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Teachers' Gestures as a Means of Scaffolding Students' Understanding: Evidence From an Early Algebra Lesson

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During classroom instruction, teachers often attempt to scaffold students' understanding of lesson content. But how is this scaffolding achieved? One obvious possibility is that teachers adjust the ways in which they communicate information relevant to the lesson. Surprisingly, relatively little is known about how teachers vary their communicative behavior in order to scaffold student understanding. However, video technology has greatly increased the range of behaviors that can come under rigorous study. Using video analysis techniques, we examined a teacher's use of verbal and gestural forms of communication.

In this chapter, we consider the possibility that teachers use spontaneous hand and arm gestures along with their speech in an effort to scaffold students' understanding. Previous research has documented that teachers do indeed use gestures in classroom settings (Flevares & Perry, 2001; Neill & Caswell, 1993; Núñez, 2004; Zukow-Goldring, Romo, & Duncan, 1994), as well as in tutorial settings (Goldin-Meadow, Kim, & Singer, 1999; Wang, Bernas, & Eberhard, 2001). However, previous studies of teachers' gestures have not directly examined gesture as a form of scaffolding.

Studies conducted in noneducational settings have demonstrated that listeners do in fact glean information from speakers' gestures (see Kendon, 1994, for a review). Speakers' gestures facilitate listeners' comprehension of the accompanying speech, particularly when the verbal message is ambiguous (Thompson & Massaro, 1994), highly complex (Graham & Heywood, 1976; McNeil, Alibali, & Evans, 2000), or degraded in some way (Riseborough, 1981, Experiment 3). Based on this prior work, it seems likely that students' comprehension of lesson content may also be aided by teachers' gestures. Gestures may be particularly important in classroom settings because students' comprehension is often challenged by instructional discourse that presents new concepts and uses unfamiliar terms. In addition, classrooms are often noisy, with multiple individuals speaking at once. Under such circumstances, gesture may play a particularly important role in comprehension.

We hypothesize that teachers use gestures to "ground" (cf. Glenberg & Robertson, 1999; Lakoff & Núñez, 2001) their instructional language, that is, to link their words with real-world, physical referents such as objects, actions, diagrams, or other inscriptions. This grounding may make the information conveyed in the verbal channel more accessible to students. We suggest that, by providing gestural grounding where appropriate, teachers scaffold students' comprehension of instructional language, and in so doing, foster students' learning of lesson content. Thus, gestural grounding may be one means by which teachers scaffold students' understanding.

If teachers are sensitive to this grounding function of gesture, they should vary their use of gesture, using more gestures during parts of the lesson for which students need greater scaffolding. There are at least three types of circumstances in which greater scaffolding is likely to be needed. First, greater scaffolding is likely to be needed when new instructional material is introduced. As the material becomes more familiar, the scaffolding is no longer necessary, and it can "fade" away without consequences for students' understanding. Second, greater scaffolding is likely to be needed for material that is more complex or more abstract. For material that is uncomplicated and concrete, scaffolding may not be necessary. Third, scaffolding may increase in response to students' questions. Based on these ideas, we can derive three specific predictions about gesture frequency during instruction: First, teachers should use gestures more frequently when they introduce new material than when they cover familiar material. Second, teachers should use gesture more frequently when they speak about material that is more complex. Third, teachers should use gestures more frequently in response to students' utterances than prior to students' utterances.

The purpose of the present study was to investigate a teacher's use of gesture in naturalistic classroom communication, with a focus on the role of gestures in grounding verbal content. In so doing, we outline a technique for analyzing video of classroom instruction. We expected that the teacher would regularly use gesture to "ground" her verbal utterances. Further, we predicted that the teacher would vary her use of grounding in an effort to scaffold students' understanding. Specifically, we predicted that she would produce more gestures when introducing new material, when talking about aspects of the lesson content that are more complex, and when responding to students' questions and comments.

To address these issues, we selected a sixth-grade mathematics lesson that focused on algebraic relations. This lesson was chosen for several reasons. First, the lesson content was challenging and unfamiliar for the students. Second, the lesson provided ample opportunities for discussing abstract concepts. Third, the lesson included a long segment in which the teacher addressed the class as a whole, during which the teacher's gestures could be examined. Fourth, the teacher's use of the overhead projector during her instruction gave us the opportunity to observe her gestures simultaneously in two planes of motion, even though we used only one camera in the classroom. This rich visual display made the video data particularly rich and mitigated some of the ambiguity sometimes associated with gesture. Our analyses focus on the teacher's use of gestural grounding and how it varies throughout the lesson.

METHOD

Source of Data

The data for this study were drawn from a video recording of a sixth-grade mathematics lesson that focused on algebraic relations. The lesson was conducted by a regular classroom teacher in a suburban school that operated with a "middle school" philosophy. The student body was 86% Caucasian, 6% Asian, 5% Hispanic, 2% American Indian, and 1% African-American. Twelve percent of the student body received free or reduced lunch, and 13% were in need of special education services. The mathematics performance of the students in the classroom on the California Achievement Test (CAT) ranged from the 5th to the 99th (highest) percentile.

