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INTERACTIVE LEARNING ENVIRONMENTS

Thinking with Hands, Eyes, and Signs: Multi-Modal Science Talk in a Grade 6/7 Unit on Simple Machines

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Running Head: HANDS, EYES, AND SIGNS

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Abstract

This study focused on the role of chalkboards in classroom science talk. Using a representative whole-class conversation, similarities of its overall structure with scientific laboratory talk are illustrated. I show how meaning emerges from the interaction of multiple modes of communication. To understand "conceptual" talk and thinking in science classrooms organized as linguistic communities one must account for the fundamental interdependence of "hands, eyes, and signs." This study has important implications for the design of technologies that allow larger numbers of students to participate in whole-class sense-making conversations.

> Ethnomethodological studies of lecturing and of mathematicians' work have identified the essential, mutually constitutive relationships between marks and the activity of their use. Rather than analyze whiteboard inscriptions as such, therefore, we are interested in viewing them in relation to activity, through the use of video records. Viewed as free-standing signs left behind in work, we assume that the sense of these marks is largely undecipherable. Viewed in relation to the activity of their production and use, in contrast, they come alive as the material production of "thinking with eyes and hands" that constitutes science as craft work. (Suchman & Trigg, 1993, p. 153)

This opening quote expresses the increasing recognition that signs (words, marks on whiteboards or paper) cannot be taken as direct evidence of individuals' thoughts but take meaning only from their situated use (Edwards & Potter, 1992; Lave, 1993). Furthermore, people (and especially scientists) do not communicate by linguistic signs alone, but simultaneously draw on an array of other resources: Linguistic, pictorial, gestural, musical, choreographic, and actional (Lemke, in press). Even in the most exceptional traditional classrooms, however, discourse contexts are "impoverished" and do not allow students to talk science let alone integrate talk, diagrams, and other forms of everyday conversation (Lemke, 1990; Pea, Sipusic, & Allen, in press). In contrast, the simple machines unit in this study was designed to allow student participation in a community's discourse practices. Various activity structures supported students to develop ways of describing and explaining simple machines, that is, to learn. Beginning with their own current language prior to the unit, students developed—through successive evolutionary changes—a new language that was more appropriate for constructing arguments. This language was constituted by, and made more efficient through, the multi-modal nature of the discourse. The purpose of this study was twofold. First, access to a shared representational device encourages the (for scientists) characteristic multi-modal science talk that is "thinking with hands, eyes, and signs." Second, this multi-modality encourages school science talk to take the form of scientific laboratory talk. I claim that forceful scientific argumentation emerges in classrooms if students are encouraged to deploy the same discursive resources (hands, eyes, and signs) that scientists routinely use in their laboratory work. When students have direct access to the chalkboard, their discourse uses the same multi-modal form available to teachers and scientists. These claims are illustrated with excerpts from a representative classroom episode—a discussion about the outcome of a tug-of-war involving a pulley system.

Talking Science

The present study follows recent developments in social psychology, cross-cultural and situated cognition, science studies, pragmatic philosophy, and education that take practices, and especially discursive practices as analysts' primary phenomena (Edwards, 1993; Edwards & Potter, 1992; Lynch, 1985; Pollner, 1987; Rorty, 1989; Suchman & Trigg, 1993). Here, all modes of discourse are treated as situated action rather than representational abstraction; language is used to get things done by members of collectivities rather than merely constituting a medium to encode meanings. In the same way, rather than treating diagrams as representations of concepts (e.g., Gerber, Boulton-Lewis, & Bruce, 1995) they are viewed in terms of their use as part of situated action. When conceptual talk is treated as situated action, discourse analysis provides performance descriptions that must be accounted for by any model of underlying competence (Edwards, 1993). However, scientific talk consists of more than words. Like all human communication, it involves the synchronicity of verbal action, inscriptions, pointing and gesture, body movements and rhythm (Lemke, in press). Interruptions of this integration—for example, when conversational participants are no longer in each others' physical presence—become visible as communicative problems. Consequences of such disruptions, as they occur during video-mediated conversation, are interactional asymmetries and "disembodied conduct" in scientific conversation (Heath & Luff, 1993).

Analyses of discourse in scientific laboratories show that there is a mutually constitutive relationship of language, inscriptions, action, and nature (Gooding, 1992). Scientists' manipulations and gestures, to be meaningful scientific actions, are functions of nature and theoretical descriptions. When scientists talk to each other, they use language, marks on paper (graphs, equations, diagrams, images), pointing, gesture, and movement that are meaningful because of their place in a paradigm (Wittgenstein talks of life forms or language games). Their shared "seeing" is constituted by a complex of activities that include fingering documents, conversational talk, and visual examination; "seeing" is interactively accomplished (Amann & Knorr-Cetina, 1990). When they finally publish their findings in scientific journals, scientists co-deploy text, graphs, tables, and images. However, graphs, tables, and images are not merely enhancements of text, but stand with it in a mutually constitutive relationship; they are not simply add-ons or means to more economically present some information, but they in fact multiply meaning (Lemke, in press).

Most traditional classrooms are characterized by a particular form of discourse in which teachers determine and control legitimate knowledge (Lemke, 1990; Poole, 1994). However, researchers are increasingly interested in classroom sense-making conversations because of their potential to engage students in the discursive practices of the domain (diSessa & Minstrel, in press; Godfrey & O'Connor, in press; Orsolini, 1993; Orsolini & Pontecorvo, 1992; Sherin, diSessa, & Hammer, 1993; Théberge, 1993; Warren & Rosebery, in press). These studies are primarily concerned with the "conceptual" content of classroom conversations. Few consider the interdependence of science talk and the representational devices used during conversations. In this respect, past studies show that large area display devices, such as chalkboards and whiteboards, serve as explicit group memory aids for face-to-face task groups (Lakin, 1990; Suchman, 1990). A number of recent studies suggest that representational technologies, such as computers, could provide not only informational resources, but also structural support to students' science conversations (Pea et al., in press; Roschelle, 1992). The present study explores the structural support classroom science conversations receive from the presence of one representational technology, the blackboard.

