Made by Hand: Gestural Practices for the Building of Complex Concepts in Face-to-Face, One-on-One Learning Arrangements

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Abstract: Our study investigates how the hands and body can serve as communicative, cognitive and interactional resources when they are employed in the teaching and learning of complex science and math concepts. We consider how speakers and hearers produce, take up, and re-use gestures to support explanation and conceptual formation in expert-to-non-expert conversation. The study suggests that in face-to-face, one-on-one interaction gesturing plays an important role in facilitating the joint achievement of new conceptual understanding for novice learners. We believe that the gestural practices used to explain complex concepts in informal interactions can be profitably extended to the teaching and learning of STEM (science, technology, engineering and mathematics) subjects in other learning arrangements such as the classroom.

Introduction

Language is an important resource for teaching and learning, but it is not the only one. The intent of this study is to closely examine how both non-verbal and verbal modalities are employed together in face-to-face, one-on-one interactions in which experts in the fields of math and science explain complex concepts to non-experts. Paying attention to how multiple modalities are employed in informal face-to-face, one-on-one explanations of complex concepts can offer valuable insight into how we design practices for teaching and learning in other learning arrangements such as the classroom.

Our study particularly investigates the coordination of gestures and body movement as we as speakers and hearers jointly produce, take up, and re-use gestures to support explanation and concept formation in the context of conversation. We consider gestures and body posturing as participating elements in communication (Becvar, Holland & Hutchins, 2005; Goodwin, 2000; Hutchins, 1996; Kendon, 2001, 2004; Stevens & Hall, 1998; Streeck, 1994, 1996) as we also examine the hands and body as explicit, tangible teaching tools.

The study illustrates how gesture facilitates the joint achievement of new conceptual understanding for novice learners in face-to-face interaction. We believe that the gestural practices used to explain and understand complex concepts in informal interactions can be profitably extended to the teaching and learning of STEM subjects across learning sites. Our study concludes with the suggestion that as we create ever more sophisticated educational designs, we may need to pay more attention to the potential of the most readily available resources – the hands and the body.

Theoretical Background and Perspective

Our overarching interest is in how knowledge is produced in interaction. We see learning as an interactional process that is dynamically constructed through actions and inter-relationships among resources (Hutchins, 1995; Stevens & Hall, 1998). These resources include participants, settings, multiple modalities, objects and sequences of activities. In our analysis, we employ the concept of *learning arrangements*, which refers to social and material configurations that people arrange for learning, with the question of whether learning is actually achieved being an empirical one for investigation (Stevens, Satwicz & McCarthy, 2007). This concept allows us to examine the resources made available in face-to-face, one-on-one learning arrangements and compare them with other learning arrangements. We are therefore able to treat gesture as both a technical resource and an interactional resource in the active and collaborative enterprise of teaching and learning. We consider how the hands act as media for representations and how the hands and body participate in coordinating available, external representations in interaction to achieve the end task of understanding.

Our study concentrates on teaching and learning in STEM fields (science, technology, engineering and mathematics) and provides perspective on the view that teaching and learning in the STEM fields involves the use of multiple representations such as graphs, models, and charts (Kress, 2001;

Stevens & Hall, 1998). We consider how the hands act as flexible, manipulable, and literally "ready-to-hand" embodied resources for representation. We also respond to recent literature that looks at how professionals in science fields build theory in collaboration. Studies suggest that idea construction and knowledge communication in professional settings happen through an interactional exchange that employs multiple resources that include gestures (Becvar et al, 2005; Hall, Stevens & Torralba, 2003; Ochs, Gonzales & Jacoby, 1996; Stevens & Hall, 1998).

Much of the recent work on the use of gestures in teaching and learning takes a psychological orientation. Such research has suggested that gestures in the classroom can be used to reinforce and extend meaning provided in speech, can aid the gesturer in thought production, and can reveal cognitive processes as a means for evaluating understanding and guiding instruction (McNeill, 1992, 2005; Singer & Goldin-Meadow, 2005; Wagner, Alibali, Flevares & Goldin-Meadow, 1997; Ozyurek, 2002). We expand upon this psychological orientation as we consider not just the relationship between gesture use and cognitive processes, but also the role that gestures play in communication. Attending to both aspects simultaneously provides a more complete and realistic view of how gestures participate in teaching and learning.

Methods

The study employs the methodology of microanalysis of videotaped interaction, which involves fine-grained, qualitative analysis of sequences of talk and action. This process of analysis allows for the close investigation of moment-to-moment, turn-by-turn, interactional exchanges giving detailed information about what is happening in a particular instance.

