphical evidence maps have also been observed in a classroom study in which users of graphs recorded more inferences and attended to more discrepant evidence than users of a text editor (Toth et al., in press).

In this article we report on our first extension of this work to a study of how notations for knowledge representation might influence collaboration in distance collaboration situations. We begin in this study with a comparison of Proximal (face to face) with Distal (synchronous collaboration via networked software) conditions, since we have studied proximal collaboration in detail and need to understand how online collaboration differs. This is not a new topic. Extensive prior research has compared performance of face-to-face collaborators to performance of users of various forms of technology-mediated communication (including audio, video, and various forms of computer mediated communication). Studies of synchronous problem solving generally show degradation of both problem solving performance and interpersonal communication due to the reduced "bandwidth" or available modes of interaction associated with technology-mediated communication (Olson & Olson, 1997; Doerry, 1996), although factors extrinsic to the technology itself may play a role (Walther, 1994). However, an extensive literature on asynchronous online learning typically concludes that there is no significant difference in learning outcomes as compared to traditional classroom learning (Russell, 1999).

It was not our intent to replicate or test these results. Rather, we sought to understand how the roles that representations play might change between face-to-face and online collaboration in order to understand how our previous work might inform the design of online learning environments. Our previous study provided a baseline understanding of how a representation such as Graph is appropriated and used by learners and influences learner's activities in a face-to-face setting. Would the role of Graph be similar when interaction is online, with a textual "chat" tool replacing spoken language?

Hypotheses

We approached this work with two divergent hypotheses in mind (and with no prior expectation that one would be dominant over the other):

(H1) *The Co-Present Affordances Hypothesis*. The influence of knowledge representations in the Distal condition will be weaker because some key representational affordances for collaboration depend upon working together in front of a physically shared display.

(H2) *The Appropriation for Communication Hypothesis*. The influence of knowledge representations in the Distal study will be stronger because participants must place greater reliance upon those representations for communication to compensate for the absence of face-to-face communication modalities.

We discuss each of these hypotheses in turn.

The Co-Present Affordances Hypothesis (H1)

Some background will help us explore the nuances of this hypothesis. Suthers and Hundhausen (to appear) discuss three ways in which representations might guide collaborative problem solving beyond the mere aggregation of their effects on individuals.

1. *Initiating Negotiations*: Collaborators will feel some obligation to propose and discuss changes to a shared representation before actually making those changes. Therefore the potential actions supported by the representation are more likely to be discussed (i.e., this influence of the representation is socially amplified).
2. *Representational proxy for purposes of gestural deixis*: Shared representations provide an easy way to refer to ideas previously developed, this reference being accomplished by gestural deixis (reference to an entity relative to the context of discourse by pointing) to the representational proxy rather than verbal descriptions (Clark & Brennan, 1991).
3. *A foundation for implicitly shared awareness*: mutual awareness of information that results from working together in front of a physically shared display can influence participants' thinking. For example, awareness that one's interlocutor may notice a discrepancy between one's proposal and something in the representation may encourage more deliberate consideration than solo work.

Our prior work (Suthers & Hundhausen 2001, 2002, to appear) was based on the observation that all three of these roles are influenced by what a given representation prompts for or makes salient. Similarly, the present hypothesis (H1) is based on the observation that all three of these roles are most effectively filled by representations if the participants are co-present with the representations:

1. One is more likely to feel obligated to negotiate activity with a co-present collaborator.
2. It is easier to refer by pointing (gestural deixis) when co-present.
3. Subtle cues about what one's interlocutor is attending to are only available when co-present.

Thus (according to H1), the affordances of shared representations will have less of an effect on interpersonal interaction when the interlocutors are not co-present. Specifically, in the Distal condition we would expect participants to act more independently upon the representation; gestural deixis to be less frequent, less successful, and/or to be replaced with more complex or ambiguous verbal deixis; and participants to generally show less awareness of their partner's attentional orientation and activity.

The Appropriation for Communication Hypothesis (H2)

Recall that H2 states that the influence of knowledge representations in the Distal study will be stronger because participants rely more on those representations for their communication in the absence of face-to-face communication. Being adaptive, people compensate for the limitations of computer media for communication. For example, Herring (1999) describes how people compensate for and even exploit incoherence in textual discourse media such as chat and threaded discussion. H2 expresses our expectation that participants in our study would rely more on the graph medium to support their communications in the absence of face-to-face communication. Therefore, there would be more opportunities for the features of the graph medium to influence the discourse. (These features are discussed further below.) An additional implication of this hypothesis is that the discourse role of activity in the graph would shift, including more deliberative process rather than simply being the final expression of negotiations undertaken verbally (as was typical in the face to face collaborations we studied).