As a result of this study, I sought specific requirements for the design of computer technologies that would enhance structural support to conversations. Small-group collective work is facilitated when participants have equal access to and power over a representational technology. In semantic mapping on desk tops, three to five participants could easily contribute; in several studies we observed that the resulting collective work was very democratic (Roth, 1994; Roth & Roychoudhury, 1992). Computers as representational technologies allowed only two individuals to fully participate in the sense-making talk; the remaining students in the group did not have enough access to input and output devices to afford the integration of hands, eyes, and signs (Roth, Woszczyna, & Smith, in press). To make large-group conversation more democratic by providing simultaneous physical access to all members, the open challenge is to design environments for the collective work of larger groups. Heavily computer-based and costly technology that provide visual languages for cooperation (Lakin, 1990), while appropriate, may not provide feasible solutions for schools. New developments experiment with "desktop" interfaces in which paper documents are scanned and projected with electronic documents onto large flat surfaces; these address the needs of participants concerning visibility, size, and orientation of displays (Luff & Heath, 1993).

RESEARCH DESIGN

Students

This study was conducted in a Grade 6/7 classroom at Mountain Elementary School (all proper names are pseudonyms) located in an urban area in Western Canada predominantly serving a middle-class clientele. There were 10 Grade 6 (5 boys, 5 girls) and 16 Grade 7 students (7 boys, 9 girls). In contrast to other classes in this school that were taught by one or two teachers throughout the year, these students saw seven different teachers each week which led to considerable variations in classroom norms and associated differences in student behavior. A high number of children with special needs (10) contributed to the fact that this class was very difficult to teach.

Simple Machines Curriculum

This unit on simple machines was based on the notion of learning as an increasing generation of and participation in discursive practices. Its main focus was on developing of students' language related to simple machines. In such a situation, curriculum design is concerned with creating opportunities for a language that makes sense to all participants, that is, students and teacher. Any discourse about simple machines therefore had to develop beginning with students' pre-unit language. By choosing appropriate artifacts (physical models and corresponding diagrams), the stage was set for the interactive production, maintenance, and development of a new language that allowed students to handle the phenomena associated with these artifacts more appropriately. The contribution of curriculum design, purpose of activities, and classroom norms to students' end of unit competence in talking science has been reported (McGinn, Roth, Boutonné, & Woszczyna, 1995; Roth, in press-b; McGinn & Roth, 1996).

The simple machines unit lasted from the beginning of October to the end of January for a total of 36 lessons and included two 70-minute and one 55-minute lesson per week. There were four types of activities that differed in terms of the social configuration (whole class, small group) and the origin of the central, activity-organizing artifact (teacher-designed, student-designed):

- Whole-class teacher-directed conversations on the topics of simple pulleys, block-and-tackle, levers, inclined planes, work, and energy in the presence of a physical device and its re-presentation on a transparency (about 25% of the unit).
- Small-group teacher-designed investigations of topics related to simple machines (about 15% of the unit).

- Small-group design—which includes conception and construction—of four hand-powered machines (about 30% of the unit).
- Student-led whole-class presentation of design artifacts with question and answer sessions (about 30% of the unit).

All four activity structures supported students' participation in talking science and engineering design but with different degrees of teacher input and feedback (Roth, McGinn, Woszczyna, & Boutonné, 1995)

This science unit differed from the students' normal school experience where they faced traditional teaching with a focus on facts and right answers: they listened to lectures, completed routine activities in silent seat work, or recited facts under the direction of the teacher. Tests reflected the same factual orientation of teaching. Students initially felt that the science unit presented a great challenge because (a) too many students were allowed to talk about their own ideas rather than immediately providing a correct answer ("You take like an hour just asking us like say, 'What do you think?' and 'Why?'") and (b) authoritative answers were not provided ("If we're asking you a question about how we can make this work or something, you could give us an answer instead of asking us."). Over the course of the four months, however, most students adapted. They did not expect immediate and authoritative responses, participated in whole class conversations, and seemed enthusiastic about the activities.

Data Collection

All lessons were videotaped with two cameras. During whole-class conversations, the second camera was used to assure that all student utterances were recorded as completely as possible. Two audiotape recorders were used to capture (a) presenting students' utterances, (b) my interactions with students during small-group work, and (c) interviews conducted in the setting while students worked independently on their design projects. Observations conducted during science class and throughout the school day complemented the audio and video tapes. Formal and informal interviews with the regular teachers of the class entered the data corpus. Photographs were taken to re-present the classroom at different moments in the cycle of activities and individual student-designed projects. Meetings with the homeroom teacher and research team members were recorded in the form of field notes.

Prior to and at the end of the unit, we evaluated student understanding in three ways:

- Written tests that included concept maps and paper-and-pencil problem relating to levers, pulleys, and inclined planes;
- Interviews (pretest, 13 students) or discussions between two or three students (posttest all students) lasting from 25 to 45 minutes each; these permitted an assessment of styudents' discursive competence before and after the unit.
- Practical problems with a range of materials to answer questions such as "How would you use this pulley to lift a heavy load?" or "How would you use two small trees to get a car out of the ditch?"

Data Analysis

The present interpretations are based on the assumption that reasoning as socially structured and embodied activity can be observed (Suchman & Trigg, 1993). Video tapes and transcripts are natural protocols of students' efforts in making sense of events, structuring their physical and social environment, or interacting with the teacher. Together with the collected artifacts, protocols provided occasions for construing the conversational and cognitive work done by individuals, groups, and the classroom community. The data analyses were conducted in sessions with two to four members of the research team according to precepts of Interaction Analysis on the basis of videotaped data sources (Jordan & Henderson, 1995; Suchman & Trigg, 1991). We played the videotapes, stopping and replaying them as often as needed and whenever a team member felt something remarkable had happened. When we had isolated an event as significant, we searched the entire database (not just videotapes) to see if the event represented a class of events. In this way, we ascertained that the phenomena reported here were representative of the database, though illustrated only with excerpts from one whole-class discussion.

Context of the Pulley Conversation

Throughout the unit, students talked in small-group and whole-class situations over and about drawings and models of simple machines. In this article, all excerpts come from one 16-minute whole-class conversation. It immediately followed a tug-of-war between myself and a group of students. This tug-of-war was mediated by a block-and-tackle attached to the railing around the porch of the classroom's outside door during the children's absence (recess) giving me a considerable mechanical advantage (Figure 1). The students lost the tug-of-war although their team included 20 members near the end of the competition. My original intent for the conversation was to let students make sense of the outcome, but student interest in arguing alternatives was so high that I let the conversation run its course.

