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DEICTIC ROLES OF EXTERNAL REPRESENTATIONS IN FACE-TO-FACE AND ONLINE COLLABORATION

Abstract. This research explores how shared, learner-constructed representations serve as resources for conversation in face-to-face and online situations. An important role of shared representations in collaborative learning is to facilitate the ease of reference to previously introduced ideas. Complex ideas are more easily expressed when their component ideas can be indicated with simple gestures. Yet gesture does not have the same immediacy in typical online learning environments. We examined the extent to which gestural deixis is inhibited online, and how shared representations serve as conversational resources in other ways. Results show that gesture was almost never used online, and was partially replaced with verbal deixis and direct manipulation of the shared representation. Verbal deixis almost always referenced ideas already in the focus of attention, posing a potential problem for reflection on prior information. These results suggest the importance of better integration between communicative tools and shared representations and the inclusion of prompts for reflection.

1. INTRODUCTION

Our research centers on the design of software tools to support learners' construction of knowledge representations (e.g., concept maps, evidence maps, evidence tables), and the effects that representational notations have on collaborative learning processes and outcomes (Suthers & Hundhausen, 2003). Shared representations play several roles specific to group use, including prompting participants' negotiations, supporting reference to prior ideas through gestural deixis, and providing a foundation for implicitly shared awareness. Since certain representational affordances for collaboration, such as gaze and gesture, are most accessible when working together in front of a physically shared display (Clark & Brennan, 1991; Fussell, Kraut & Siegel, 2000), we are exploring how these roles of representations in supporting collaboration might be fulfilled in online learning.

Extensive prior research has compared the performance of face-to-face collaborators with the performance of users of various forms of technology-mediated communication. Many of these studies show that problem solving and communication is compromised for online users due to the reduced modes of interaction provided by technology-mediated communication (Olson & Olson, 1997; Doerry, 1996). Other studies show that people can compensate for and even benefit from restricted interaction (Herring, 1999; Burgoon, et al. 2002), and that factors extrinsic to the technology itself may play a role (Walther, 1994). It is not our intent to test these results, nor to compare the merits of face-to-face and technology-mediated communication. Although we compare face-to-face and online interaction as a research strategy, our goal is to learn how to design better representational support for online collaboration, not necessarily to replicate face-to-face modes of interaction (Hollan & Stornetta, 1992).

This paper reports a new analysis of data from a study initially conducted to determine whether the representational effects that we previously observed in face-to-face collaboration (Suthers & Hundhausen, 2003) would be obtained online. Our first analysis (Suthers, Hundhausen, & Girardeau, 2003) showed that in the online condition, a graphical evidence-mapping tool was appropriated for communicative functions that were undertaken verbally in the face-to-face condition. Online participants were more likely to propose new ideas in the graph. However, we also observed less use of gestural deixis and less rich discussion in the online condition. This raised the question of whether participants compensated for the lack of gestural deixis by drawing on shared representations as resources for conversation in other ways. The analysis reported in this paper addresses this and related questions.

In the remainder of the paper we summarize the study design, and report both quantitative results and typical examples. We illustrate how face to face participants used gestures to shared representations to easily reference both previously encountered ideas and current information. We then investigate whether online participants accomplished this referential work through other means, namely verbal references or direct manipulation. We found that online verbal deixis was most often temporally indexical, and therefore focused on recently added items. This raised the question of how online participants revisited prior information. Our analysis showed that more revisitations were accomplished through direct manipulation of representational proxies. Finally, we note that most interpretative and reflective interaction is accomplished verbally. Since online verbal interaction is temporally focused, online participants may be less reflective about connections to prior information. This hypothesis was corroborated by an analysis of essay quality. We conclude with implications for the design of online learning environments.

2. DESIGN SUMMARY

This study built on a prior study that compared three representations in a face-to-face condition: graph, matrix, and text (Suthers & Hundhausen, 2001, 2002, 2003). The design of the present study is detailed in Suthers, Hundhausen & Girardeau (2003) and summarized here. We implemented a synchronous online collaboration version of the graph software and compared performance and interaction to that of the previous study's face-to-face graph condition. Therefore, this study employs a single-factor, between-subjects design with two participant groups: *face-to-face* and *online*. The primary dependent measure addressed is the mode and quantity of references to ideas previously expressed in the graph representation. The online group consisted of ten self-selected, same-gender pairs from introductory natural science courses at the University of Hawai`i. Gender balance and mean grade point average did not differ significantly from those of the 10 face-to-face pairs.