Expected Changes in Previously Studied Measures

Because we wanted to see how the roles of representations changed when introducing computer-mediated distance interaction, we planned to apply the measures already used in the Proximal condition as part of our previous study to see how these measures might change in Distal. Those measures that are relevant to H1 and H2 are discussed below.

Two measures, *Epistemic Classification* and *Evidential Relation,* are concerned with categories that are specifically supported by the knowledge representation software. The Graph provides shapes for categorizing ideas as empirical Data or theoretical Hypotheses (Epistemic Classification) and links for relating them as being consistent or inconsistent with each other (Evidential Relation). If we accept H2 then we would predict that greater reliance on the knowledge representation as a medium of *interaction* would result in more of the interaction being concerned with these categories.

The *Revisitation* measure is relevant to H1. According to H1, without co-presence, the representations will not function as well to remind participants to return to previously represented information nor will they as easily facilitate reference to previous information through gestural deixis. Therefore there will be less revisitation in Distal. According to H2, revisitation of previously represented items would be quite natural while interacting via the knowledge representation medium (as well as via chat).

The previous study also included measures of post-session performance, including an individually taken test of recognition memory and the quality of an essay written collaboratively after the problem solving session was over. Although H1 does not make direct predictions about either of these measures, one might infer from H1's prediction that distally-shared representations will be less effective in coordinating collaborative work that there will be a degradation of the quality of the collaborative essay. Therefore we included and analyzed the essays in the Distal condition for comparison to our Proximal results.

The remainder of this paper reports how we explored these hypotheses in the context of our prior study of representational affordances in the proximal condition. The next three major sections of the paper report the experimental design; detail our methods of data collection and coding; and report the quantitative results. Our results showed that the distribution of activity was quite different between the Proximal and Distal groups, with the quantitative process data largely supporting H2, and with some indirect support for H1. The conclusion of the paper synthesizes these hypotheses and discusses broader implications for the nature of collaborative learning with knowledge representations.

Design

The present study built on a prior study that compared three representations: Graph, Matrix, and Text (Suthers & Hundhausen, 2001, 2002, to appear). 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. Therefore the present study employs a single-factor, between subjects design with two participant groups: Proximal (face to face) and Distal (synchronous collaboration via networked software). 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 in the Graph as they encountered them. Dependent measures reported here include (a) the content and location of participants’ utterances and representational actions, and (b) the quality of a collaboratively written essay.

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. Pairs of participants were randomly assigned to the three treatment groups such that (a) there were no differences in the gender balance of each group, and (b) there were no significant differences between the groups' mean grade point averages.

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 and the Distal version in Figure 2.

The right-hand window of the Proximal version and the upper-right window of the Distal version each enable one to advance through a series of textual pages. Each of these pages presents a piece of information pertaining to one of two problems: the cause of mass extinctions at the end of the Cretaceous, or the unsolved mystery of ALS-PD, a neurological disease combining symptoms of Parkinsonism and dementia, which historically had an unusually high occurrence on the island of Guam. We designed a sequence of pages in which new pages bear upon the interpretation of information seen several pages earlier. One clicks on the "next" button to advance to the next page. The software does not enable the user to revisit previously encountered pages. We decided to control the sequence of page visitations to enable us to study the utility of the different representations for relating new to prior information by comparing each groups' work.

---------- Insert Figure 1 about here ----------

In both cases, 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., 2001), and enables one to build a graph of nodes (data items and hypotheses) and links (evidential relations). To create a data item node (a green rectangle), one types the data text into the text field centered above the graph drawing area, clicks on the "Add Data" button, and finally drags and drops the node in the graph drawing area. One creates a hypothesis node (a pink rounded rectangle) in the same way, except that one clicks on the "Add Hypothesis" button. Finally, to create a link, one clicks on the "Add + link" (supports), "Add – link" (conflicts), or "Add ? Link" (unsure or unspecified) button, and then clicks, in sequence, on the two nodes between which the link is to be positioned.

