The Computer Display As a Support of Collaborative Development of Scientific Models of Magnetism

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Abstract: Some student difficulties in learning science can be understood by considering the background knowledge that people necessarily assume in conversations. In learning science, students have to develop meanings and understandings that can be taken as shared in conversations. Small groups of students can be aided in their development of shareable understandings by constructing explanations of their thinking on a computer.

This paper describes student interactions in a physical science course for preservice teachers. A group of students working at a computer showed fluent use of the computer screen to support making concrete statements and to extend their understandings. Their use of the screen helped the group to established shared meanings along the way to developing models of magnetic materials.

Keywords: discourse analysis, HCI, physics, shared knowledge

The problem of learning in science

Constructivist epistemology problematizes communication. The notion that a person can't transfer ideas to another requires that educators think carefully about what happens when people talk to each other (von Glasersfeld, 1991; Bettencourt, 1993). Two of the problems faced by learners are that learners have to construct understandings that fit with what they know (that "make sense), and that to communicate learners have to compare their understandings with those of others. This latter problem is not always solved in modern classrooms - students sometimes can’t tell when their ideas are much different from what the teacher tried to say.

An idea from the sociology of communication can explain this (Heritage, 1984). Garfinkel proposed that people in a conversation jointly construct a "reciprocity of perspectives." Because a great deal of the information relevant to every discussion is not explicitly stated in conversations, each participant must assume that relevant information is understood and shared by the other. Thus, each listener interprets statements based on his or her own current, developing understanding of the topic as well as on interpretations of the speaker's understandings and purposes. This is a process of "reciprocal" construction of meanings that the participants feel are mutual or at least non-problematic. In Garfinkel's words, in any conversation, "much that is being talked about is not mentioned, although each [member of the conversation] expects that an adequate sense of the matter being talked about is settled" (Garfinkel, 1963).

Despite the potential of having substantially different understandings, people regularly structure conversations this way for the sake of economy. It is impossible and often unnecessary to explicitly state every piece of information that supports the meaning of a given statement. This omission in conversation of all but the critical pieces of new information, claimed Garfinkel, is supported by powerful social norms. While it is possible to talk more explicitly, doing so involves risks. For example, if a listener repeatedly asks for clarifications that seem unnecessary to the speaker, this becomes a challenge to the perceived normality of the conversation because it breaches the trust that the speaker placed in the listener. Maintaining "reciprocal perspectives," then, is not only a cognitive activity, but also a normatively sanctioned activity "in which each actor trusts that the other will accomplish as a matter of moral necessity" (Heritage, 1984, page 82). This issue is particularly salient in physics classrooms - - students' understandings and expectations of "normal conversation" may stand in the way of their developing ideas consistent with powerful accepted physics ideas.

The two problems of learning mentioned above lead to something like a double bind. For communication to be effective, students must establish repertoires of meanings and interpretations that are useful to them, and that are reasonably similar from student to student, and from student to teacher. But students can have difficulty establishing such agreed-upon sets of scientific meanings because such an effort is socially risky - - conversations that explicitly question and negotiate assumptions challenge the perceived normality of discussions.

This paper takes the position that structured classroom activities and computer tools can be profitably enlisted in the task of helping students question and discuss ideas deeply and explicitly. Computers have the potential to help with this problem because they can flexibly provide representations for students' use, they can present many of them in an organized and sequential fashion, and because their different physical configuration may allow different relationships between students. Students might also benefit from using computer — based representations in ways similar to how scientists use inscriptions to communicate and establish meanings.

Using inscriptions to support science talk

Scientific communities rely on systems of meaning that are distinct from everyday kinds of discussion. One way that scientists establish and support systems of taken-as-shared meanings is by enlisting inscriptions to make their cases (Latour, 1987). The representations that appear in scientific journals, presentations, and textbooks are common referents in scientific discourse. Every particle physicist should be able to draw Feynman diagrams, and every paleontologist has to be able to read a geologic map. The meaning of these special representations or methods of their interpretation are thought to not vary much between members of a scientific community because they are available to all members of the community, and because their meanings or interpretations have been explicitly negotiated.

Scientific representations are particularly important because scientists are most concerned with ideas and explanations rather than physical objects. The most concrete objects in scientific conversations are those graphs and diagrams to which scientists and other interested parties can point. They are important to communication because they are shareable - each member of a conversation can look at and refer to the same thing. Sharing scientific representations and discussing or debating their interpretations may be at the root of establishing shared scientific language and taken-as-shared scientific understandings. Special representations are clearly enlisted in the construction and maintenance of scientific reciprocal perspectives.