The database consists of video-recorded conversations in which experts in STEM fields explained complex concepts to non-experts. Participants came from a pool of volunteers who responded to requests for participation that were distributed via e-mail to STEM departments of a large university. Conversations were held primarily in the offices and labs of the experts and lasted between 30 and 60 minutes. Participants discussed topics of their choosing which they deemed as relevant concepts to their defined discipline and/or research. The recorded interactions were logged and transcribed and the verbal and gestural techniques used to explain concepts were identified and analyzed.

Data Sources and Evidence

In this paper we analyze segments from three interactions in which experts (two professors and one graduate student) explain concepts in microbiology, mathematics and animal biology in one-on-one conversations with a non-expert. These segments exemplify moments in our data in which the interactions take a conversational format for exchange of knowledge, as opposed to a lecture-like format in which the expert delivers information and the learner is relatively passive. Close examination of the use of gesture in these exchanges shows that the gestures are not merely the outward manifestation of the speaker's cognition, but rather can be co-constructed with a recipient in the service of building conceptual understanding.

Results

Through our analysis we demonstrate that gestures and posturing are not just the unconscious by-product of a speaker's cognitive processes, but rather often are tactically employed for communicative purposes that respond to particular contingencies of the situation and perceived learning needs of a recipient. As evidence for this perspective we outline examples showing how gestures are (1) built step-by-step for and with the recipient, (2) positioned and adjusted for the recipient, (3) used to correct the learner's misunderstanding (in response to the learner's gesture), (4) used by both the speaker and the hearer to drive the interaction toward the shared goal of achieving understanding, (5) treated as a communicative artifact by speaker and hearer. Finally, we show how, in a single segment, gestures can be seen to support both cognitive and communicative processes.

Example 1: Constructing a Gestured Object for the Learner

The first segment shows how an expert engages in the process of building, step by step, a gestured object. Sakina is a graduate student in molecular biology. She is explaining the replication of DNA. She first explains the basic architecture of DNA. To do so, she constructs a model layer by layer, enlisting her hands as the material for construction. Sakina begins the construction for the learner/hearer by saying,

"Then there are two strands," as she simultaneously lifts her two index fingers, positioned side-by-side, and lowers them--drawing two lines in space (see Figure 1).

Figure 1. "Then there are two strands"

Sakina then raises her left index finger, pointing up, establishing it as a model of the DNA strand. As she says, "One strand we call it the five prime end and the three prime end?" she lifts her right hand and points to a spot toward the tip of her finger and then another spot towards the base of her finger. The right hand thus takes on an indexical role as the left hand models the DNA strand (see Figure 2).

Figure 2. "Five prime end and the three prime end"

Once this basic structure has been established, Sakina alters it to show the learner that the strands go in opposite directions. She does this by straightening her right index finger and then flipping the hand so that the finger is now parallel to the left index finger, but pointing downward. She completes this movement as she utters "anti-parallel" (see Figure 3).

Figure 3. "Anti-parallel"

The gestured object is sequentially constructed for the benefit of the hearer. This is evidenced by 1) the gaze direction of the participants, 2) the speaker's positioning of the gestured-object and 3) the speaker's adjustment of the gesture.

As she begins to set up the model, Sakina shifts her gaze to her hands. The hearer tilts her head to see Sakina's hands (see figure 4). This move by the hearer displays her recognition that the built gestured-object is for her, and that this information is consequential for her understanding.

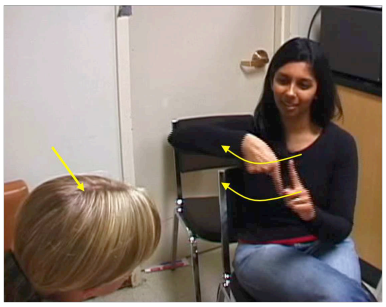

Figure 4. The hearer tilts her head to see S's gesture; S repositions the gesture.

Sakina immediately responds to the hearer's head tilt by repositioning the gestured-object so the hearer can see it. Sakina's adjustment is a marker that the gestured-object is intentionally constructed and placed for the learner. The speaker's repositioning also works to outline the interactional field. The speaker's body acts as frame, defining a field of action. The speaker and hearer conjointly establish this workspace: first the hearer tilts her head and then the speaker adjusts.

Example 2: Repairing Understanding through Gesture

In the following example, gestures participate in the repair of a misconception. After Sakina reaches a completion point in her explanation, the learner initiates a turn by putting up two fingers, thus taking up the previously constructed gesture-object. As she does this she says, "Okay so you have the two strands." The gestured-object she displays, however, shows the parallelism of the strands but fails to show the opposing directionality (see Figure 5).

Figure 5. "Okay, so you have the two strands."