---------- Insert Figure 2 about here (or together with Figure 1) ----------

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 "send" button was pressed. Both versions of the software supported gestural 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 maximize the potential of the knowledge representation as a resource during conversation in the Distal as well as Proximal condition.

Tasks

Participants were told to prepare for an imaginary field trip to Guam by studying some background articles on the ALS-PD disease, with the ultimate goal of discovering the cause of the disease. They were asked to formulate a set of hypotheses regarding the cause of ALS-PD and evaluate data for and against those hypotheses. Participants were instructed that the right-hand window would present background research, one page at a time. They were instructed to record the information on each page using the software tool in the left-hand window and that they would not be able to revisit a page once they clicked on the "next" button. Finally, they were advised that, upon completing all of the pages of background research, they would individually take a short multiple-choice test designed to evaluate their familiarity with the information they explored, and then work with their partners to write an essay summarizing the results of their research. The essay instructions asked participants to write (a) a brief paragraph describing each hypothesis they formulated and summarizing the evidence for and against the hypothesis, and (b) a concluding paragraph that identifies the hypothesis or hypotheses that they believe were best supported by the evidence, and justifies this decision. The primary emphasis in the instructions was on uncovering the cause of the disease rather than on preparing for these assessments.

Procedure

At the beginning of the learning session, participants (co-present in both conditions) were given a brief (10-minute) introduction to the software they would be using. At the conclusion of this introduction, one of the Distal participants was led to a different room containing an identical computer setup. Then, in both conditions, participants worked on a warm-up problem (on mass extinctions) that was unrelated to the main problem, so that they could become acquainted with the software and the information-recording process. After 12 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. When they reached the page that informed them that there were no more pages left, the experimenter asked them whether they felt they were done. Some participant pairs decided that they wanted to work further on their representations; they were given as much additional time as they needed. Once a participant pair declared themselves done, the experimenter instructed them to turn off their computer screen(s), at which point they were given 20 minutes to individually complete a multiple-choice post-test. (We did not have any specific predictions about the outcome of this test, but administered it to keep the conditions the same as Proximal.) At the conclusion of this test, the Distal participants were brought back together. In both conditions, participants then were allotted 30 minutes to complete a collaborative essay using a word processor.

Data Collection and Transformation

We had to employ several nontrivial methods to collect and prepare our data for analysis. In this section, we summarize the process by which we collected our data, as well as the methods we used to transform our raw data into analyzable data. Details of the coding may be found in Suthers & Hundhausen (2001, 2002, to appear).

Gathering Session Data

In the Proximal condition, we recorded and merged two video streams of participants' interaction. One captured their gestures on the screen and the other captured the contents of the computer monitor. Participants' talk was recorded in stereo, with the participants' voices recorded in opposite channels. In addition to this audio/video record, we collected automated software logs containing time stamped records of changes to the information pages and of participants' actions within the representational software. We created detailed transcripts of the 10 participant sessions by transcribing all participant interaction and gestures from the videos into the software logs.

In the Distal condition, all data collection was conducted automatically via the software logs. In addition to logging changes to the information pages and participants' actions within the representational software, the software logged their chat interactions. Thus no manual transcribing was required for the Distal condition.

Coding Learning Session Segments

The transcripts so obtained were broken up into *segments*. Segmentation of utterances (whether verbal or in the textual chat) was based on the principle that a single proposition or idea should occupy a single segment. Likewise, each high-level action in the software (for example, creating a new data item or hypothesis) was transcribed as a single segment. We then performed a content analysis of participants' learning processes by coding all segments in the 20 transcripts into 8 mutually exclusive "topic" categories, including Evidential Relation and Epistemic Classification. In addition, we coded topic segments with "modifier" categories, according to whether the segment was *verbal* or *representational*, *recited* (from materials we provided) or *non-recited,* and *introduced* or *repeated*. See Suthers & Hundhausen (to appear) for details. In order to verify the reliability of our coding system, we had two independent analysts code 20% of the transcripts. With respect to the eight mutually exclusive "topic" categories, our analysts attained 89% overall agreement, and 0.86 kappa. With respect to the modifier categories, agreement levels ranged from 88% (0.77 kappa) for introduced vs. repeated, to 100% agreement (0.99 kappa) for verbal vs. representational. We decided that our coding system was sufficiently reliable, and had a single analyst code the remaining 80% of the transcripts.