Education research has begun to expose the similar importance of representations to students doing scientific investigations (Meira, 1995; Lehrer, et. al, 1998). According to Meira, "cultural conventions, such as notational systems, shape in fundamental ways the very activities from which they emerge, at the same time that their meanings are continuously transformed as learners produce and reproduce them in activity." Meira's "very activities" include the conversational establishment of taken-as-shared meanings. Since inscriptions are important to establishment of shared meanings within scientific communities, it seems likely that they can be similarly useful to students. To understand learning in science, it is therefore important to understand relations between students' use of representations, their development of understandings, and their development of reciprocal perspectives in conversations with each other.

Research on students constructing models of magnetic materials

This paper presents results of analyses of conversations in a group of three students as they tried to understand magnetic materials. In the process of doing inquiry activities, they developed repertoires of taken-as-shared meanings and interpretations about magnetism. How they did so in the context of typing and drawing on a computer screen, and how the computer screen supported these developments, is the topic of this paper.

The students in this study were enrolled in a physical science course for prospective elementary teachers at a large US university. The course used a specially designed pedagogy and course materials that were designed to support students' inquiry learning of physics (Goldberg, 1997). (For further information on the pedagogy and materials, visit the CPU web site at http://cpuproject.sdsu.edu.)

During much of this class, students worked in small groups at computers. On-screen instructions in page — layout type documents directed students to perform experiments alongside the computer and to consider particular questions about the current topic. Groups simply opened these documents and scrolled through them, typing answers directly below questions and drawing diagrams or drawing on top of existing pictures. Typically one student operated the computer, but all three students contributed interpretations of the questions and suggestions for group responses. The activities and questions in these documents were carefully planned and sequenced based on published research in student learning of physics and on previous classroom trials.

During this research study, the students were studying magnetism and magnetic materials. Student groups magnetized nails and tested for attractions and repulsions in a variety of experiments. The class goal, successfully met at the end of the magnetism segment, was for student groups to construct theoretical models of magnetic materials that could explain a wide variety of experimental results. All of the groups settled on models similar to the accepted "magnetic domains" model of ferromagnets.

When the students worked in groups, the documents on the computer screen served a number of purposes. They provided instructions for doing experiments, and they frequently asked groups to answers or draw diagrams on the screen. These responses constructed by groups served as records of the groups' thinking. But more importantly, as they were constructing responses, group members talked to each other at length about what they thought and how to express it on the screen. They uncovered similarities and differences in their thinking, and they explored new issues and ideas. These discussions were supported by representations on the computer screen in a number of ways.

Research methodology

Videotapes of one group's discussions were transcribed and analyzed in detail using qualitative hypothesis testing. (LeCompte & Preissle, 1993). The group's working models of magnetic materials were identified using a variety of triangulated information, and their interactions in discussions were characterized from video data using a "typological analysis" (LeCompte & Preissle, 1993, p. 257). The group's discussions while constructing responses on the computer screen were found to comprise a range of categories or types of group activity (Johnson, 1999). Some of these categories clearly involved inventing or clarifying language and taken-as-shared meaning, and they relied on the computer screen as a communication tool. To illustrate how the students used the computer screen to construct and maintain Garfinkel's reciprocal perspectives, two different interaction types are described below.

Example 1: Making explicit statements from conversation

One of the ways the group used the computer screen in conversation was as a support of their construction of explicit statements. When they faced a new question or issue that they had not considered before, they first talked about what they thought before writing anything down on the screen. Then when the group was ready to begin typing, they often found that their statements had not been sufficiently explicit to be typed, so they had to construct explicit statements from less specific talk. They relied on the computer screen to hold their emerging statements. An example follows.

Early in the magnetism unit, the students used a magnetized nail that was free to rotate. They placed it at different locations around a bar magnet and marked the orientations of the nail at each spot. Their results, copied from their activity document, are shown to the left in Figure 1. The magnetized nail acted like a compass needle. The head end of the nail was attracted to the right end of the magnet, and the point end of the nail was attracted to the left end of the magnet. Then, using a computer simulator, the group placed "compass needles" around a "magnet" to compare with their own diagram. The two diagrams show that the real nails and the simulated compass needles behaved similarly at the ends of the magnets. In the simulator picture, the lighter gray ends of the compass needles apparently correspond to the head ends of the nails.