[INSERT FIGURE 1 ABOUT HERE]

The conversation is contextualized in three ways: (a) by documenting the ways in which it is representative of conversations in this classroom more generally, (b) by situating it in the entire sequence of pulley-related activities, and (c) by providing a sketch of students' pulley-related learning.

(a) The conversation was representative of what generally happened in this classroom in the following respects:

- Co-presence of physical models and two-dimensional re-presentations (inscriptions on chalkboards or transparencies);
- Student talk rather than teacher lectures over and about models and re-presentations;

- Students' freedom to decide whether and to what degree they wanted to participate—here, 15 of the 24 students participated, though 5 more so than the others;
- conversations ran their course and were terminated when student interest waned.

(b) This conversation was one of 13 pulley-related activities (see Table 1); these included whole-class discussions, small-group activities during which students summarized their views of pulley-related whole-class discussions, small-group activities during which students used pulleys for their designs of machines, and written and verbal answers to our pretest and posttest questions.

[INSERT TABLE 1 ABOUT HERE]

(c) In the course of these activities, students' talk about pulleys and answers to pulley-related problems changed considerably. Before instruction, all students maintained that a fixed pulley attached to a ceiling (as in Figure 2b) made it easier to pull a load but that a moveable pulley on a rope attached to a ceiling on one end and held by a person on the other (as in Figure 2a) increased the effort. They explained that it was easier to pull down in the first situation but harder to pull up in the second. On the posttest, students' competence was evident from the three types of assessment:

- On the written part, 12 students correctly identified the size of all forces in a system involving a moveable pulley; 11 students correctly recognized the symmetry of pairs of forces, but incorrectly identified the magnitudes (4 too small, 7 too large); the remaining two students identified forces such as to include the same friction-related measurement differences that had occurred during demonstrations and class discussions.
- Each group was given a load, string, and a pulley and asked how they would lift the load while minimizing the effort. Here, 8 groups correctly suggested a situation similar to that in Figure 2a, while 4 groups proposed a pulley fixed to a support (Figure 2b). These 4 groups argued that for a moveable pulley system to work, the

person had to stand above the pulley on a roof (or equivalent); they held that it was easier to pull a rope down (using the person's own weight) although the effort was almost twice that in the other possible situation.

- During the interviews, many students demonstrated a remarkable range of pulley-related discursive and material practices. The pairs maintained their conversation with turns of considerable length and without further prompting, attesting to their discursive competence.

HANDS, EYES, AND SIGNS IN PULLEY CONVERSATIONS

The simple machines curriculum was designed to support students in developing a language that could appropriately handle various situations featuring simple machines. Central to the curriculum design were the artifacts (inscriptions and models) that served as the starting point for the development of a language shared within the community (including students and myself). In the course of this unit, students had extensive opportunities to talk science in whole-class and small-group situations: Talk and form of argument became quite sophisticated. It will be shown that (a) forceful scientific argumentation emerges in classrooms if students are encouraged to deploy the same discursive resources (hands, eyes, and signs) routinely used by scientists in their laboratory work and (b) when students have direct access to the chalkboard, their discourse uses the same multi-modal form available to the teacher here and to scientists in their everyday situation.

The argument proceeds in two steps. First, sense-making conversations were not simply concerned with explaining situations, but they used adversarial exchanges to elaborate alternative designs and languages. The conversation over and about a block-and-tackle and diagrams of pulley configurations is used as a representative example of conversations in this classroom. This conversation shared, in some deep sense, essential features with discourse during fact construction in scientific laboratories ("Pull(ey)ing

Things Together: Scientific Explanations and Arguments"). Second, three contrasting episodes—distinguished by the current speaker's control of the inscriptions on the chalkboard—illustrate (a) the problematic nature of discourse when speakers have no control of inscriptions, (b) the improved situation when the designs on the chalkboard are drawn by another person (teacher or student) according to the speaker's instructions, and (c) the resemblance with authentic scientific discourse when the representational medium is accessible to the speaker. The contrast in these episodes illustrates the claim that forceful scientific argumentation emerges in classrooms if students are encouraged to deploy the same discursive resources (hands, eyes, and signs) that scientists routinely use in their laboratory work ("Drawing Pulleys Together: Communicating with Hands, Eyes, and Signs").

Pull(ey)ing Things Together: Scientific Explanations and Arguments

During the first five minutes of the conversation, students and I constructed an explanation of my victory in the tug-of-war. Then, in a major shift of the conversation, students proposed alternative designs. In the end, students and I had described and considered seven designs (Figure 2). I had offered two designs (Figure 2a, b) and drew two further designs instructed by individuals (Alain for Figure 2f) or several students (Figure 2c). Students had drawn the remaining three. Alain proposed his configuration (Figure 2f) explicitly for the purpose of setting class and teacher equal; in a similar way, Dave drew his pulley configuration (Figure 2g) to equalize the stakes. Both Shaun's and Alain's configurations included two "banisters" previously proposed by Krista.

[INSERT FIGURE 2 ABOUT HERE]

In its overall structure, this conversation shared similarities with those among scientists in their laboratories. The conversation established not only an explanation ("Constructing an Explanation") but also alternate versions of a tug-of-war that should have led to different outcomes ("Designing Alternate Situations"). The "material" evidence (marks on chalkboard) were constructed from distributed ideas in the community. Through this conversation, these ideas were "pulled together" and found simultaneous expression on the shared representational device. Here, they were available for inspection and argumentation. In a final move, I summarized ("pulled together") the various parts of the conversation by reference to the records that the communicative work had left behind.