Coding Information Items

Participants chose to represent and relate the information they encountered in different-sized semantic units. In order to ensure that pairs who chose to divide information into smaller semantic units did not get credit for representing or talking about more items, we performed the same task as the participants in our study, identifying a set of 15 data items, 4 hypotheses, and 22 evidential relations that we believe a scientist exploring the materials would have identified. These items, which we call *reference items*, were obtained by full consensus of the first two authors and served as normalized semantic units for our counts.

Coding Elaborations

Several of our analyses are concerned with the extent to which alternative representations encourage participants to revisit and elaborate on previously represented items. Since we were specifically interested in elaborations that may have been prompted by participants' representations rather than by our information pages, our analysis operationalized *elaboration* as any reference (whether verbal or representational) to an item that took place while participants were viewing an information page that followed the page they were viewing when they initially represented the item.

Scoring Essays

To assess the quality of reasoning in the essays, we wanted a weighted measure that reflected the fact that (a) certain items were more important to the final analysis of evidence than others, and that (b) certain items were more difficult to infer than others. We devised three separate metrics to weight the importance and inferential difficulty of reference evidential relations found in the essays:

- *Evidential strength*—the strength of the evidential relationship, on a scale of 0 to 4 as follows: 0 = neutral, 1 = apparently relevant because it was mentioned in materials; 2 = weak correlation or expert opinion; 3 = strong correlation or expert opinion, and 4 = demonstration of causality.
- *Inferential difficulty*—the number of information pages that must be accessed in order to infer the relationship, with 0 indicating that the relationship is explicitly stated in the material, 1 indicating that the relationship can be inferred from a single information page, 2 indicating that one must combine information given on two pages, and so on.

- *Inferential span*—the difference (in page numbers) between the first and last page needed in order to infer the relationship. This is a measure of how well participants integrate information given at different pages, which should be sensitive to the utility of the representation.

Results and Interpretations

This section reports our quantitative results and provides initial interpretations of these results in relation to H1 and H2. (Further discussion is deferred until the final section.) We group analyses concerned with the content of *activities and talk* during the learning session, *revisitation of represented items* during the learning session, and *quality of inferences* in the essays.

Learning Session: Activities and Talk

In this section we report measures based on our coding of transcript segments, which include Verbal and Representational activity. 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.

Baseline Counts

Table 1 shows the mean time to complete the learning task (covering the 15 ALS-PD information pages), and Table 2 shows the mean numbers of verbal and representational acts, excluding off task and recited acts, accomplished during this task. Differences between groups were tested using an ANOVA, and were significant for both time on task (df =1, F=8.40, p=0.0096) and number of verbal segments (df=1, F=7.68, p=0.0126), but not for total number of segments nor for number of representational segments. Distal participants took much longer (typically 31 minutes longer) to complete the task, while Proximal participants engaged in over twice as much verbal activity. These results, which do not bear directly on H1 or H2, are not surprising given the greater difficulty of conversing and coordinating activity over a computer connection.

---------- Insert Table 1 about here (or earlier) ----------

---------- Insert Table 2 about here (or earlier) ----------

Epistemic Classifications

An “epistemic classification” is an assertion that a statement is derived from empirical sources (“data”) or theoretical considerations (“hypothesis”). The Graph representation supports epistemic classifications by providing shapes in which participants can classify their statements as “data” or “hypothesis.” Previous classroom research (Toth et al., to appear) found that a graph representation similar to that used in the present study encouraged more epistemic classifications than a text representation (a word processor). However, this effect was not obtained in our laboratory study (Suthers & Hundhausen, 2001, to appear). How might Distal interaction affect participant’s tendency to be concerned with epistemic classifications?

The “Co-Present Affordances Hypothesis” (H1) predicts that representational guidance is less effective when participants are not co-present. Therefore, we might expect that the Graph’s prompting for epistemic classifications would be even less influential in Distal than it was in the laboratory Proximal condition. The “Appropriation for Communication Hypothesis” (H2) predicts that more of the communicative activity will take place in the knowledge representation medium as it is appropriated to make up for the loss of spoken “bandwidth.” Since the Graph software provides primitives for epistemic classifications, we might expect to see either more epistemic classifications overall, or more *Representational* epistemic classifications at the expense of such classifications in the Verbal medium in Distal.