The experimental software provided a graphical tool for constructing representations of the data, hypotheses, and evidential relations that participants gleaned from the information pages. The graph tool was based on version 3 of Belvedere (Suthers et al., 2001), and enabled one to build a graph of nodes (data items and hypotheses) and links (evidential relations) representing an evidence

model. Links can be created to represent consistency (+), inconsistency (-) or unspecified (?) relations.

An information window enabled participants to advance through a series of textual pages presenting information on the unsolved mystery of ALS-PD, a neurological disease with an unusually high occurrence on Guam. Each new page may bear upon the interpretation of information seen several pages earlier, and users cannot revisit pages. Control over the sequence of information enabled us to study the utility of different representations for relating current and prior information.

The software for the online condition provided a chat tool. Messages typed into an entry box were sent to both participants' shared chat displays once the Return key was pressed. Both versions of the software supported gestural deixis in two ways; one being automatic and the other requiring more deliberate action on the part of the user. If the user passed the cursor over an object, the fill-color of the object changed to blue. This was intended to enhance the deictic value of the cursor by making its location more visible. If the user deliberately selected an object with the cursor, the object was highlighted in yellow. The online version of the software replicated both of these color changes to the remote display. To maximize the potential for online participants to use this option for gestural deixis, we demonstrated this highlighting during their instruction phase.

Pairs were given a 10-minute introduction to the problem, the task and the software. In the online condition, one participant was then led to a separate computer in a different room, while in the face-to-face condition they worked together in front of a single shared computer. Both groups then engaged in a 12-minute warm-up exercise on an unrelated problem (mass extinctions). The main problem consisted of 15 informational pages on the ALS-PD disease, and participants were allowed to continue their interaction until they felt they had reached a conclusion. At the conclusion of the session, the computer monitors were turned off and pairs in both conditions were given 30 minutes to collaborate on writing an essay from memory in which they summarized their hypotheses, the evidence for and against them, and their final conclusions.

Transcripts were manually created from video in the face-to-face sessions and automatically logged in the online sessions. Transcripts were divided into "segments," each consisting of a verbal (spoken or typed) utterance (multi-propositional utterances were divided into individual segments) or a change to the representation. Our analysis restricted attention to segments classified as *on-task* and *nonrecited* (i.e., excluding reading aloud of the materials). We further classified these segments as *verbal* (accomplished by spoken language or natural language chat), or *representational* (accomplished by acting on the representation). In the present study, our analysis was concerned with how participants used the external representation as a resource for conversation, particularly by leveraging its potential for deictic reference to previously represented ideas and potentially new relationships between them. Therefore our coding focused on gestural and verbal deixis and changes to the representation.

Two modes of gestural deixis were analyzed: pointing with the finger or hand, and use of the cursor. Since manual pointing was only communicatively relevant in the face-to-face condition, it was not recorded for online participants. Although

cursor-based deixis was available in both conditions, other evidence besides the mere presence of the cursor over an object is needed to ascertain referential intent. We therefore considered only those gestures where such communicative intent could be identified by its coordination with a spoken or typed utterance. For example, one partner might say, "This goes to that" while pointing to two items.

We also considered *verbal only* deixis, consisting of verbal references to the representational proxies of domain-related items or ideas without gesturing. For example, a statement such as "Connect that" might be entered into the chat tool. *Gestural only* deixis was not analyzed, since its meaning is difficult to determine in the absence of verbal communication. Therefore, our results may not capture some more subtle communicative uses of representations through gesture (particularly in the face-to-face condition). Finally, we examined *direct manipulation* of the graph as an alternate means of communicating with external representations.

3. RESULTS AND EXAMPLES

A total of 4530 segments in the face-to-face condition and 2719 segments in the online condition were on-task and nonrecited. Of these, 3646 (80%) face-to-face and 1556 (57%) online segments were verbal (spoken or typed). An independent samples t-test shows a significant difference between the numbers of verbal segments (1556, df = 1, T = -2.77, p = 0.0126). Thus, as would be expected due to the greater ease of speaking, there is more verbal interaction in the face-to-face condition.