Constructing an Explanation

Re-presenting the tug-of-war. The lesson began with a tug-of-war that, in addition to the normal rope, included a huge block-and-tackle (Figure 1) that favored my position unbeknownst to the students. The rope was attached to a railing (banister) on the back porch of the class. More and more students eagerly joined until about 20 pulled the rope. To the students' surprise, they lost. I invited the class to a sense-making conversation. Students' initial accounts included the key features of the system, the pulley and banister. However, their talk was not directed to either of these features in a conceptual way. That is, it was not clear why these features should have helped the teacher and not the class. To move the conversation to discussion of pulley configurations previously used during conversations, I drew one of them (Figure 2a). After establishing where the class and I had pulled, students answered the question, "Who or what supported the teacher?" Again, students' answers included the pulley and railing. But now, the students talked about the diagram on the chalkboard, pointed to it as they talked, and referred to participants' positions as "A" and "B."

Moving the conversational topic from the block-and-tackle to the diagram was significant, because it allowed a change in discourse and an associated change in the shared language. Our conversation was no longer about the messy tangle of pulleys and rope, but about a single drawing in which the block-and-tackle was reduced to one pulley represented by a circle and three lines marking the rope. Students described characteristic features of the drawing rather than the physical device itself. They talked about the ceiling to which the pulley was attached in the drawing, but not the ring stand of the actual device. This shift corresponds to the equivalent move by scientists from "raw" phenomena, which present themselves often in complex and messy ways, to inscriptions which outline only key features.

Establishing the Contrast. In the next step, students were to integrate the present conversation with a previous one on the topic of pulleys and to further their understanding through a contrasting configuration. They were asked to predict the outcome of the tug-of-war if the configuration had been different (Figure 2b). In the subsequent discussion, they proposed several alternate solutions. One episode yielded a new description that had not yet occurred during the conversation, the balancing aspect of the force exerted by the students. Jon described students' pull as "support." Later, others picked this theme up stating "You had your support, if all of us had let go, you would have been in [a distant city]" and "The class was your strong support, we were holding it." Sharon described the pulley as attached to the railing, but David disputed this description. He suggested that the rope was "going around something" and that I pulled a rope which was attached to the banister behind my back.

After about five minutes, I summarized the conversation. At this point, many classroom conversations would have ended. The tug-of-war was intended as another situation in which students could see a pulley in action, and describe a phenomenon in their terms. Up to this point, students had described these significant features: the railing and teacher opposing students' combined forces and the mediation by the pulley. The two drawings were intended to tie this discussion to those that had occurred earlier in the class. However, students' interest provided enough momentum to take the conversation into a new dimension.

Designing Alternate Situations

The conversation then took a major shift: Rather than concentrating on one explanation of what happened, students began to design alternate situations that included the same elements (pulley, rope, banister) but would not have been disadvantageous to the student team in the tug-of-war. Shaun opened the discussion by suggesting a different configuration.[1]

[INSERT EPISODE 1 **EXACTLY** HERE]

Here, Jon, Sharon, and Shaun produced the first verbal description of an alternate configuration of the pulleys, ropes, and banister that should have led to a victory for the class. This configuration was to differ from that actually used during the tug-of-war, but also differ from the trivial case of simply changing the class' and my own position or adding a larger number of participants on the students' side. At the same time, Shaun intended to show with his configuration that it was not the banister that provided me with the advantage (lines 1.1, 1.9). Not in the position to construct their idea in diagrammatic form, the three collaborated in establishing a verbal description of the situation. The repetitions in lines (1.4-1.9) can be read as part of the work to achieve mutual alignment in the discussion, stabilization of new and yet unfamiliar ways of talking, and a collective product (Roth, 1995a, b, in press-a).

Likewise, students proposed several other alternative designs. At first, I remained next to the chalkboard and drew diagrams according to students' instructions. Later, students drew their own diagrams or acted as intermediaries and drew for other students. All the designs proposed after the initial, explanatory phase (Figures 2a, b) were offered in an oppositive manner—possibly facilitated by the competitive aspect of the earlier tug-of-war. That is, their purpose was no longer mere explanation but, reflected the competitive tug-of-war and opposed my claim that pulley and banister helped me to win. Several students appeared to argue that there are designs in which I would lose even if the banister was on my side. Objections to proposals made by others and arguments over candidate accounts are further evidence for the adversarial pattern of this conversation.

Drawing Pulleys Together: Communicating with Hands, Eyes, and Signs

The previous section illustrated the macro-structure of this sense-making conversation. At first, it was concerned with description and explanation of what happened. Then, by means of an oppositive device, alternative configurations of pulleys, banisters, and ropes were proposed that would have changed the competition's outcome. The phenomenon under consideration was described by the actual configuration and in contrast with other possible configurations that would have led to different outcomes. This macro-level clarifying of the conversation was facilitated by a concomitant change at the micro-level. Here, students increasingly participated in the construction of the diagrams on the chalkboard. Together, we drew diagrams of pulley configurations; and, as a consequence, we brought together socially-distributed knowledge of pulleys until it was simultaneously re-presented on the chalkboard (Figure 2).

In this section, the different forms of talk arising from differential access to the representational device are illustrated. I argue that when students have direct access to the chalkboard, their discourse uses the same multi-modal form available to the teacher here and to scientists in their everyday situation. The following three episodes show increasing participation in a scientific argument that was made possible through equality of access to, and power over, diagrams on the shared chalkboard. In the course of these episodes, the increased reliance on hands and eyes in the mutual alignment of participants becomes evident; furthermore, the speakers have increased opportunities to shape inscriptions on the chalkboard.

"What's Your Point?"

Laboratory talk is replete with indexical terms. In the presence of referents, the meaning of indexicals can be disambiguated; in their absence, equivocality makes "conceptual" science talk difficult if not impossible. That is, although participants' eyes were active during the conversation, the physical distance between speakers and the referents of their talk excluded the hands as important contributors in communicative acts. Talk alone was insufficient "to make the point" so that students repeatedly asked, "What's your point?" The following episode shows the problematic of talking without referents within reach of the speaker.