Sakina moves to repair the misunderstanding, not through speech but through action. Sakina demonstrates the anti-parallelism with her hand. As she does this, she repeats the learner's previous phrase, "so you have the two strands." The language is the same; it is the gesture that provides the correction. In response, the learner flips her hand to mirror Sakina's and repeats "two strands" (see Figures 6 and 7).

Figure 6. "So you have two strands."

Figure 7. "Two strands."

Example 3: Assuming the Perspective of the Learner

Another indicator that gestures can be intentional teaching tools is when a speaker shifts position to assume the hearer's perspective on an already built gestured-object.

Max, a professor of geometry, explains the concept of four-dimensionality. First, he explains a more basic concept: three-dimensionality. Max creates the object using the fingers to represent three dimensions (see Figure 8). Once he settles on this construction, he then pauses in the process of explanation. He holds the gesture in its established space and, as though detaching himself from his role of maker of the gestured-object, he steps out of conversational space, crosses the interaction field and observes the built object from the learner/hearer's visual perspective (see figure 9).

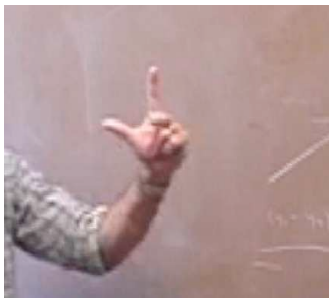

Figure 8. Three dimensions

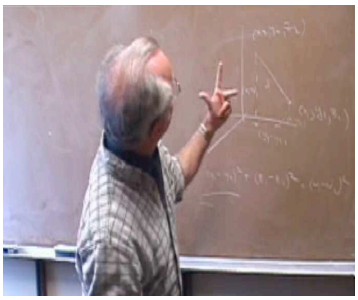

Figure 9. Takes learner/hearer's perspective

Here is a clear embodied representation of recipient design (Sacks, Schegloff & Jefferson, 1974), as the speaker not only constructs and displays the gesture, but steps into the physical position of the learner/hearer in order to "check out" how the gesture looks from that perspective.

Example 4: Thinking through Gesture Together

A fourth segment shows gesture playing a major role in an extended process in which the expert and learner work toward a shared understanding of a scientific concept. In this case, the expert, Mara, (a biologist) is explaining how fish gills function. Mara, in response to the learner's question about the shape of a fish's gills, moves the discussion away from the process of oxygenation and on to the relationship of surface area to oxygen consumption. In this sequence we see several of the phenomena discussed so far. For instance:

- gestured-objects are constructed for the benefit of the learner;
- gestures are used to repair and clarify the learner's misconceptions; and,
- gestures participate in the moment-to-moment assessment of where the learner is in the process of understanding.

In addition, this segment also shows how the function of the gestured-object may shift as it is passed back and forth by the expert and learner as it also reveals how the body organizes this exchange.

There is a dynamic development of a single gesture that happens as the gesture is passed between the interacting participants. The specific gesture that is the focus of this discussion is made up of an open hand with the thumb pulled to the palm and four fingers loosely separated (see Figure 10). The gesture refers to the gills of a fish. Mara introduces the gestured-object by placing it in the center of the interactional space in the learner's sight line and asking, "But what does this give you when you are like that?" The central placement of the gesture and the use of deictic pronouns "this" and "that" direct the learner's attention to Mara's gesturing hand. The learner, in the turn to follow, takes up the gesture and reproduces it with her own hands (see Figure 10).

Figure 10. "But what does this give you when its like that?"
Speaker displays and hearer mimics "gill" gesture.

The learner's taking up of the gestured-object acts as a demonstration for the participants that the "hand-as-gill" gesture has now been established as a shared object central to the explanation.

When Mara presents the hand-as-gill gesture it is acting as a representational model. When picked up by the learner the gesture shifts to become a manipulable model used to work out an idea, i.e., a thinking tool. This shift of function is evident from the learner's treatment of the gestured-object. She pulls the gesture from the center of the interactional space and to its periphery. She draws it closer to her own body and performs actions on the gestured-object in an abbreviated manner. The gesture, now a thinking tool in the hands of the learner, is used by the learner to explore various relationships between a gill and water. As the learner's left hand maintains the hand-as-gill gesture, the right hand is used to simulate various aspects of the movement of water over the gill such as pressure, impact and flow (see Figure 11). For example, in one simulation the learner moves the fingers of her right hand (the right hand representing water) between the fingers of the left hand (the left hand acting as gill) and utters "it [water] can get through."

Figure 11. Learner uses gestured-object as a thinking tool.