3.1 Gestural Deixis

We expected less use of gesture for communicative purposes in the online condition. This was indeed the case. We could identify only two cases where online pairs were clearly using gestural (cursor-based) deixis for referential intent in conjunction with chat (a negligible .07% of on-task, non-recited segments and .1% of chat segments). In contrast, face-to-face pairs used gestural (cursor or manual) deixis coordinated with spoken utterances at least 169 times (3.7% of on-task non-recited segments and 4.6% of spoken segments).

Gestural deixis on a shared representation supports rich conversation by making it easy to identify ideas or information that have representational proxies. One can quickly express complex ideas by gesturing to the component ideas. Gesture is spatially indexical: idea that has a representational proxy in the shared visual field is equally available regardless of whether that information was recently or previously encountered. Therefore gesture is useful for integration of new and old information. Table 1, below, illustrates a typical exchange in which face-to-face participants use this property of shared representations to their advantage. (See Table 2 for a key of codes used in the examples.) Participants are trying to decide whether the toxicity of cycad seeds is an independent explanation for the disease, or merely a component of a water contamination hypothesis. In the process, previously represented ideas are reintroduced into the conversation.

Table 1: Example of use of gesture, face-to-face condition

Context: Participants have just created H1, and P1 is linking it to several data items.

#	*Who*	*Act*	*Object(s)*	*Spoken content or link type*
1	P1	A	H1+D5	*+ [a consistency link is added between H1 and D5]*
2		A	H1+D6	+
3	P2	S/G	D5, H1	Actually, you can't say that this goes to that, though.
4	P1	S		Why?
5	P2	S		Because other people drink from the water too, yeah?
6	P1	S		Like who?
7	P2	S		The Navy people.
8	P1	S		Maybe they, maybe they got their stuff from somewhere else.
9	P2	S/G	*D7, H1	And then this will go against the idea of this.
10	P1	S/G	*D9	Except when they get here, though.
11	P2	S/G	H1, D9	But then this will go with this, you know what I'm saying?
12	P1	S/G	D9, D8, D7, D6, H1	Yeah, but this would make this whole thing go with it, though. *[Gesture sweeps through four D to H1]*
13		S		I mean, because the seeds are soaked in the water, it makes the seeds part of the water hypothesis.
14	P2		*D8	This lady thinks it could be just from the seeds, though.

Key		
	H1	ALS-PD comes from the contaminated water of Guam
	D5	all ALS-PD patients between 1947-52 were native Guamanians
	D6	fading, the seed of cycad, is an ingredient in their traditional medicine and food
	D7	fading is toxic
	D8	According to Marjorie Whiting, a nutritionist/anthropologist, Cycad seeds could cause the Guam diseases
	D9	seeds are soaked in the water for a long time

3.2 Verbal Deixis

Gestural deixis to both recent and prior information was functionally important in face-to-face conversations, yet much less common online. How might online participants have used the representations to accomplish similar deictic functions without gesture? One alternative is the use of verbal-only deixis, in which participants refer to elements of the graph in the chat channel. Was this form of deixis sufficient to compensate for the lack of gestural deixis?

There were 39 chat segments containing indexical references to elements of the graph (1.4% of on-task non-recited segments and 2.5% of chat segments). Therefore, verbal deixis did occur, but less than would be needed to compensate for the percentage of gestural references in the face-to-face condition (3.7% and 4.6%, respectively), let alone the numerous (but unanalyzed) verbal-only indexical references to the graph that occurred in the face-to-face condition. Without the aid of gesture, verbal deixis is not always effective online, as illustrated in Table 3.

Participant 2 (P2) uses the phrase "the water" (line 2) to identify a hypothesis that is in the visual display, but further clarification is required by P1.