[INSERT EPISODE 2 **EXACTLY** HERE]

In this episode, I was the only person within reach of the block-and-tackle; I was the only participant who could directly point to the parts of the system—rope, two double pulleys, attachments. My utterances and gestures not only indicated where students pulled, but also that I was not clear about what the other speakers had said. Students' talk did not provide unambiguous descriptions, for the referents of students' indexical terms were not clear; that is, in the absence of gestural references to the block-and-tackle, there were no indications within the talk that would have elaborated the meanings of "where," "that," or "it" ("<u>where the pulley is</u>," "<u>that's</u> a strong support," "<u>It</u> wouldn't have moved," "<u>it</u> is attached," "actually <u>it</u> does"). Shaun (lines 2.1, 2.10), Sharon (line 2.6), and Alain (line 2.7) asserted that the students' rope was attached to the pulley which in turn was attached to the banister. Standing over the block-and-tackle, I used conversational resources not available to the students. My pointing to a particular rope (line 2.3) while uttering "this one here" made evident where students had pulled; pointing to the respective pulley disambiguated the utterance "that pulley" (line 2.9). While in line (2.3), the pulley's attachment was only implicit, it was made explicit in the co-deployment of "<u>that</u> pulley isn't attached" and pointing to the moveable pulley. Thus, although all discourse participants employed indexical terms, those I used were disambiguated through unequivocal reference; students' indexicals, however, remained equivocal. Episode 1 already illustrated that the same problems of mutual alignment occurred when participants did not have access to the diagrams.

<u>Drawing for Another Person</u>

When speakers only have mediated access to a joint representational device, much work has to be done just to complete the diagrams rather than the argument. Producing the diagrams can then be regarded as side sequences to the actual conversation concerned with conceptual issues. In this classroom, there were repeated situations in which one member (student or teacher) drew a diagram based on another member's instructions.

[INSERT EPISODE 3 **EXACTLY** HERE]

Here, I attempted to create the drawing from my hearing of students' utterances (including those prior to the episode). As before, I used the label "A" for the location of the class. In each step, I ascertained (a) whether my drawing corresponded to students' descriptions (lines 3.1, 3.8) or (b) where I should put a particular item (lines 3.3, 3.5). Indicated by Julie's (line 3.9) and Shaun's confirmation (line 3.10), the drawing finally corresponded to the students' earlier descriptions. The entire sequence from (lines 3.1-10) was necessary to bring about the diagram but it had not moved the discussion ahead. After this sequence and with the students' configuration available for inspection, I was able to question its status as a new contribution (line 3.11); in and as of diagram, the students' case had become arguable. When I asked how the new diagram differed from a previous one, Shaun retracted his agreement, and suggested a modification (line 3.12); Krista further supported Shaun in proposing a modification (line 3.13).

Similar situations occurred when one of the students (Jon) was selected to do the drawing corresponding to a verbal description given by several students, or when I drew a design according to Alain's instruction. Again, Jon and I had to seek feedback whether our drawings corresponded to that which the sitting students' wanted. In these situations, students not only argued their case, but also provided verbal descriptions of something that could be better expressed over a drawing. This, then, required repeated instructions and feedback between the speaker and the person drawing. From a discourse perspective, these had to be considered side sequences because they only established the drawing rather than proceeding with the argument.

<u>Authentic Argumentation</u>

When all participants had access to the representational device, here the chalkboard, efficient communication occurred. The production of marks and coordination of hands, eyes, and talk happened all at once, integrated into a multi-modal development of arguments in a way that is characteristic of talk in scientific laboratories. In Episode 4, Shaun and I were the major players. He came to the chalkboard to argue his design in which I could still have the banister, but the two sides in the first diagrams were reversed.

[INSERT EPISODE 4 **EXACTLY** HERE]

Shaun's argument was constituted by drawing, gesturing, pointing, writing, and talking. His dramatic performance, greeted with applause at the end (line 4.19) underscored the presentation as part of the overall argument. By means of his theatrical emphases (lines 4.9-18), Shaun aligned his audience to the key elements of his design. It was this placement that had been ambiguous in the earlier verbal presentations by Shaun, although he was supported by some of his peers who apparently understood. Shaun completed his drawing. Unlike his verbal presentation that was not understood by the audience in Episode 3, his description on the form of a drawing became available for critique (line 4.21).

Episode 4 illustrates that the access by both speakers to the representational device afforded a multi-modal form of communication. To communicate, Shaun drew on such resources as gestures, hand placement, and signs (written text, spoken words, graphic symbols). To understand, other students and I had to "see" (not just hear and read). Shaun indicated the rope and its placement over the pulley both visually (by drawing it) and verbally (line 4.2). Although "this" referred to two different objects, the different position of his hand made clear that the first occurrence referred to the rope, while the second evoked the pulley. His gesture [4.3.1], co-deployed with "you can have that," unmistakably attributed the banister to me. Previously existing ambiguities were clarified in his second diagram by adding graphical and textual features. Shaun added "another banister" (line 4.18) and not only attributed the different sides to the two competing parties in the tug-of-war, but he also wrote "Roth" and "class" next to the corresponding ropes. At this point then, Shaun's ideas had become inspectable and with it, arguable. While students and I found it difficult to understand Shaun's previous argument, Alain's critique (line 4.21) and my implied agreement (applause) became possible after Shaun had completed his multi-modal presentation (line 4.18).

Through interactions such as this, the presentations were collaboratively achieved. "Drawing together" can then be understood in a double sense: We brought together all the communicative resources necessary (signs, hands, eyes) and we co-constructed the diagram. The participants in the argument had immediate access to the drawing which they took as shared space for their interaction. The drawing afforded efficient communication by allowing the participants to point to and unmistakably identify locations and directions.

DISCUSSION

This study focused on the multi-modality of classroom conversations. In written scientific communication, text is often accompanied by various inscriptions (graphs, tables, equations) that interact to give rise to multi-modal communication. In face-to-face laboratory talk and presentations to audiences, new modes of communicating become available. The importance of these modes have long been overlooked. Only recently, when researchers began to experiment with technology that could mediate the collaboration over distance, did these issues become the focus of attention. The illustrative and iconic elements of speakers' and listeners' gestures lost their performative impact as they were mediated over distance. Although it has been recognized that representational technologies are an integral part of collective thinking, many teachers have not yet accommodated this aspect in their science classes (Pea, Sipusic, & Allan, in press). This study is part of a research program fundamentally concerned with the role of representational technologies in collective sense making, emergence of shared knowledge in classroom communities, and mediation of different languages.