---------- Insert Table 3 about here ----------

Table 3 quantifies the segments that were coded as epistemic classifications in the two conditions. We present this data as both counts and percentages of On-Task segments, breaking down the counts and percentages according to whether the acts were Verbal or Representational. We applied statistical tests to all of the means in Table 3, using ANOVAs for the counts and a nonparametric Kruskall-Wallis for the percentages.[1] All but the total counts were significant: Total Count: (df = 1, F = 3.21, p = 0.0900); Total %: (df = 1, H = 11.58, p = 0.0007); Verbal Count: (df = 1, F = 15.14, p = 0.0011); Verbal %: (df = 1, H = 7.89, p = 0.0050); Representational Count: (df = 1, F = 7.30, p = 0.0146); and Representational %: (df = 1, H = 12.63, p = 0.0004).

The pattern of results matches the predictions of H2 but not H1. There were more epistemic classifications in Distal, both as counts and percentages. Comparing the Verbal and Representational columns, the Proximal participants did their classifying mostly Verbally while Distal participants did their classifying mostly in the Representational medium. These results are consistent with the prediction that Distal participants will place greater reliance on the knowledge representation medium for work that was done in the Verbal medium by Proximal participants; this especially being the case for content that is specifically supported by the knowledge representation medium.

[1] In cases in which we are comparing relatively continuous numeric data (e.g., means of post-test scores or counts), we use an analysis of variance (ANOVA), and a standard post-hoc parametric test (Tukey). In contrast, in cases in which we are comparing ratios with varying denominators (which we report as percentages), the assumptions of the parametric ANOVA are violated, because the data are not of interval scale. Therefore, in these cases, we use a non-parametric Kruskall-Wallis test, along with a non-parametric post-hoc Fischer-PLSD test.

Evidential Relations

Our previous work (Suthers & Hundhausen 2001, 2002, to appear) showed that the knowledge representations used by learners can influence the extent to which they focus on issues of evidence. As with epistemic classifications, we asked how this influence might change in the Distal situation, and our reasoning is similar. According to the Co-Present Affordances Hypothesis (H1) we might expect that the Graph software's prompting for consideration of evidential relations would be less effective in Distal. According to the Appropriation for Communication Hypothesis (H2), we might expect to see more activity focused on evidential relations in Distal, with the difference attributable to an increase of Representational activity at the expense of Chat activity, since the Graph software provides primitives for expressing evidential relations.

---------- Insert Table 4 about here ----------

Table 4 quantifies the extent to which the two groups were focused on issues of evidence, as measured by evidential relation segments. As before, we applied ANOVA to the counts and Kruskall-Wallis to the percentages in the table. The results were not significant for Total Count (df = 1, F = 0.0, p = 0.9454) but were significant for all other comparisons: Total %: (df = 1, H = 5.86, p = 0.0155); Verbal Count: (df = 1, F = 38.90, p < 0.0001); Verbal %: (df = 1, H = 14.50, p = 0.0001); Representational Count: (df = 1, F = 7.83, p = 0.0119); and Representational %: (df = 1, H = 14.30, p = 0.0002).

The pattern of differences is again inconsistent with the prediction of H1: an equal number and greater percentage of segments are concerned with evidence in Distal, not less as predicted. The pattern is again consistent with the prediction of H2: Distal participants address evidence more than Proximal participants, and do so primarily in the Graph medium (as opposed to Chat), while Distal participants rely on the Verbal medium (speech).

The results of this section show that online participants appropriate the knowledge representation medium for what it is designed to support —in this case, classifying statements as data or hypothesis and capturing evidential relations between them. These results suggest that designers of online learning environments should carefully consider the conceptualizations that are supported by the software.

Learning Session: Revisitation of Represented Items

A good representation helps remind its users of information that was previously encountered, and return to that information when it is appropriate in relation to new information. Forming connections between given and new information is important from a learning perspective because it is a form of elaboration, which leads to learning gains (Craik & Lockhart, 1972; Stein & Bransford, 1979; Chi et al., 1989). Therefore, our original study compared the various representations we studied on elaboration, using revisitation as a proxy measure. In that study, we found that structured representations (Graph, Matrix) increase elaboration over Text.

Would the Distal situation change the value of Graph for elaboration? Following reasoning similar to that previously applied, H1 predicts that in the Distal situation, participants will be less likely to feel that they need to address elements of the shared representation, and less able to use the deictic value of the representation in revisiting prior ideas. Therefore there will be less elaboration in Distal. H2 predicts that participants will be conducting more of their interactions in the Graph medium. Therefore, under H2 we might expect that participants will be more likely to notice and reference previous information items, and specifically that they will do so in the Graph medium.