Students were algebra novices, although they had participated in a set of lessons on simple algebra story problem solving about 3 months earlier. Algebra was not a standard part of the sixth-grade curriculum for this school. However, the teacher was participating in an experimental program aimed at understanding early algebra learning and instruction. The content of this lesson was not specifically developed within this research collaboration, but was chosen by the classroom teacher, based on materials she had obtained earlier.

As is typical of many middle school mathematics instructors, the teacher was trained in elementary education rather than in mathematics. She had been teaching for over 10 years. She had a warm manner with her students and saw many of them for multiple subject areas (including language arts, foreign language, science, and homeroom). Throughout the class periods, the teacher used several forms of class organization, including small groups, individual seatwork, and whole class discussion.

The target lesson was designed to introduce students to the power of algebraic sentences (equations and inequalities) to model the physical world. The goal was to help students understand how algebraic relations can serve as mathematical models of physical systems, and thereby help to give meaning to systems of equations and inequalities, while providing a formal approach for determining the value of unknown quantities. The lesson involved illustrations of pan balance scales, like that seen in Figure 22.1, with various combinations of objects of unknown weights. As the teacher described it (video of 1/21/99), "We're going to translate some of these … pans into equations."

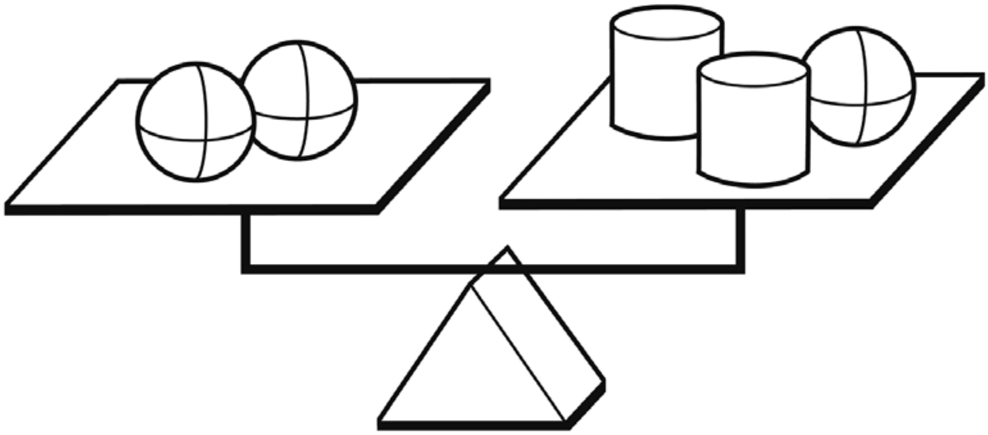

Figure 22.1. Pan balance problem 1 ($2S = 2C + S$).

The teacher operated with several major objectives: First, she set out to show the parallel structure between the pan balance and important features of the algebraic sentences. In particular, she wished to highlight how balance related to equality (and to the equal sign), how lack of balance related to inequality (and to the greater than sign), how collections of the same object related to scalar multiplication, how collections of different objects related to addition (and to the "+" operator), and how the unknown weight of each object related to the use of variables. Second, the teacher supported students' construction of possible algebraic models of the pan balances. Third, the nature of the problems led to the construction of systems of interrelated equations or inequalities that could be simplified through meaningful operations, such as canceling out identical objects from opposite sides of the pan balance (or algebraic sentence), and substituting known relations (as when one sphere balances the weight of two cylinders).

The video analyses focus on instruction with three pan balance configurations, including two configurations that balanced (problem 1, $2s = 2c + s$, and problem 2, $2b + c = s$), and one that did not (problem 3, $3b + 2c > s + c$). Students constructed equations to symbolize the configurations of the pan balance (i.e., balanced or unbalanced scales), and attempted to simplify these equations, first working individually, then in small groups. The current analyses focus on a segment that follows the small group work when the teacher convenes a whole-class discussion on algebraic modeling. The analyses are based on 23 min and 40 sec from a 90-min class that also included other mathematical and administrative activities.

Video Analysis

The video excerpt was transcribed in two "passes." In the first pass, the teacher's speech was transcribed, and the verbal transcript was divided into meaningful idea units, following a procedure similar to Kintsch (1998). In this chapter, we refer to these units as utterances.