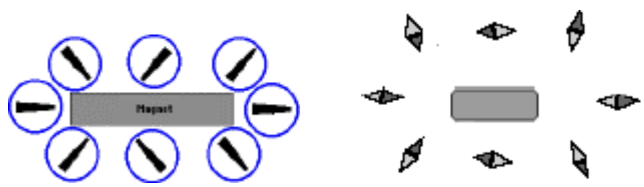

Figure 1: Students' observations with a floating nail in different locations (left) and the computer simulation picture (right)

The computer document provided space and a request for students to compare the two pictures and to type their comparison into the document. The students seemed to recognize that the two patterns had similarities, but they struggled fruitlessly with words until Donna suggested to Anne (who was at the keyboard) that she begin typing some of the things the group members were saying:

Donna	The important thing is that -
Marge	is that it -
Anne	on one end, yeah.
Donna	one end.
Marge	Yeah, you have opposites.
Anne	Also in our experiment our . . ends were opposite.
Marge	Mhmm.
Anne	I don't know how to say it exactly - basically we're saying
Donna	you know
Anne	[*gesturing on the screen*] It's similar with them like their opposites are at one end and - opposite - [*laughs*]
Anne	The nails are pointing in one direction onto the magnet
Donna	on, in one side

Anne	and in the other the opposite ends of the nail are pointing
Marge	pointing to the magnet. Mhmm
Donna	yeah
Anne	Also evident in our
Donna	You need to write - Type when you're talking so you don't lose it. That's what I do.
Anne	I know

At the beginning of this discussion, the group members' talk was hesitant and may not look meaningful in the transcript. The three students clearly agreed that the two pictures had similarities and that they showed something opposite at the two ends of the magnet, but they seemed to be searching for words to use. It seems as if the group members relied on the two diagrams to endow their statements with meaning.

Anne, the typist for the day, admitted that she didn't quite know how to describe the similarities. Her first attempt at a formal statement ("It's similar with them. . ") may seem unclear, but her gestures to the pictures on the screen seemed to make her idea clear enough to Marge and Donna. There was no question for the group about the interpretation of the pictures, their focus was instead on finding a way to describe the similarities. This transcript does not suggest that any of the three students could describe similarities between the two pictures in a straightforward way. However, as soon as Anne began typing, the group began to make headway. The following transcript takes up where the previous one ended. The text that Anne typed either during or directly after the speech is shown in the right column.

	Spoken	**Typed by Anne**
Anne	Okay. Um - So, the, uh. . .	In the picture above, the
	The end of the, uh, one - I was going to say set. Could that be considered a set?	[Anne then deleted "the"]
Anne	One end of the	one end of the magnet has the
Donna	How about cer-	nails
Marge	Attracts the light grey point and the other end attracts the dark grey point.	["has the nails" deleted;] attracts the light grey

Donna	points	points of the nail and the opposite end attra-
Donna	Attracts the dark grey	-cts the dark
Marge	The dark grey	grey
Donna	points	points

Notice how the group members responded to the typed words as much as to each others' speech. Marge's important contribution "Attracts the light gray point. ." was strictly a response to Anne's typed beginning "In the picture above, one end of the magnet . . ." In the fourth line from the bottom when Donna said "points" she was also responding to the text, maybe helping Anne resume the flow of the typed sentence. Near the bottom of the transcript, when Anne stopped at "and the opposite end attra," Donna responded to the stopped cursor on the screen by saying "Attracts the dark grey". The group produced the following statement:

> "In the picture above, one end of the magnet attracts the light grey point of the nail and the opposite end attracts the dark grey points. This is similar to our experiment, where the pointy ends were attracted to one end of the magnet and the thick ends were attracted to the opposite end of the magnet."

In typing this response, the group established a way of talking about the two ends of magnets - "one end and the opposite end" and they established ways of talking about the attractions "light grey points are attracted to one end" and "dark grey points are attracted to the other end." These are evidence for the group’s development of a taken-as-shared way of talking about how magnetized nails and compass needles orient at the two ends of a magnet. The group did use these ideas later.

A few days later, the group was trying to describe differences between static electric and magnetic effects. They remembered the two ended behavior of the magnets and nails, which they hadn’t seen in static electricity. Marge said to her group members that when they rubbed the nail, "we had an attraction at one end and a repulsion at the other end and in [the static effects] we just had a repulsion - it didn't make any difference." This statement, admittedly an incomplete statement of the behavior of magnetized nails around a magnet, was meaningful to Donna and Anne because it relied on a taken-as-shared meaning extracted from their previous shared experience of making sense of the nail behavior.