The present conversation shared structural similarities with scientific laboratory talk. Beginning with the construction of a first explanation for a discrepant event, members of the community began to elaborate pulley configurations by means of an oppositive device. In the end, the chalkboard was "littered" with pulley diagrams, the material productions of this activity. In their contrast, these diagrams provided insights to the functioning of pulley systems more generally. More so, because they were produced as "material" evidence, these diagrams had become inspectable, scrutinizable, and arguable. While members of the community groped for understandings when there was talk alone, many configurations of simple machines could be displayed and argued when they were available on the shared representational device. We observed similar features in small-group conversations when students designed their own machines. Here, little ground appeared to be covered as long as students merely talked. As soon as students drew diagrams or gestured, providing material basis to their discussions, their design efforts made progress. Again, the co-deployment of materials, tools, diagrams, gestures, and talk facilitated students' interactions (Roth, McGinn, Woszczyna, & Boutonné, 1995).

The change of the conversational topic from the original block-and-tackle to the drawings was significant, because it corresponds to the cleaning up of data in the sciences. When only essential elements remain, data are much more convincing (Bastide, 1990; Knorr-Cetina & Amann, 1990). This then allowed a shift in the conversation. Participants began to use "graphemes," basic graphical elements representing rope, pulley, and stable support in various combinations to make their arguments, present ideas, or design alternate configurations. For this to work, the graphical formalism needed to be shared by the participants. In our class, graphemes were used in a consistent way throughout the course as they appeared on transparencies, student worksheets, and material evidence of classroom discussions "published" on the bulletin board. By the time of this conversation (see Table 1), a set of graphical conventions was already shared so that participants could use them to construct the setting of their work. That is, graphemes drew meaning from their intersituational reference to other conversations; I understand this intersituational reference as the conversation-related equivalence of Lemke's (1993, in press) notion of intertextuality. Here, all participants use the same formalism provided by previous meetings. However, the particular referent of specific graphemes was not constant. For example, marks representing the "banister" in the present situation, were previously used to represent the iron ring of a ring stand and a "ceiling" (in each situation, however, it stood for a fixed support); the circle which was previously used to represent a single pulley now stood in for the block-and-tackle; the lines had changed their meaning from string in earlier sessions to rope in the current conversation.

On the chalkboard, participants expressed the relationship between the elements (pulley, support, ropes). It is in these relationships that the "conceptual" was embedded, not in the graphemes themselves. In this, drawings are subject to a phenomenon similar to language where conceptual understanding is expressed through the relationship between words, not in the words themselves. For the present conversation to work at all, relationships between individual elements in drawings and the physical device had to be specified, and relationships among elements within each of the two clarified. In the early part of this conversation, interactional work had to be done to assure that participants understood how the graphical objects related to the physical device (block-and-tackle). Initially, I took this relationship as unproblematic and proceeded with using the formalism in the talk. Early in the discussion, however, I realized that this assumption was not warranted. As part of Episode 2, I returned to the block-and-tackle and pointed out the relation of the individual parts of the system, the ropes pulled by students and teacher, the "banister," and the pulley. Once the correspondence between device and its re-presentation as diagram had been established, the diagrams substituted for the actual devices as objects of conversation. The drawing can be thought of as superimposed over the actual device; talk over and about the drawing can stand for talking about the physical device. The language used by participants expresses this substitution. Referring to lines on the diagram, participants used talk such as "you can pull on here... and then we pull here" (Shaun), "but then Mister, Doctor Roth doesn't have anything to pull at" (Alain), and "you guys were pulling on this one here" (teacher over device). Talk over and about physical devices becomes indistinguishable from talk over and about drawings that represent them.

It has been argued that talk over and about inscriptions democratizes discourse (Lakin, 1990). In this case, the orientation of group meetings around a visual stimulus changes the control of discourse. Rather than being dominated by verbally (or politically) dominant individuals, it encourages increased participation from the entire group in the generation of ideas, evaluations, and descriptions. The present study shows that this is not generally true. As the sequence of Episodes 2 to 4 illustrated, such democratization in classroom discourse may be a function of access. When students had free access to the chalkboard (equaling that of the teacher), we observed conversations that integrated conceptual talk with other modes. It is in this sense that the conversational activity here was "authentic." Through argumentation, students could elaborate alternative pulley designs. When they had direct access to and control over the chalkboard, their discourse used the same multi-modal form available to the teacher here and to scientists in their everyday situation.

Affordances of the Chalkboard

In this study, the chalkboard was a shared interactional space to which participants were oriented perceptually, discursively, and physically (body orientations). Speakers integrated various modes of communication (talk, gesture, drawing) to describe and explain alternative designs; they bridged the separation between modes of expression, a separation which is the result of schooling and ontogenetically posterior to expressional unity (Lemke, in press). When a lack of shared understanding was apparent, it could be remediated immediately and without verbal description. With access to and control over the chalkboard, speakers had opportunities to employ the multi-modal talk common in scientific laboratories. Thus, in situations as described here, the chalkboard became a medium for the construction of shared conceptual objects--various designs constituted by the different arrangements of the graphemes (various versions of the three basic building blocks, "banister," pulley," and "rope"); that is, these diagrams were "configurable" (Pea et al., in press). Diagrams expressed relationships that are said to exist in the corresponding elements of the physical device. They are also visible marks that can be pointed to, used as reference to a gesture, erased, and reproduced in different configurations. Over the course of the conversations, topics of talk were visually constituted, and in turn, brought about change in the talk. As such, different designs of the tug-of-war were proposed, considered, changed, and reconsidered.

Access to the chalkboard allowed more than simply the integration of talking, drawing, and writing: Through the speakers' gestures, the drawings were also animated. With a sweeping motion of the hand, a student could animate a diagram and indicate not only the existence of a force but equally important, its direction. In such animation of diagrams, science concepts exhibited their full nature as "semiotic hybrids, simultaneously verbal-typological and mathematical-graphical-operational-topological" (Lemke, in press). Furthermore, through an individual's hand movements, the diagrams retained the dynamic character of the earlier tug-of-war. In the presentations, we not only configured our own designs from the basic graphemes, but we animated them with gestures and pointing.