In the second pass, all of the observable gestures that the teacher produced along with her speech were identified and incorporated into the transcript. Gestures were classified into three categories. Pointing gestures were defined as gestures used to indicate objects, locations, inscriptions, or students. Most pointing gestures were produced with the fingers or hands; some were produced using a pen as a "pointer." For example, in Figure 22.2, a frame from the video shows that the teacher points with her pen to the sides of the balanced scales as she states, "This side equals this side." Representational gestures were defined as gestures in which the hand shape or motion trajectory of the hand or arm represented some object, action, concept, or relation. The category of representational gesture as used here collapses across the categories of iconic and metaphoric gestures as described by McNeill (1992). It refers to gestures that pictorially "bear a close formal relationship to the semantic content of speech" (p. 12) by depicting either a concrete object or event, or an abstract, "invisible" idea (p. 14). For example, Figure 22.3 shows a sequence of still frames of the teacher (a) first miming plucking (pictures of) two spheres from either side of pan balance A, and then (b) "picking up" an *s* variable from both sides of an algebraic equation (note how her left hand has shifted down the screen from the pan to the equation area). (A transcript of the teacher's utterances leading up to and accompanying these gestures is provided in Appendix A.) Writing gestures were defined as writing that the teacher produced while speaking, and that was temporally integrated with speech in the same way that

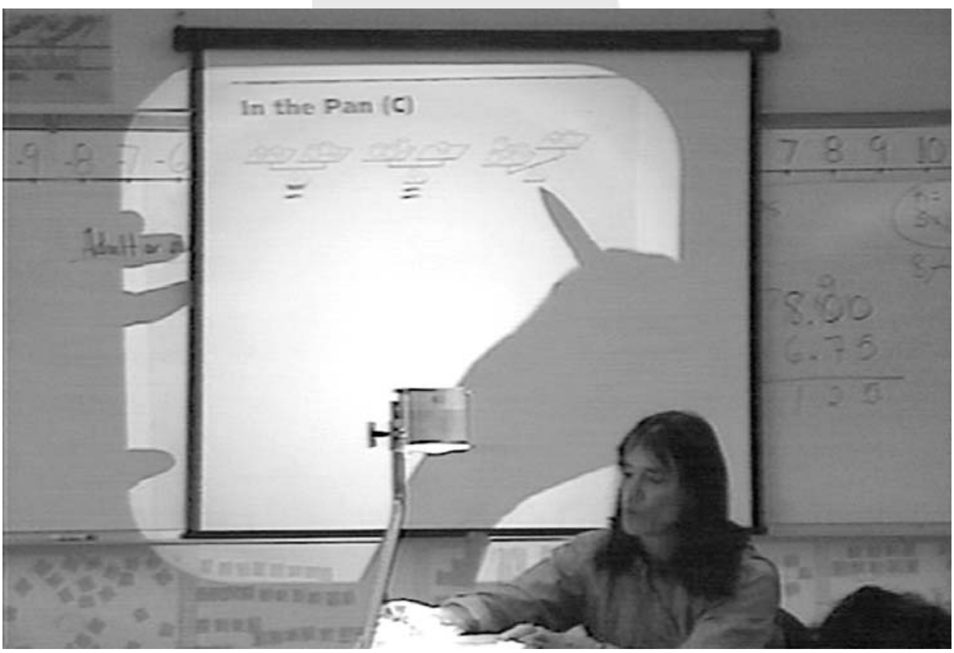

Figure 22.2. Example pointing gesture. In this instance, the teacher points with her pen.

Figure 22.3. Examples of representational gesture, accompanying the verbal utterance "I'm gonna take away a sphere from each side." (a) Teacher mimes picking up a sphere from each side of the pan balance. (b) Teacher mimes picking up the variable *s* from each side of the equation.

hand and arm gestures are temporally integrated with speech. For example, in Figure 22.4, the teacher used a writing gesture while talking about the effects of removing a sphere from one side of the pan balance and the equation. (Note that writing that was produced in the absence of speech was not coded as a form of gesture.) Pointing, writing, and representational gesture are all taken to be forms of grounding, as discussed earlier.

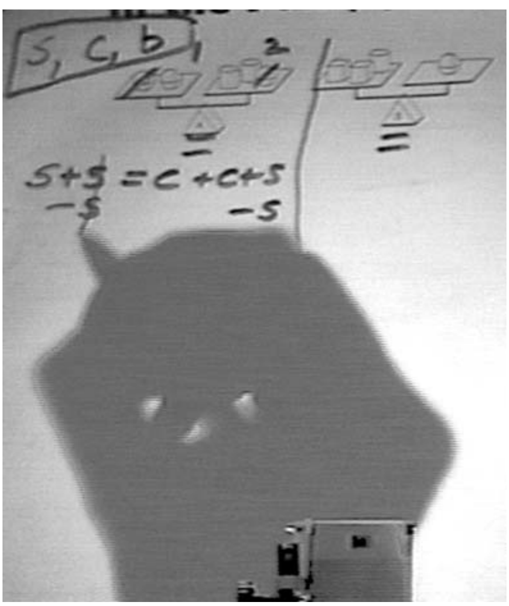

Figure 22.4. Example writing gesture, accompanying the verbal utterance "Do I have a sphere anymore? No. Naa (sound like game show buzzer), alright?"