Table 2: Codes used in examples

Acts:	A	Object added to representation
	C	Chat
	D	Object deleted from representation
	G	Gesture on the indicated objects
	M	Object modified in representation
	S	Spoken content
Objects:	*	Previously represented object is being reintroduced into the conversation
	D	Data object
	H	Hypothesis object

Table 3: Example of verbal deixis, online condition

Context: Participants have just finished creating D26 and linking it to D25

#	*Who*	*Act*	*Object(s)*	*Chat content or link type [spelling as given]*
1	P1	C		Does it link with any of the hypothesis?
2	P2	C		Maybe the water
3	P1	C		Haha most of our hypothesis has the word water in it
4		C		Which one haha
5	P2	C		Bc its southwest guam
6	P1	C		Ohhh ok
7		A	H1?D25	? *["unspecified" link added]*
Key:		H1	aluminum oxides found in Southern Guam's streams hazardous to health	
		D25	local hosp. rcrds. (1950s) combined w/ census rprts at time: indicate rate of ALS-PD in Guam far highest in small village of Umatac (guam's SW shores)	
		D26	roughly 1/2 of adult pop. in Umatac died of ALS-PD	

Interestingly, the reference "it" in line #1 of Table 3 is understood without trouble, even though the literal text is less restrictive than "the water." Unlike "the water," "it" refers to a recently manipulated item: it is temporally disambiguated. While coding the data, we noticed that much of the verbal deixis online tends to refer to recently manipulated items in the graph. To verify our impression, we examined the counts and percentages of deictic references to the graph (both verbal and gestural) that refer to recently introduced versus reintroduced ideas. An idea is defined as "reintroduced" if reference to it is made after the information page from which it came has been replaced with another page. Results show that face-to-face participants were more likely to refer to old ideas through deixis, while online users tended to refer to the most recently manipulated items. In the face-to-face condition, 130 of the 169 verbal/gestural deixis events (76.9%) reintroduce an idea previously represented. Online, only 2 out of 39 verbal deixis events (5.1%) reintroduce a previously represented idea. Our impression is that online deixis is temporally

indexed because mutual awareness is most focused on recently manipulated items, while face to face deixis can be spatially as well as temporally indexed because mutual awareness of the visually shared representation is stronger.

3.3 Direct Manipulation

If online verbal conversation shows fewer deictic references, and these tend to reference recently manipulated items, might there be another manner in which participants use external representations as a resource for referencing represented ideas and information? Prior analysis (Suthers, Hundhausen & Girardeau, 2003) established that online participants are more likely to propose new ideas directly in the graph, while face-to-face participants discuss proposed ideas before modifying the graph. A similar effect may be present with respect to reintroductions of previously represented ideas. Instead of discussing these ideas with gestural or verbal deixis, participants might express proposed modifications by directly manipulating the representational proxies of these ideas. To test this conjecture, we looked at how often face-to-face and online participants reintroduced a prior idea by manipulating its representation (changing it or linking to it) without prior discussion.

Table 4: Example of direct manipulation of the representation, online condition

Context: Participants have just opened page titled "High Concentrations of Aluminum Found in Diseased Brains"

#	*Who*	*Act*	*Object(s)*	*Chat content or link type [spelling as given]*
1	P2	A	D26	ALS-PD patients have high Al concentration in brain
2		A	D27	normal Al level is 1:3 parts per million
3	P1	A	D28	1-3 per million = normal
4	P2	A	D29	ALS-PD Al level is 300:600 parts per million
5		A	D26+*D5	+
6	P1	D	D27	*[deleted]*
7		M	D28	Al level 1-3 per million = normal
8	P2	A	D29+D28	+
9		A	D28+D26	+
10	P1	M	D29	Al level 300-600 parts per million ALS-PD brains
11	P2	A	D29+*H2	+
12	P1	M	D29	Al level 300-600 parts per million = ALS-PD
13	P2	M	D5	drinking water contains high levels of Al in S. Guam
14		D	D6	From S. Guam
15		M	*[various]*	*[repositions various objects for 30 seconds]*
16		C		boy we got something
17	P1	C		heheh ALUMINUM!!!!

Key	H2	Al or AlO is the cause
	D5	drinking water contains high levels of Al *[before modification]*
	D6	from S. Guam

Although there were no differences in total percentages of data and hypotheses revisited, a Kruskall-Wallis showed significant differences between face-to-face and online conditions 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), with more representational revisitations in the online condition. Hence, online participants appear to be substituting direct manipulation of previously represented information for verbal or gestural deixis to that information. The example in Table 4 illustrates revisitation through direct manipulation. Two reintroductions of prior information (marked with *) occur in this example: D5 on line 5 and H2 on line 11.