This example shows two ways that the computer screen was used as a communication tool. Students enlisted pictures on the screen were into their discussion to support their intended meanings. The on-screen pictures, visible to all three students, served as shared referents in the conversation. Also, as the students typed their responses, they used the emerging text to negotiate terminology that became part of more deeply explicated and therefore more robust reciprocal perspectives. The computer screen provided resources for the emergence of meaning within the group.

The computer screen also provided resources for the emergence of new topics of discussion, and thus new ideas. The following example shows one case of this.

Example 2: Extending beyond current expressed ideas

Sometimes features on the computer screen prompted the group to extend their ideas about magnets. Sometimes this was intended by the course designers, sometimes it was not. Often the on-screen instructions deliberately raised issues that the students had not talked about, and probably had not thought about. At other times, however, the group members discovered questions or problems by chance. Their curiosity about phenomena or representations on screen created opportunities to extend their ideas. This happened on one occasion when the group was drawing a diagram of their current model of magnetism.

Partly as a result of the above discussion about the two different effects at the two ends of magnets, the group had decided that an unmagnetized nail had North and South charges mixed up inside, and that magnetizing the nail moved all the North charges to one end, leaving the South charges at the other end. This "charge separation model" is a common idea about magnets (Maloney, 1985; Kraus, 1995, Borges, 1998, Johnson, 1999) because it explains their two-ended behavior in a simple way. However, it is not consistent with the accepted "magnetic domains" model of magnets.

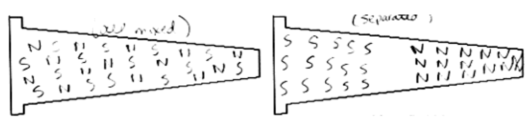

Figure 2: The group's idea about unmagnetized (left) and magnetized (right) nails.

At one point Donna was watching Anne draw a diagram of a nail. Anne was placing N and S letters at opposite ends of the magnetized nail picture. An idea occurred to Donna, and she asked her partners what they thought:

Donna - - think there's a space in the middle of the nail?

Anne I dunno

Donna Do you think like the south - they just butt up?

Anne Just meet at each other.

Donna You know what I'm saying?

Anne Yeah

Marge We didn't test anything for the middle of it, I don't know what happens

Donna I mean just based on our model, do you think, because we're drawing a picture of what we think's happening, do you think that Ss come right up to the Ns, or do you think there's a space in the middle of it?

Marge I don't know. It'd be interesting to take a magnet and

Donna Put it in the middle

Marge yeah, and go up and see when it changes. See if you can keep attraction, attraction, attraction all the way up through the center

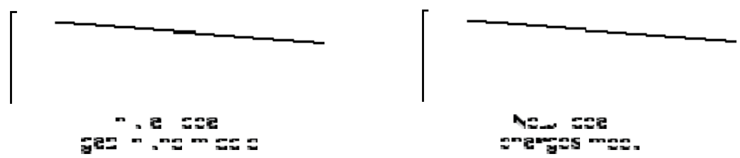

Figure 3: Two different charge separation models

The diagram that Anne was drawing on the computer screen had an influence on the group's thinking. Donna asked her question while Anne was placing N and S symbols on a diagram of a magnetized nail. It seems likely that Donna's question occurred to her as a result of wondering where Anne should stop placing the N and S symbols. Because of this, an issue was raised that the group had not previously considered. Thus, the students' construction of their diagram led to examination and refinement of their model.

As a result of their discussions, the group eventually established a new scheme for drawing magnetized nails. This time they developed not only a shared way of talking, but also a more detailed agreed-upon way of drawing a model. This constituted the development of a taken-as-shared understanding, supported this time by a diagram instead of by text. Once they accepted this new model, each member could treat it as part of the group's repertoire of experiences. Later on, a group member could talk about "how far the Ns must be in the point of the nail" and her partners would know what she was talking about. Group members later mustered this understanding about "how far the charges go in the nail" as accepted background information in conversations.

The computer supported this development by providing diagrams on a screen that was visible to all members of the group, so that any group member was free to point to them. Both Donna and Marge did this as they talked about where the charges go in the nail. Also, the simple fact that all three students were looking at the screen while Anne placed N and S symbols on the nail seemed to provide the setting for Donna to ask her question in the first place.

What if they hadn't used a computer?