We measured and tested revisitation for data and hypotheses (combined) separately from evidential relations, since evidential relations are often handled differently (Suthers & Hundhausen, to appear).

---------- Insert Table 5 about here ----------

Table 5 reports the percentage of Data and Hypothesis items revisited. Although there were no differences in total percentages of Data and Hypotheses revisited, a Kruskall-Wallis showed statistically significant differences between Proximal and Distal with respect to the percentage of Verbal revisitations and of Representational revisitations (df=1, H=11.66, p<0.0006 in both cases, as they are complements of each other). The difference is in the direction predicted by H2, with more revisitations being Representational in Distal and more being Verbal in Proximal.

---------- Insert Table 6 about here ----------

Table 6 reports percentages of Evidential Relations revisited. Kruskall-Wallis tests showed a significant difference in percentage of Evidential Relations revisited (df=1, H=7.82, p=0.0052), as well as in the Verbal and Representational breakdowns (df=1, H=7.85, p<0.0051 in both cases). The difference was again in favor of H2: Distal participants revisit items more than Proximal participants, and the differences are accounted for by a shift from verbal activity to activity in the knowledge representation formalism.

With the caveat that the results, although significant, did not involve large numerical differences, the results of this section suggest that information that should be elaborated on ought to be given visible forms in online learning environments.

Essays: Quality of Inferences

Weighting evidential relations included in the essays by their Evidential Strength, Inferential Difficulty, and Inferential Span, we obtain Table 7. All three measures were significant under an ANOVA in favor of Proximal: Evidential Strength (df = 1, F= 7.39, p = 0.0141); Inferential Difficulty (df = 1, F= 7.53, p = 0.0133); and Inferential Span (df = 1, F= 8.04, p = 0.0110). We interpret this result to be indirectly in support of H1. Distal participants are not able to take full advantage of the representations as resources for conversation because they are not co-present. Therefore their shared conception of the evidential structure of the domain is not as richly developed, as reflected in the collaboratively written essay.

---------- Insert Table 7 about here ----------

Summary of Results

The results showed that a greater percentage of acts in the Distal condition were concerned with categories provided by the representations (Epistemic Classification and Evidential Relations). Both numerically and in percentage, there were many more Epistemic Classifications in Distal. 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 interaction. These results were consistent with H2.

We documented a shift in reliance on Verbal communication in Proximal to Representational communication in Distal. Participants in the Distal study represented the Epistemic Classification and Evidential Relation categories over two times more than Proximal participants. However, Proximal participants discussed Epistemic Classification nearly five times more than Distal participants, and Evidential Relation categories over nine times more than Distal participants.

The data on revisitation supported the (H2-derived) claim that more communicative work will happen via the knowledge representation, so there will be more revisitation of items in that medium. However, rates of revisitation for evidential relations were low, possibly because evidential relations represent the culmination of inferential work that may not merit revisitation in participants' minds.

The major quantitative evidence for H1 was found indirectly in the essay data: inferential quality of essays suffered in Distal relative to Proximal. However, this result can be attributed to differences between the mode of interaction (face to face versus online), rather than to a reduction in utility of the representations in online interaction. The knowledge representation clearly played an important role in the online interactions, as we have documented.

Conclusions

We began this study hoping to learn more about the differences between the roles of representations in Proximal and Distal synchronous collaboration. Two competing hypotheses were advanced without prejudice:

(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; or

(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.

Our quantitative results provide adequate evidence for the second hypothesis. Talk in categories supported by the knowledge representation software (evidential relation and epistemic classification) increased online, and there was a clear shift to a greater number of communicative acts being undertaken in the representational medium.

This is not to say that we have rejected H1. Our informal review of the transcripts shows many examples of poorly coordinated activity in the online groups, such as disconnects between the activity in the workspace and the verbal activity in the chat. H1 and H2 are not in direct conflict, and may be synthesized as follows: Lack of mutual awareness of orientation towards shared representations may result in poorer coordination of immediate activity and the thinking behind it (H1). At the same time, greater reliance may be placed on those very representations as the medium *through* which activity takes place, biasing activity towards actions best supported by the representations (H2).