Multi-modal practices such as described are not supported by other modes of interacting with students as was illustrated by the communicative difficulties when students contributed to the conversation without access to a shared representational device. These problems were remediated when students such as Jon, Dave, or Shaun used the chalkboard as part of their talk. But even in the presence of a representational device such as a computer, the interaction of its size with the social configuration may prohibit the integration of multiple modes of communication. For example, when more than two or three students sit in front of a computer, the orientation toward the small screen and input devices prevents other people from interacting with others over the images; they no longer have access to one of the modes (Roth, Woszczyna, & Smith, in press). Mediated access to the chalkboard also led to inefficient talk. The trouble in conversations where one participant draws for another arises from the potential that both do not refer to the same objects. To facilitate this situation, the participants have to engage in many action-feedback cycles to produce the drawing rather than discuss the "conceptual" issue to be expressed by the drawing.

These findings provide some insights as to why some students have difficulties learning from lectures. As in the present situation, lecturers engage in a multi-modal presentation. They talk, draw, write, gesture and point. What students usually end up with, however, are copies of the marks and traces left by the multi-modal presentation. Moreover, students do not know what to keep invariant when reducing the multi-modal presentation to a re-presentation in their notebooks. What their notes do contain are all the other aspects of the lecturer's presentation. Readers may have had the experience that although they had everything the teacher or professor wrote on the blackboard, the meaning of these marks is gone. They are decontextualized, no longer part of lecturers' rhetorical practices deployed to enroll listeners into their own ways of seeing the world.

The chalkboard was the setting for constructing alternate designs of tug-of-war and simultaneously served as a recording device that allowed references between various designs. These diagrams became available in subsequent conversational activity and summary. Items entered became records during and at the end of the lesson. Utterances of spoken discourse were soon lost in the temporal succession of other talk. In contrast, diagrams afforded inspection, analysis, and re-analysis at later points, or comparison with other diagrams. They became "fixed points" for the discussions. In this, they became inspectable and arguable.

In the present situation, the chalkboard had an advantage over the transparencies used in this class in that all of the designs were present simultaneously. It also presented a space that could easily be shared by multiple participants. The space on transparencies was limited, and multiple designs had to be viewed in succession rather than simultaneously. On the other hand, transparencies were easily carried from one situation to another so that they were available for future reference. They were records that could be posted, or projected again.

Implications

In Talking Science, Lemke (1990) suggested that students learn science by participating in science conversations; his more recent work underscores that scientific communication cannot be relegated to utterances and written text but has to be understood in and as the deployment of multi-modal communicative resources and their situational and intertextual relations (Lemke, in press). The present study showed that science educators need to consider not only students' participation by allowing them more utterances, but that they also need to be in direct control of representational technologies.

The present study implies some specifications for a representational technology that could have facilitated the conversation and would have provided opportunities for more contributions by other members. The challenge is to design a technology that:

- allows ideas and their representations to become more fully arguable;
- makes possible equal, easy, and rapid physical access to the shared display;
- affords configurable designs that allow students to add to existing designs, or add new designs;
- affords pointing to specific parts or repeating particular features in gesture;
- allows storing the design work done during a conversation so that it is accessible during future conversations;
- allows animation of the designs so that they can be subjected to tests of feasibility.

Such representational technologies allow teachers to engage in collaborative inquiry with larger groups while supporting the communicative practices that small-group face-to-face interactions afford to their participants. The represented diagrams themselves, models of the physical reality, do not need to implement strict epistemic fidelity (Ehn & Kyng, 1991; Roschelle, 1994). What the diagrams and representational medium do need to support are settings in which alternate languages (worldviews) can be negotiated and changed. Through establishment and participation in communicative practices shared by students and teachers can we expect students to learn to participate in expert worldviews.

NOTES

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[1] The beginning of the action described is indicated by "[" and occurs simultaneously with the talk (under Audio) on the same line. In the drawings, items in square brackets such as "[2]" indicate positions for ease of reference in the body of the article; they were never actual marks on the chalkboard. I used the following transcription conventions:

[3.2.1]: For referencing a specific gesture. [3.2.1] refers to gesture [1] in line 2 of Episode 3.

=: Indicates latching, the second speaker takes a turn without waiting the elapse of the normal pause

//begining and]

end of overlap]: To indicate overlapping utterances.

(1.2 s): Pause in seconds.

(.): Audible but unmeasured pause.

(applause): audible features other than words.

.,!?: punctuation is used to indicate intonation rather than grammatical structure.

<u>underline</u>: emphasis on word.

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Table 1

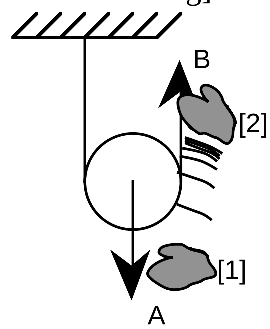
<u>Sequence of all activities including pulleys in the 36-day unit</u>

1. Students were asked to reason about a pulley situation in paper-and-pencil (Day 1).
2. Thirteen students (50% of the class) talked about their answers in #1 with a member of the research team (Day 2).
3. One whole-class sense-making conversation over and about two pulley systems and corresponding drawings (Day 3).
4. Throughout the unit, students designed and built models of machines that sufficed certain conditions (lifting 100 g to 15 cm height; moved a 100 g load over a distance of 2 m; had a mechanical advantage). In the course, students made use of pulleys and other wheel and axle arrangements so that they had opportunities to learn about them. Approximately 37% of all projects included at least one pulley (Day 4-32).
5. There were whole-class conversations over and about the student-designed artifacts described under # 4, during which the question of pulleys was raised whenever students had used them (Day 4-32).
6. A second whole-class sense-making conversation over and about pulleys and corresponding drawings (Day 8).
7. Small-group activity during which students summarized their understanding of the pulleys discussed on the previous day. The worksheets included copies of the transparencies used during the whole-class discussion (Day 9).
8. **A tug-of-war between teacher and students by means of a block-and-tackle attached to a banister (drawings on blackboards)** (Day 17).
9. A brief review of pulley systems (using drawings on transparencies) (Day 28).
10. Students wrote answers about the forces in a drawing of a moving pulley (Day 33).

11. Students talked in pairs (two triplets) about their answers on the written tests; investigators encouraged students to convince each other of their answers (Day 34-35).
12. Same groups as under 11 were asked to demonstrate how they would use a pulley if they had to lift a heavy load (Day 34-35).
13. Final, whole-class debriefing on all simple machines, including pulleys (Day 36).