There were a total of 301 teacher utterances in the data set. For 29 of these utterances, the teacher was off camera, so the presence of grounding could not be assessed. Each of the remaining 272 utterances was classified as either speech alone or speech with grounding. For utterances with grounding, the method of grounding (e.g., pointing, representational gestures, writing, or some combination of these) was noted. In addition, the total number of grounding acts (i.e., distinct gestures) that accompanied each utterance was noted.

In addition to coding for gestural grounding, utterances were also coded for their referents. Three categories of referents were of greatest interest; (1) pans, defined as the concrete, pictorial representations of the pan balance; (2) mathematical relations, defined as symbolic equations or inequalities, in this case, algebraic sentences used to model the pan balance; and (3) links, defined as conceptual links or correspondences made between particular configurations of the pan balance and algebraic sentences. Of course, many of the teachers' utterances did not refer to one of these three categories of referents. These utterances were excluded from analyses that focus on referents.

These three categories of referents vary in level of abstraction. Pans as illustrations of physical objects are considered to be the most concrete of the three types of referents. Algebraic sentences as inscriptions of equalities and inequalities are less concrete, but still physically locatable, and are therefore considered to be of a moderate level of abstraction. Links, which lack physical and visual presence but exist conceptually, are considered to be the most abstract of the three types of referents.

RESULTS

The data analyses focus on the teacher's use of grounding; how it changes over the course of the lesson, how it varies depending on the referent of the utterance, and how it relates to student utterances.

How Many of the Teacher's Utterances Included Some Form of Gestural Grounding?

Overall, 56% of the teachers' utterances included some form of gestural grounding; 21% included at least one instance of pointing; 20% included at least one instance of representational gesture; and 15% included at least one instance of writing gesture. Some utterances included more than one form of grounding.

If the analysis is restricted to utterances that focus on the instructional task itself (i.e., utterances that focused on the pan, algebraic sentences, or links between the two, rather than on classroom management or other matters, $N = 158$), the teacher's use of gesture is even more striking. For this subset of utterances, 74% of the teachers' utterances included some form of gestural grounding. 34% included at least one instance of pointing, 22% included at least one instance of representational gesture, and 24% included at least one instance of writing gesture. Thus, grounding with gesture was pervasive in the teacher's instructional communication.

How Did the Teacher's Use of Grounding Change Over the Course of the Lesson?

Recall that we hypothesized that the teacher would produce more gestural grounding when new material was introduced than after that material had become familiar to the students. Based on this hypothesis, we predicted that the teacher would use more gestural grounding at the outset of the lesson, and that this scaffolding would "fade" from the first to the second problem, which were similar in structure (i.e., both simple equations). Further, one might expect that gestural scaffolding would "rebound" for the third problem, which was a new problem type, namely, an inequality.[1] As seen in Figure 22.5, this prediction was borne out. The proportion of utterances that included gestural grounding was much lower for the second problem than for the first or third problems, $\chi^2(2, N = 263) = 12.17, p < .01$.

Because many utterances included multiple grounding acts, we next examined the mean number of grounding acts that the teacher produced per utterance for each problem. This provides some insight into how heavily concentrated the teacher's use of gesture was at various points in the lesson. As seen in Figure 22.6 (total heights of the bars), the mean number of grounding acts per utterance decreased from the first problem ($M = 0.78$, $SE = 0.08$) to the second problem ($M = 0.40$, $SE = 0{,}07$), and then increased again for the third problem ($M = 0.67$, $SE = 0.08$). The number of grounding acts per utterance differed significantly across problems, $F(2, 260) = 5.35, p < .01$. Post hoc tests indicated that the teacher used significantly more grounding acts per utterance on the first problem and on the third problem than on the second problem. Part of the reason for this pattern is that the teacher was more likely to use multiple grounding acts for any given utterance on the first problem (32% of utterances) and the third problem (25% of utterances) than on the second problem (10% of utterances). Thus, it

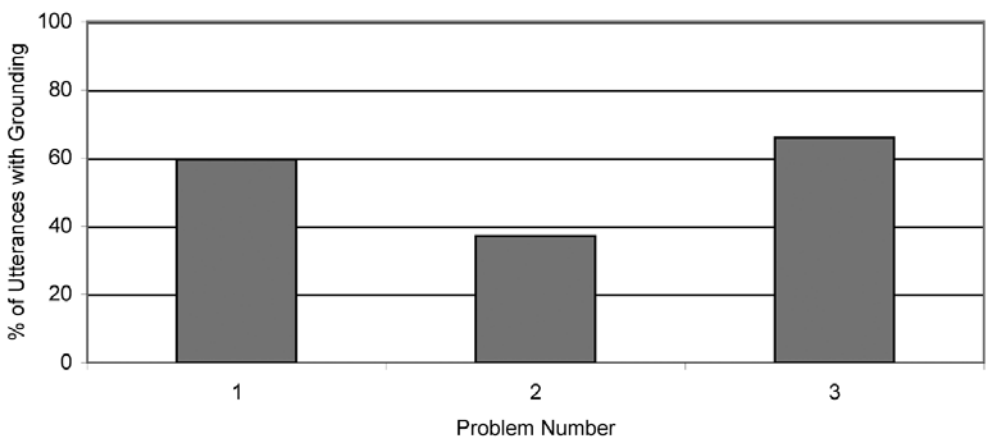

Figure 22.5. Percentage of utterances that included some form of grounding for each of the three problems.