With respect to the design of software for on-line learning, perhaps the major conclusion to be drawn from this study is that close attention must be paid to the design of *all* representations as affordances for discourse and media that might be appropriated as a channel through which discourse takes place, regardless of whether the representation was originally intended to be a discourse medium. This conclusion also implies the necessity of coordinating multiple representations. 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 (Ainsworth, et al., 1998; Hoadley & Enyedy, 1999; Suthers, 2001b; Turoff, et al., 1999).

Our future work will focus primarily on asynchronous rather than synchronous online collaboration. This study has helped form a bridge to that work. Yet there remains much to be studied in the proximal versus distal paradigm. The roles of representations can be studied with different tasks, populations, and types of representations. Studies undertaken in classroom or other learning environments would offer greater external validity than this laboratory study. Data analysis might profitably focus on qualitative aspects of the roles that representations play in learners' interactions, using methodologies such as interaction analysis (Jordan & Henderson, 1995). Whether undertaken in face-to-face, synchronous distal, or asynchronous conditions, we believe that further studies of representational affordances for collaborative interaction will be fruitful for development of both theory and practice.

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Tables

Table 1 Mean time to complete learning task, by treatment, in minutes and seconds

	Time on Task	
Treatment	*M*	*SD*
Distal	1:19:14	33:09
Proximal	46:51	12:13

Table 2 ***Mean number of Total, Verbal, and Representational Segments that Were On Task and Non-Recited***

	Total		Verbal		Representational	
Treatment	*M*	*SD*	*M*	*SD*	*M*	*SD*
Distal	271.9	169.2	155.6	137.7	116.5	58.9
Proximal	453.0	231.8	364.6	194.7	88.4	38.6

Table 3 ***Mean Epistemic Classification Segments as Counts and as Percentages of the Total, Verbal, and Representational On-Task Segments***

	Total				Verbal				Representational			
	Count		%		Count		%		Count		%	
Treatment	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Distal	64.4	31.0	27.8	10.7	2.5	4.0	0.9	1.2	61.9	31.2	27.0	11.0
Proximal	43.9	18.7	10.3	3.0	12.0	6.6	2.9	2.0	31.9	16.1	7.4	2.5

Table 4 ***Mean Evidential Relations Segments as Counts and as Percentages of the Total, Verbal, and Representational On-Task Segments***

	Total				Verbal				Representational			
	Count		%		Count		%		Count		%	
Treatment	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Distal	56.1	31.5	22.6	7.4	3.5	5.1	0.8	1.1	71.8	44.9	21.8	8.1
Proximal	56.9	18.3	14.4	6.5	31.4	13.2	8.2	4.9	34.7	12.3	6.1	2.1

Table 5 ***Mean Percentages of Represented Data Items and Hypotheses Revisited within the Learning Session***

	Total % Items Revisited		% Revisitations that were Verbal		% Revisitations that were Representational	
Treatment	*M*	*SD*	*M*	*SD*	*M*	*SD*
Distal	58.4	21.7	48.1	21.1	51.9	21.1
Proximal	46.7	16.5	62.3	17.0	37.8	17.0

Table 6 Mean Percentages of Evidential Relations Revisited within the Learning Session

	Total % Items Revisited		% Revisitations that were Verbal		% Revisitations that were Representational	
Treatment	*M*	*SD*	*M*	*SD*	*M*	*SD*
Distal	13.7	15.8	31.0	29.5	29.0	28.0
Proximal	0.0	0.0	0.0	0.0	0.0	0.0

Table 7 ***Mean Evidential Strength, Inferential Difficulty, and Inferential Span Scores for Evidential Relations Included in Essay***

	Evidential Strength		Inferential Difficulty		Inferential Span	
Treatment	*M*	*SD*	*M*	*SD*	*M*	*SD*
Distal	9.6	9.6	5.2	6.5	10.5	14.8
Proximal	22.5	11.5	13.7	7.3	31.3	17.8

Figures

Captions:

Figure 1. Graph interface used in Proximal condition

Figure 2. Graph and chat interface used in Distal condition

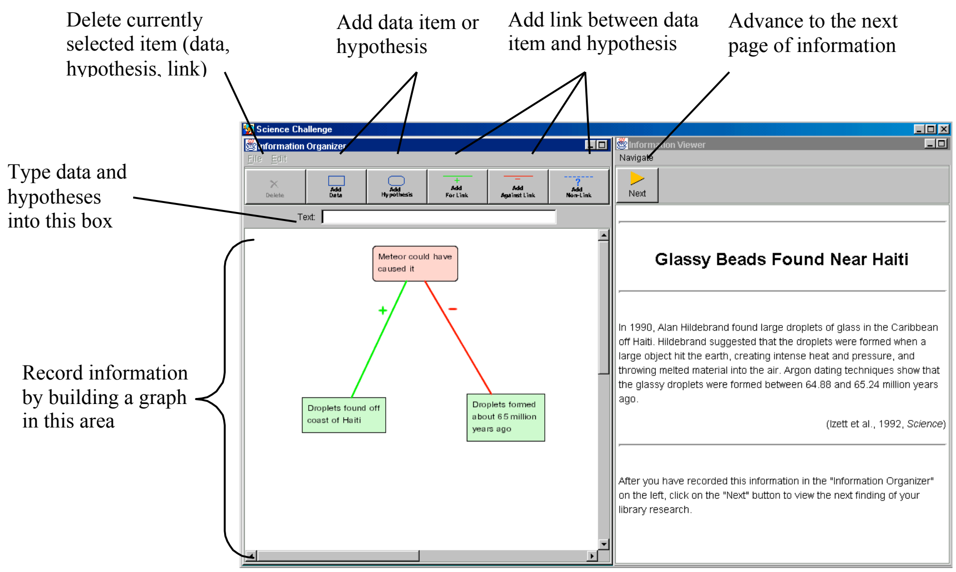
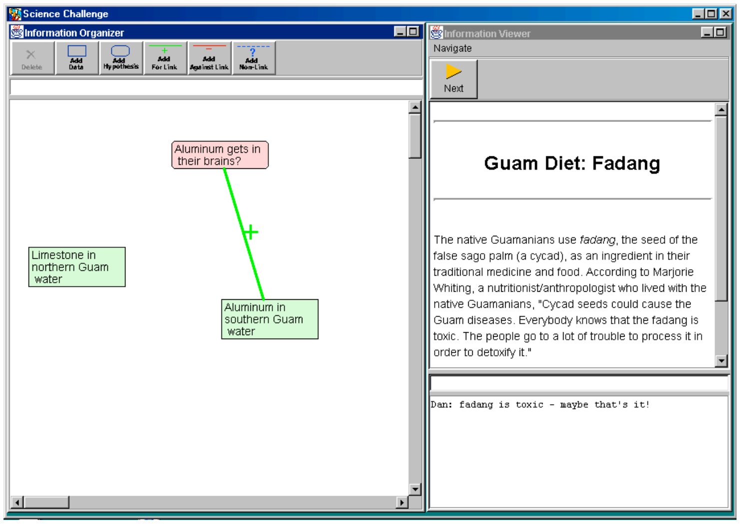

Delete currently selected item (data, hypothesis, link)
Add data item or hypothesis
Add link between data item and hypothesis
Advance to the next page of information
Type data and hypotheses into this box
Record information by building a graph in this area
Science Challenge
Information Organizer
File Edit
Delete
Add Data
Add Hypothesis
Add For Link
Add Against Link
Add Non-Link
Text:
Meteor could have caused it
+
-
Droplets found off coast of Haiti
Droplets formed about 65 million years ago
Information Viewer
Navigate
Next
Glassy Beads Found Near Haiti
In 1990, Alan Hildebrand found large droplets of glass in the Caribbean off Haiti. Hildebrand suggested that the droplets were formed when a large object hit the earth, creating intense heat and pressure, and throwing melted material into the air. Argon dating techniques show that the glassy droplets were formed between 64.88 and 65.24 million years ago.
(Izett et al., 1992, Science)
After you have recorded this information in the "Information Organizer" on the left, click on the "Next" button to view the next finding of your library research.

Figure 1

Figure 2


Science Challenge
Information Organizer
Delete
Add Data
Add Hypothesis
Add For Link
Add Against Link
Add Non-Link
Aluminum gets in their brains?
Limestone in northern Guam water
Aluminum in southern Guam water
Information Viewer
Navigate
Next
Guam Diet: Fadang
The native Guamanians use fadang, the seed of the false sago palm (a cycad), as an ingredient in their traditional medicine and food. According to Marjorie Whiting, a nutritionist/anthropologist who lived with the native Guamanians, "Cycad seeds could cause the Guam diseases. Everybody knows that the fadang is toxic. The people go to a lot of trouble to process it in order to detoxify it."
Dan: fadang is toxic - maybe that's it!