Some readers might be thinking that the interactions described in this paper do not seem to require a computer to provide the group with a representational space. Wouldn't this group have had similar discussions around similar text and pictures on some other common representational space like a large sheet of paper or a prepared whiteboard? The simple answer is "probably not." This is because the social context that arises in interaction is due partly to the particular features and affordances of the representational space. For example, suppose the group had a large paper version of the computer document instead of a computer displaying the document. Students would write and draw directly on the paper. This would require that a group member put her hand in the space where she was writing, making that space unavailable (and possibly not visible) to her partners. The computer, on the other hand, separated the hands of the typist from the location where the words appeared. Because of this, the "ownership" or "occupation" of the emerging text was certainly different from what would happen on paper. All three group members were able to read and gesture at the screen, even when words were being typed. A group working with a pencil on paper would not have the same equality of access or flexibility in modifying text. It is hard to imagine that they would speak as freely in response to their partner's words being written on the paper as they did to words spilling across the computer screen.

We also should not overlook computers' abilities for storing, organizing, and re-presenting large amounts of detailed information, such as a large collection of multi-page documents containing text and pictures from a classroom full of students. Computers provide critical logistical support for classroom activities that would not be feasible using other representational media. The course materials used in this classroom could not have been shared within groups of students without the use of computers.

Conclusions

The preceding analyses have attempted to show how a group of students established understandings and meanings that each group member could use as "background information" in scientific conversations about magnetism. Representations on the computer screen, both those provided to the students, as well as those constructed by the students, enabled meaningful discussions about new issues in magnetism. These led to more viable (from a scientific standpoint) reciprocal perspectives among students in a small group.

When they were typing responses, the group members used the computer screen as a place to keep their emerging statement while they formulated the next part of their statement. By serving as a holding place, however, the screen provided more than just a reduction in cognitive load. Rather, each group member read the existing text on the screen to help them formulate the next part. Each new explanation emerged in an interaction between the three students reading what they saw on the computer.

The computer as a representational medium had some important features that supported the students' willingness and ability to collaborate:

- The screen was a shared space for the group. Each student could clearly see features on the screen and use them in conversations. This allowed students to say things that they weren't quite ready to put into words. Referring to words and diagrams on the screen seemed to be a first step in the group's development of ways to talk about magnetic effects and magnetism models. The words and diagrams on the screen provided a means around the "double bind" described at the beginning of this paper, in which it seems that students need to have knowledge in order to develop knowledge. The students were able to bootstrap their conversations about magnetism partly by referring to shared representations provided on the computer screen.

- The group considered their responses to be shared. The act of constructing representations on the screen (typing or drawing) was separated from the representations themselves through use of the keyboard and mouse. Even though one student operated the computer, her hands did not dominate the spaces where text and pictures appeared. This allowed joint ownership of the typed text. Each member could gesture at the group's representation on the screen, without feeling that she was invading the typist's personal space. This is a unique feature of computers screens.

- The group's work became part of the on-screen representations. The text and pictures that the group constructed on the screen served as a kind of record of the group's thinking while they were typing or drawing. It was as if the computer said "here is how you are saying you think." The group members were able to check whether they agreed with what was being produced. This allowed the group members to treat their ideas more like objects of reflection, and it presented the group with opportunities to make modifications, clarifications, and extensions in their text and drawings and in their thinking. Once the group finished working on a response, it became a historical record of the group's thinking. Group members looked back over printed versions of their computer documents and used their responses as reminders of the group's experimental results and ideas.

- The screen supported collaboration. Because there was only one place for the group to put each response, the members felt some obligation to collaborate on statements rather than putting down one student's ideas without question. Each group member felt obligated to have some part of her ideas on the screen. This normally required in-depth group discussions in which students paid much more attention to details and assumptions of each other's thinking than one would expect in normal every day conversations. The students' expectations of "normal conversation" described in the introduction probably changed significantly because of the requirement of one answer per group, on a computer that was ostensibly jointly "owned." The students spent substantial amounts of time finding out how the others thought, and trying to accommodate all three views in one explanation or diagram. This is the way that computer use supported the group's development of taken-as-shared meanings and interpretations.

Acknowledgments

I gratefully acknowledge people who helped discuss this work and provided support - Fred Goldberg, Janet Bowers, Valerie Otero, Elsa Feher, and Jim Monaghan. Thanks also to anonymous reviewers, who helped encourage and strengthen this paper. This work was supported by funds from the National Science Foundation via grant number ESI-9454341.

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