[1]Nine utterances were excluded from these analyses because they focused on helping one of the students find some missing pens and pencils rather than on any of the target problems.

seems clear that the teacher used gestural grounding most extensively when she introduced new material (i.e., on Problems 1 and 3) and this practice faded as the material became more familiar to students.

Finally, we examined the mean number of each of the three types of grounding acts (pointing, representational gesture, writing) for each problem.

The data are presented in Figure 22.6. As seen in the figure, pointing was the most frequent type of grounding act overall, followed by representational gesture and then writing. Further, pointing was the most frequent method of grounding for each of the three problems. Representational gesture was used more frequently than writing on the first and second problems, and they were used similar amounts on the third problem.

How Did the Teacher Ground Utterances With Different Types of Referents?

Recall that we hypothesized that the teacher would produce more gestural grounding for aspects of the lesson content that were more abstract. Based on this hypothesis, we predicted that the teacher would produce the greatest proportion of grounding acts for utterances about the links between algebraic sentences and the pans, and the lowest proportion of grounding acts for utterances about the pans themselves. Figure 22.7 presents the proportion of utterances with each type of referent that included some form of grounding. As predicted, a greater proportion of utterances about links included some sort of grounding than utterances exclusively about algebraic relations or pans, $\chi^2(1, N = 158) = 4.13, p < .05$. The proportion of utterances that included grounding was lower and similar for utterances exclusively about algebraic relations and utterances exclusively about the pans.

We next examined the mean number of grounding acts per utterance. As seen in Figure 22.8 (total heights of the bars), utterances that referred to links between the

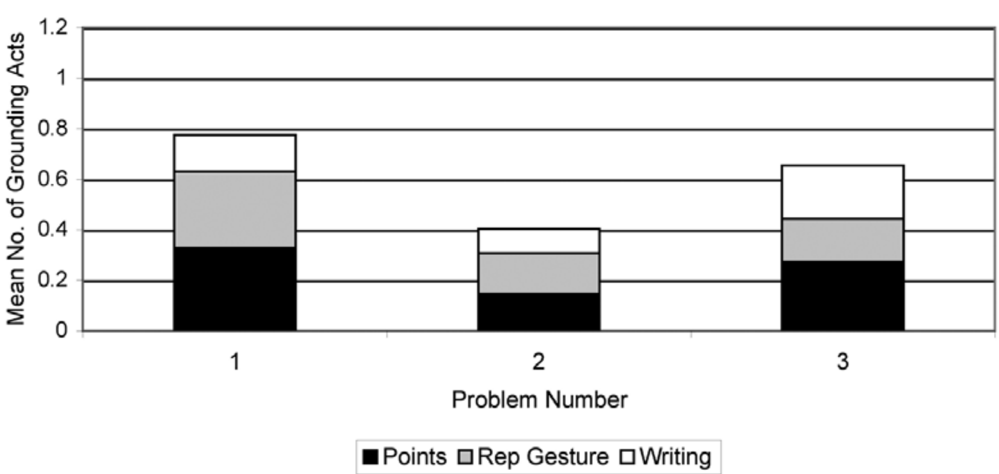

Figure 22.6. Mean number of grounding acts of each type produced per utterance for each of the three problems.

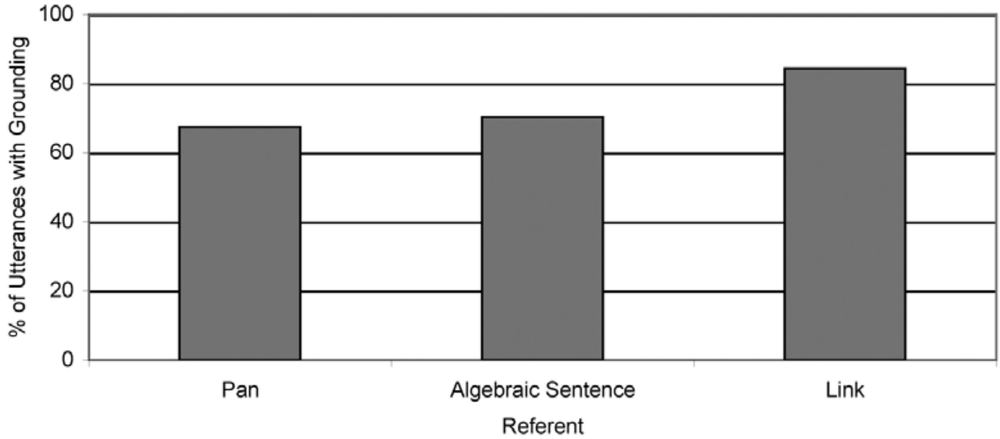

Figure 22.7. Percentage of utterances with each referent that included some form of grounding.