This example also illustrates how participants can collaborate almost entirely though manipulation of the representations. Upon reading a new information page, both participants begin to record data from that page (line #1-4). There is some redundancy in their parallel work, which P1 removes (# 6, 7, 10, 12) while P2 groups related observations with the + link (#5, 8, 9, 11). The only verbal interaction that takes place outside of the representation is a brief exchange in lines 16 and 17 acknowledging the significance of this work for the aluminum hypothesis.

3.4 Integration of Distributed Information and Essay Quality

It is evident from the transcripts that interpretation and integration of multiple sources of information and other forms of reflection take place mostly in verbal (spoken or chat) modes rather than through the other communicative modes that we have investigated. (See for example lines 2-14 of Table 1.) Combined with previous results, this observation raises the possibility that online participants engaged in less reflection on and integration of previously encountered information, because verbal interaction in the online condition tends towards a focus on temporally recent ideas and information. We should note, however, that most of the sessions concluded with reflective discussion. This discussion typically referenced ideas conceptually rather than through their representational proxies.

Integration of information can be assessed indirectly through the essays written by each pair of participants. We scored the evidential arguments in their essays on three measures of quality: *evidential strength* (the strength of relationship cited, from circumstantial to causal), *inferential difficulty* (how many different pages of the presented information had to be consulted and combined to make the inference), and *inferential span* (how many pages apart the relevant information was presented). Details of this coding method are available in Suthers & Hundhausen (2003). Two of these measures, inferential difficulty and span, are sensitive to how well participants integrate new information with previously encountered information. All three measures were significantly higher in the face-to-face condition under an ANOVA: evidential strength ($df = 1$, $F= 7.39$, $p = 0.0141$); inferential difficulty ($df = 1$, $F= 7.53$, $p = 0.0133$); and inferential span ($df = 1$, $F= 8.04$, $p = 0.0110$). This result suggests that online collaborators need better integration of information encountered over time.

4. DISCUSSION

This study examined how learner-constructed graphical evidence maps were used by learners to support conversation through deixis to the contents of the evidence map in face-to-face and online conditions. The results show that although external representations play important roles as resources for collaboration in both face-to-face and online learning, they are appropriated in different ways to support communication and collaboration. In face-to-face collaboration, deixis was accomplished quite effectively through gesture. Gesture is spatially indexical: it can select any information in the shared visual space, regardless of when that information was previously encountered or introduced. Online collaborators also used external representations for referential purposes, but through verbal deixis and direct manipulation rather than gestural deixis. Verbal deixis in the chat tool was temporally indexical: it most often selected recently manipulated items.

These results raised the question of whether and how online participants revisit prior information. Direct manipulation of the representations seemed to play this role most effectively, and indeed constituted an alternative means through which some aspects of communication about problem solution took place. However, communication in an evidence map (graph) is limited to propositions in the domain and the evidential relations between them. Direct manipulation is in a sense "first order" – higher order reflections such as discussion of possible interpretations of the information available are undertaken more often in the verbal media (speech or chat). Putting these observations together, there is a danger that online discourse may be less reflective, especially in its integration of new and prior information, because the most reflective mode of interaction – verbal – focuses on recent (temporally indexed) items online; while the easiest means of reintroducing prior information is through direct manipulation. This speculation was consistent with the reduced integration scores seen in the essays of online participants.

5. CONCLUSIONS

We conclude that the role of external representations as aids for integrating old and new information in an interactive, conversational manner can be weakened online due to the awkwardness of or lack of deictic affordances. Designers of online learning environments are advised to seek more natural means of referencing the contents of shared representations, particularly in conjunction with verbal communication. For example, chat or discussion tools might be designed to enable easy insertion of visual references to elements of other representations being discussed. Designers might also investigate other methods for helping online collaborators mutually attend to prior information, such as redisplay of prior information along with reflection prompts provided after a period of time.

These conclusions are limited to a laboratory study of a single task under constrained conditions, and further study is warranted. The results are also specific to synchronous interaction. An extension of this work to asynchronous computer mediated communication could examine how users of threaded discussion tools reference shared artifacts.

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