Other uses of the hand-as-gill gestured-object spin out of this interactional activity. In addition to acting as an evaluative tool and a thinking tool, the gesturing also becomes an interactional tool used specifically to organize and *co-coordinate* the teaching and learning. Mara and the learner use their hands and body as mechanisms to steer the direction of the conversation toward the achievement of the shared goal of understanding the concept in play. Mara uses the body positioning to direct the learning toward the kind of investigation that will get to conceptual understanding, and the learner making use of the evaluative benefits of making her thinking visible, uses the hands and body to *check in* and assure that her exploration is on the right track.

As Mara presents the hand-as-gill gestured-object, her body remains on the very outside edge of the interactional space (see figure 10) while the gestured object takes a central position. By remaining on the periphery and foregrounding the built gestured-object, Mara's body positioning further signals for the learner that she is now to step in and take over the learning. The learner responds by doing just that – picking up the gesture-object and exploring it. As she begins to act upon the gestured-object now in her possession, Mara drops her gesturing hand out of the center of the field. The pass has thus been completed. Mara steps out of explanation mode and allows the learner to slip into exploration mode.

The learner's introspective focus, demonstrated not only by the abbreviated manner of her action on the gesturing hand, but also suggested by the slight pulling inward of her body to create her own frame

around the gesturing, marks the current function of the gesture as a thinking tool. But it is not just a cognitive tool in use for the learner. It is part of a documentation that is meant to be seen by Mara. The learner's choice to reveal her thinking to Mara through the visibility of the gestures and the audible "figuring out" talk suggests that the learner is seeking on-going guidance from the expert. The learner's vacillating gaze from an inward focus on her hands to outward focus toward Mara also functions to keep the expert "on deck" as a resource while the learner works through learner's questioning. Mara picks up the learner's bid for approbation and/or clarification and shows this as she shifts her body back into the space (see Figure 11) when the learner verbalizes an idea that may move her toward an understanding of the concept. In just a few turns, we witness the intricate, multimodal work participants perform in this interactional process of explaining and understanding.

This final segment shows the importance of adopting both cognitive and interactionist perspectives on the use of gesture. We see that gesture may be employed by the learner and the expert as a (1) communicative tool, (2) a thinking tool to work out and organize knowledge, and (3) an interactional tool to organize the trajectory for learning. The various functions the hands and body can assume are determined and negotiated through a complex interactive exchange between speaker and hearer, learner and expert.

Conclusion

Our analysis shows that the hands and body do something important in the teaching and learning of complex concepts in face-to-face, one-on-one learning arrangements made up of experts and novices. The gesturing hands can be employed as tools to build a representational object that both the speaker and the hearer act upon in order to achieve a shared understanding of a complex concept. The examples we describe show that gestured-objects are constructed for the benefit of the learner, that gestures participate in moment-to-moment ("formative") assessment in face-to-face, on-on-one interaction, and that gestures are used to repair and clarify misunderstandings. Gestures can be used by both the speaker and the hearer as proposals, cues, and requests that steer the interaction toward the shared goal of achieving understanding. These multiple roles that gestures take in interaction demonstrate that the hands and body are prominent resources for learning in these types of learning arrangements.

Our study also provides evidence that gestures in face-to-face, one-on-one interaction can have both cognitive and communicative functions. Seeing gesture as both cognitive and communicative is an improvement on the dominant cognitive view in that it (1) reveals an important way in which people routinely accomplish teaching and learning in informal talk, and (2) clarifies how both the artful production and the perceptive recognition of gesture is a critical interactional activity achieved and negotiated by all participants.

We believe that by examining the interactional activity that happens in face-to-face, one-on-one learning arrangements between experts and novices we can come to better understand the material and social resources used in the explanation of complex concepts. In all three examples from our study, representations made by the hands and negotiated in interaction become vital aspects of the process of explanation. We invite research that explores ways to extend the benefits of gesture activity for concept learning from face-to-face, one-on-one interaction into the classroom. Certainly, by the very nature of the classroom arrangement, the available uses and functions of gestures are different compared to those present in face-to-face, one-on-one arrangements. Particular gesture activities in co-present interaction may be endogenous to that specific learning arrangement. If so, what certain aspects of gesture use in interaction can be organically and effectively performed within current arrangements for classroom learning? It is, for instance, certainly not possible for teachers to have their gestures respond to each and every learner's displayed understanding but it does seem possible, and worthwhile, for at least some of this to happen.

Our study encourages further research into the profitability and possibilities of extending effective gesture practices that happen in face-to-face, one-on-one interaction into the classroom. We also suggest that investigating gesture use in a variety of learning arrangements will offer more insight into how gestures are shaped by and function within social and material configurations and thus further inform educational design and practices.

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