pans and the algebraic sentences received the greatest number of grounding acts per utterance (*M* = 1.18, *SE* = 0.12). Utterances that referred exclusively to the algebraic sentences and utterances that referred exclusively to the pans received comparable numbers of grounding acts per utterance (algebraic sentences, *M* = 0.83, *SE* = 0.09; pans, *M* = 0.84, *SE* = 0.12). The number of grounding acts per utterance differed significantly across referents, $F(2, 155) = 3.60$, $p < .03$. Post hoc tests indicated that the teacher used significantly more grounding acts per utterance for utterances about links than for utterances about pans or algebraic sentences. Part of the reason for this pattern is that the teacher was especially likely to use multiple grounding acts for utter-

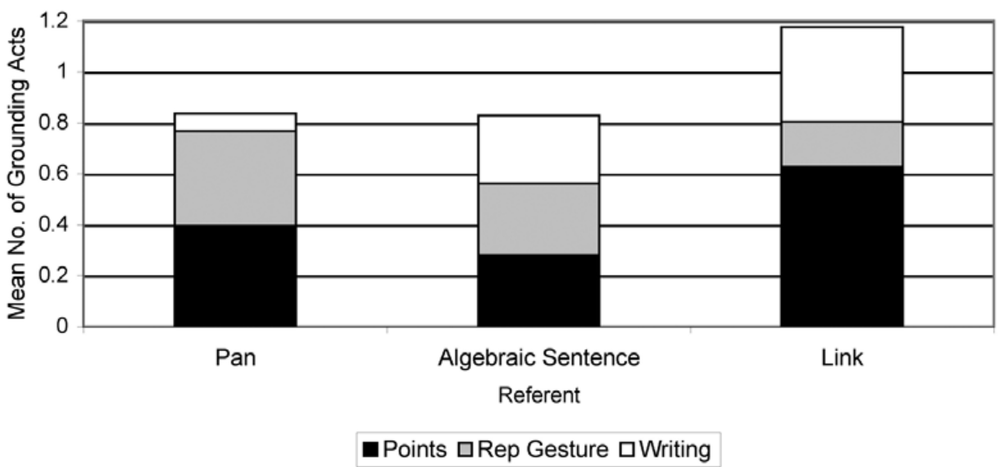

Figure 22.8. Mean number of grounding acts of each type produced per utterance for each of the three referent categories.

ances about the links between pans and algebraic sentences. Indeed, 57% of utterances about links received multiple grounding acts, compared to only 27% of utterances about algebraic sentences and 28% of utterances about pans.

Utterances about links often involved a pointing gesture to some aspect of a pan, followed by a pointing or writing gesture to the corresponding aspect of an equation or inequality, or vice versa. For example, near the outset of the lesson, the teacher sought to establish the correspondence between the fulcrums of the pan balances (which she referred to as "wedges") and the relational symbols (equal signs) used in the algebraic sentences.

Speech: OK, um (pause) we want to think of these wedges as the equals sign, right?

Gesture: {1} {2} {3} {4 }

Gesture descriptions:
1, points with pen to fulcrum in Problem A
2. points with pen to fulcrum in Problem B
3, points with pen to fulcrum in Problem A
4. writes equal sign under fulcrum in Problem A

As in this example, the teacher frequently used gestures to delineate the correspondences between different representations of the same mathematical information. In other cases, the teacher integrated aspects of multiple representations in a single utterance, as in the following example, where she highlights that the greater-than symbol can describe the relationship between the pans.

Speech: you'd have to say, well right now, this side's greater than that side

Gesture: {1} {2} { 3 }

Gesture descriptions:
1. points with pen to left pan in Problem C
2. points with pen to greater-than symbol below Problem C
3. points with pen to right pan in Problem C

We suggest that students may be more likely to attend to and understand the relationships among representations when these relationships are instantiated with gestures.

Finally, we examined the mean number of each of the three types of grounding (pointing, representational gesture, writing) for each referent. The data are presented in Figure 22.8. As seen in the figure, pointing was especially frequent for utterances about the links between pans and algebraic sentences. This is due in part to the fact that pointing is adept at highlighting correspondences, such as the correspondence between a written variable symbol in an equation and its referent object on the pan balance. Representational gesture was especially likely to be used for utterances exclusively about the pan, in part because actions such as removing objects from the pan could readily be described using representational gestures. Writing gestures were highly likely to be used for utterances about the algebraic relations, in part because these mathematical relations could be produced or elaborated with writing (e.g., underlining each side of an equation) as it was being described in her speech.

Was the Teacher's Use of Grounding Influenced by Student Utterances?