Episode 1

	Audio		**Video**
1.1.	Shaun:	You can have the banister, if that, if that pulley there, the pulley there, if that was on our side then, ahm.	[Points toward chalkboard in the general direction of earlier drawing]
1.2.	WMR:	This was, this [1] <u>was</u> on your side, because the class was pulling here [1], and I was pulling here [2].	(see figure below)
1.3.	Shaun:	No, but if that, switch it around=	
1.4.	Sharon:	=You were B.	
1.5.	Jon:	//If you were B]	
1.6.	Shaun:	Switch the] whole thing around, like say, we were pulling.	[gestures switching]
1.7.	Sharon:	//If we were B]	
1.8.	Jon:	If we were B] and you A	
1.9.	Shaun:	No, if we were B but you had the banister on your side (1.0 s)	[points toward chalkboard]
1.10.	Jon:	Ha?	
1.11.	Shaun:	Like if the banister was on that side (.) OK, just say there was a banister on that side.	[points toward chalkboard]

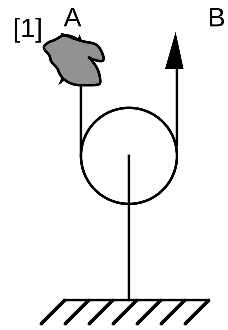


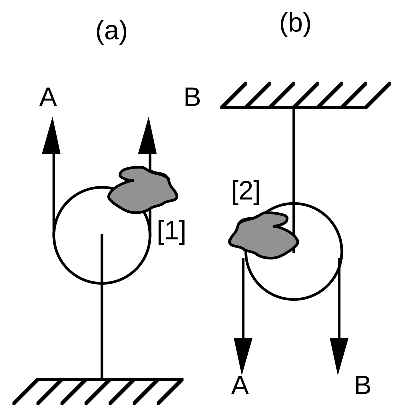
Episode 2

		Audio	**Video**
2.1.	Shaun:	If we pulled the hardest, then the banister would fly.	
2.2.	David:	We were pulling where the pulley is.	
2.3.	WMR:	You guys were pulling on this one here.	[I point to string [students]
2.4.	Jon:	That's a strong //support.]	in Figure 1]
2.5.	Alain:	But you] would have lost if there was a 1000 people on //there.]	
2.6.	Sharon:	It woul]dn't have moved because I think //it is attached.]	
2.7.	Alain:	Yeah, exactly.]	
2.8.	Shaun:	See, he is,] actually it does	
2.9.	WMR:	It is attached to that pulley, but that pulley isn't att//ached.]	[I point to pulley [1] and [2] in Figure 1].
2.10.	Shaun:	No, but] it's attached to the banister.	

Episode 3

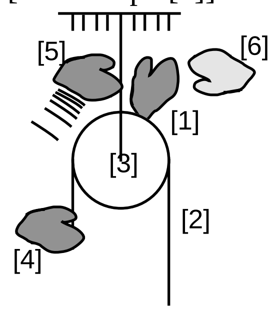
	Audio		**Video**
3.1.	WMR:	The banister is over here? (1.8 s)	[I begin to draw]
3.2.	Shaun:	Yeah, the banister is over //here]	
3.3.	WMR:	And] who is here [1]?	
3.4.	Julie:	Us.	
3.5.	Kevin:	Us.	
3.6.	WMR:	The class?	
3.7.	Andre:	The class is, against you.	
3.8.	WMR:	And like this? (3.4 s) Is that what you mean?	[I end drawing]
3.9.	Julie:	Yeah.	
3.10.	Shaun:	Yeah.	
3.11.	WMR:	How is that [1] different from this [2] //one?]	
3.12.	Shaun:	No], no, it's like that, but you have a banister on your side.	
3.13.	Krista:	Like both have banisters.	



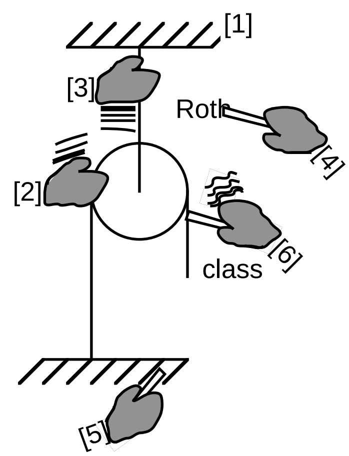


Episode 4

		Audio	**Video**
4.1.	Shaun:	OK (2.5 s)	[looks at Figures 2a-d]
4.2.		And then this thing [2] over this [3].	[draws rope [2]]
4.3.		You can, you can still have that [1], but if we [4]=	
4.4.	WMR:	=Where do I pull? Which end do I pull?	
4.5.	Shaun:	You can pull on here [5].	



4.6.		With the, OK (3.8 s) this is a banister.	[starts new diagram by drawing a banister]
4.7.	WMR:	But we have the banister here [6].	[points to [6]]
4.8.	Andre:	Oh God	
4.9.	Shaun:	(5.2 s)	[erases in part diagram in 4.1-4.5] [begins new one]
4.10.		Banister [1]	
4.11.	WMR:	OK	
4.12.	Shaun:	Long string [2]	
4.13.	WMR:	OK, pulley	
4.14.	Shaun:	Roth [4], pull here [3]	
4.15.	WMR:	OK.	
4.16.	Shaun:	Then there is a pulley.	
4.17.	WMR:	And where do you pull? (1.7 s)	
4.18.	Shaun:	And then there is another banister here [5], and then we pull (.) here [6] [class]	



4.19.	Xs:	Ah, yeah (4.2 s) (applause)	[several students applaud]
4.20.	WMR:	OK, thank you very much, can you?	[I signal Shaun to sit] [Shaun reluctantly leaves]
4.21.	Alain:	But then Mister, Doctor Roth doesn't have anything to pull at!	[I applaud Alain]

CAPTIONS

Figure 1: Configuration of block-and-tackle during the tug-of-war which provided a 5:1 ratio in the teacher's favor.

Figure 2: Drawings produced during this conversation. All but 2d, which was erased to make place for 2e, were available for the summary at the end of the conversation.