Another way to evaluate whether the teacher uses grounding adaptively is to examine whether she uses gesture more in response to students' questions and comments than otherwise. To address this issue, we compared her gesture rate in utterances that respond to student utterances to her gesture rate in utterances that immediately precede student utterances. These two categories of teacher utterances should be similar in terms of topic, level of engagement, and the point at which they occur during the class period. For extended back-and-forth sequences between student and teacher, we focused on the first student utterance of the sequence, and included the teacher utterances that immediately preceded and followed that student utterance in the data set.

The differences in the teacher's behavior are clear. The teacher was more likely to gesture after a student utterance than before (56% vs. 31%). In cases when the teacher gestured only before or after a student utterance ($N = 15$), she was much more likely to do so only after, rather than only before (binomial test, $p < .02$) Further, the mean number of gestures per teacher utterance was significantly greater in utterances that immediately followed student utterances than in utterances that immediately preceded student utterances [0.69 vs. 0.33, $t(35) = 3.17$, $p < .01$]. Thus, it appears that student utterances trigger more elaborate, grounded responses on the part of the teacher.

DISCUSSION

The present results indicate that gesture is pervasive in instructional communication. Furthermore, the results suggest that gesture serves a scaffolding function. As predicted by the scaffolding hypothesis, gesture was used most frequently for new material, for referents that were highly abstract, and in response to students' questions and comments. Thus, gesture appears to be one means by which this teacher attempted to scaffold student comprehension.

Of course, some limitations of the present work must be acknowledged. The study focuses on a single lesson from a single teacher. Differences in lesson content, teaching style, classroom context, and the population of students may influence how gesture is used to scaffold new mathematical concepts. The larger body of gesture research suggests that some of the patterns we observed in this study should also appear across different lessons, teachers, settings, and populations, but this must be established empirically. In addition, we did not examine whether individual gestures reinforced or complemented the accompanying speech. Future analyses of this lesson may reveal even more about the ways that information conveyed in gesture relates to the accompanying speech. Finally, it remains to be seen whether the grounding of abstract ideas through gesture aids student comprehension of lesson content and leads to greater learning. Some recent experiments using videotapes of teachers carrying out instruction suggest that this may be the case, at least for lessons that focus on procedural knowledge (e.g., how to use a compass, Glenberg & Robertson, 1999) and visuospatial concepts (e.g., symmetry, Valenzeno, Alibali, & Klatzky, 2003; Piagetian conservation, Church, Ayman-Nolley, & Mahootian, 2004). However, studies of the impact of gesture on student learning in naturalistic, instructional settings are needed. We suspect that such studies will show that teachers' gestures do indeed influence students' comprehension and learning.

We have argued that the evidence supports a view of teacher gesture as a form of scaffolding. However, at least one alternative possibility must be acknowledged—namely, the teacher's gestures may index her own cognitive state. Past research has shown that gestures are not solely communicative; they also serve a cognitive function for the speaker, helping to support the reasoning process (e.g., Alibali, Kita, & Young, 2000; Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001). This perspective suggests that the teacher might decrease her use of gesture as she becomes more familiar with the mathematical content in the lesson (e.g., from the first to the second problem). When new cognitive demands arise (e.g., on the third problem, or in response to a student question or comment), she may gesture more as means to support her own reasoning processes. Future research will be needed to explore whether the cognitive account or the scaffolding account better explains teachers' use of gesture in classroom settings, or whether both accounts are viable. It is worth noting that, even if the teacher produces gesture to support her own reasoning processes, those gestures may still help student learning by helping her articulate her thoughts more clearly.

Regardless of which account ultimately proves correct, it is clear that teachers' gestures reveal aspects of their thinking. Indeed, an extensive body of past research has shown that gestures are a unique and revealing window on speakers' thought processes (e.g., Crowder, 1996; Goldin-Meadow, Alibali, & Church, 1993; Schwartz & Black, 1996). We suggest that teachers' gestures reveal aspects of their thinking, not only about lesson content but also about students' abilities. If teachers produce more gestures when they believe students need greater scaffolding, then teachers' gestures may reflect their implicit models of students' knowledge and potential areas of difficulty. It is possible that teachers may use gesture differently when explaining the same content to different students, depending on their beliefs about the students. We plan to explore this issue in future work.

This research emphasizes the communicative nature of teaching (e.g., Flevares & Perry, 2001; Valenzeno et al., 2003), and underscores the importance of gesture research for teacher education and professional development. In addition, this work highlights the many tasks that teachers face in communicating abstract material to students for the first time. Because gesture works in tandem with speech, it can provide conceptual grounding for new and abstract ideas in a visual and holistic manner. Teachers can use the verbal modality to articulate abstract concepts, while using gesture to direct students' attention to the referents of their speech, and to ground those abstract concepts to ideas that are concrete and familiar.

The use of gesture as a form of grounding bears on one of the fundamental challenges in the field of cognitive science, namely, the "symbol grounding problem" (Harnad, 1990). This is the problem of how meaning can be explained in terms of arbitrary symbols (such as words) that have behavior governed exclusively by syntactic rules (or grammars). Embodied accounts of cognition (e.g., Barsalou, 1999; Glenberg, 1997; Glenberg & Kaschak, 2002) offer one solution to this problem, namely, that symbolic representations are grounded from the "bottom up," via their links to bodily experiences and actions. We suggest that gestures may be one manifestation of the embodiment of cognition. The teacher's gestures reveal a natural, spontaneous way to provide the grounding that is necessary for meaning to be attached to the objects of instruction.

According to Harnad (1990), grounding can be achieved either through "iconic representations," which are analogs of sensory information, or through "categorical representations," which encode invariant features of object and event categories. This perspective could help explain the teacher's adaptive use of gesture across different referents. As seen in Figure 22.8, the teacher often used representational gestures, such as iconic representations of physical actions, when she spoke about the pan balances. Further, she often used pointing to highlight object features when she spoke about the links between the pans and the algebraic sentences. Thus, different referents afforded different types of gesture. These findings suggest that lessons that involve different types of representational material will likely elicit different types of gestural grounding. Future research on this issue is needed.

The prevalence of gesture and its role in instruction raises an additional issue fundamental to classical cognitive theory. In its canonical form, information processing is the core of the cognitive system. Outside of the "central processing unit" are the "peripherals"—the sensory inputs that provide information from the perceptual systems, and the actuators that are output systems for acting on the world. As Wilson (2002) characterizes it, "Perceptual and motor systems, though reasonable objects of inquiry in their own right, were not considered relevant to understanding 'central' cognitive processes. Instead, they were thought to serve merely as peripheral input and output devices" (p. 625). Thus, a great deal of cognitive research assumed that very narrow forms of data—reaction times, accuracy, and verbal responses—were sufficient to characterize complex behavior. The symbol processing view, seemingly fundamental to classical cognitive science, has recently come into question. As Eisenberg (2002) muses,

> As I write this sentence, I am glancing over at the color printer sitting beside my screen. In the popular jargon of the computer industry, that printer is called a "peripheral"—which, upon reflection, is a rather odd way to describe it. What, precisely, is it peripheral to? If the ultimate goal of my activity is to produce a physical artifact, then one would have to conclude that the printer is a central—maybe the central—technological device in sight. (p. 1)

From our perspective, physical gesture appears to be essential to teachers' ability to conduct their practice, and its place in the complex, cognitive activity of real-time instruction is not peripheral, but instead quite central. For this reason, we expect to see a growing appreciation for the importance of gesture research and the use of video data as part of the scientific study of instruction and teacher cognition.

The current study sheds some light on instructional practices that are necessarily overlooked in analyses of classroom speech alone. By broadening the scope of discourse analysis to include body motions, referent objects and inscriptions, as well as the language that accompanies them, one can achieve a more nuanced view of the communicative processes involved in instruction and learning. Although gesture often reinforces the information expressed in the verbal channel, it sometimes reveals information that is not expressed in speech (e.g., Church & Goldin-Meadow, 1986; Perry, Church, & Goldin-Meadow, 1988). Further, listeners may glean different messages from speech, depending on whether or not that speech is accompanied by gesture, and depending on whether gesture provides reinforcing or complementary information (e.g., Goldin-Meadow & Sandhofer, 1999; McNeil et al., 2000; Singer & Goldin-Meadow, 2005). In some situations, such as the lesson analyzed here, gesture may serve as the "glue" that helps to forge the links among various other representations (in this case, the illustrations of the pan balances, and the symbolic representations) for listeners. A deeper understanding of the communicative aspects of instruction will require serious attention to the multi-modal nature of instructional communication. This goal can be achieved only with the use of video data, and with the continuing development of methods for video analysis.

ACKNOWLEDGMENTS

We are grateful to Amy French for her participation in this study of her teaching practices. We also thank Kate Masarik for assistance with videotaping and field-based research, and Emily Coleman for assistance with transcription and coding. This research was funded in part by a grant award "Understanding and Cultivating the Transition from Arithmetic to Algebraic Reasoning" from the Interagency Educational Research Initiative, an alliance of the National Science Foundation, the Department of Education Institute of Educational Sciences, and the National Institute of Child Health and Human Development within the National Institutes of Health.

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APPENDIX

Transcript

If I take away a sphere on each side / does this still balance like Robbie said? / Yeah, it still balances / Doesn't it? / OK! So a way that you can notate that down in your equation, down here is you can say "OK, now I am gonna take away an S" / "I am gonna take away a sphere from each side" / "instead of taking it off the pans" / "I am going to take it away from this equation" / So, I'm gonna take away an S here / which is like crossing that one off / Are you with me? / (Yeah) / and it's like taking away an S over here / Follow me? / … / Just teaching you a (short pause) way to notate this / and a way to think about this / Ok, so now what happens if I take a sphere / if I have a sphere and I take one away / do I have a sphere anymore? / No. / Naa (sound like game show buzzer), alright? (Video of 1/21/99, 5:35–6:15)