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What the Teacher's Hands Tell the Student's Mind About Math

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Does nonverbal behavior contribute to cognitive as well as affective components of teaching? We examine here one type of nonverbal behavior: spontaneous gestures that accompany talk. Eight teachers were asked to instruct 49 children individually on mathematical equivalence as it applies to addition. All teachers used gesture to convey problem-solving strategies. The gestured strategies either reinforced (matched) or differed from (mismatched) strategies conveyed in speech. Children were more likely to reiterate teacher speech if it was accompanied by matching gesture than by no gesture at all and less likely to reiterate teacher speech if it was accompanied by mismatching gesture than by no gesture at all. Moreover, children were able to glean problem-solving strategies from the teachers' gestures and recast them into their own speech. Not only do teachers produce gestures that express task-relevant information, but their students take notice.

Teachers communicate with their pupils using a wide range of behaviors, both verbal and nonverbal. It is obvious that verbal behavior is crucial to teaching and learning. We ask here whether nonverbal behavior also plays a role in instruction. The set of behaviors that can transmit information nonverbally is large and includes posture and use of space, eye gaze, facial expression, and hand gestures (Knapp, 1972; Neill & Caswell, 1993). Educators have begun to recognize that nonverbal behavior has the potential to play a unique role in teaching, precisely because messages that are not conveyed through talk may be conveyed nonetheless—through nonverbal means (Neill, 1991).

What are the possible pedagogical values of nonverbal behaviors? There are at least two nonmutually exclusive functions that nonverbal behavior can assume in instruction: (a) Nonverbal behavior can reveal the attitudes and motivations of teacher and pupil, and (b) nonverbal behavior can provide insight into the content of the lesson itself.

Teachers' nonverbal behaviors have been shown to reflect their attitudes toward the child or the lesson (Andersen & Andersen, 1982; Woolfolk & Galloway, 1985). For example, a teacher may scowl when children approach his desk for help, thus conveying that he is not as open to questions as his words imply. Alternatively, nonverbal behaviors can reveal affective dimensions of the teachers' own personalities. For example, on the basis of a small sample of their nonverbal movements during a lesson, teachers can be reliably rated on scales of optimism, confidence, dominance, enthusiasm, and warmth, ratings that correlate with student evaluations of teacher effectiveness (Ambady & Rosenthal, 1993). Thus, nonverbal behavior has an acknowledged role in the affective aspects of teaching. These affective aspects, in turn, are likely to influence the learning process itself.

We explore here the second function that nonverbal behavior can assume in teaching. We ask whether nonverbal behavior conveys substantive information about the lesson itself and, in this way, contributes directly to the cognitive aspects of teaching. We and others (Goldin-Meadow, Alibali, & Church, 1993; Kendon, 1980; McNeill, 1992; Schwartz & Black, 1996) showed that the spontaneous gestures that accompany speech can reveal aspects of the speaker's message rather than (or in addition to) the speaker's affective stance. For example, consider a speaker who says, "the population increased steadily" while moving her hand upward in a series of step like motions. The speaker reveals through her gestures—and only her gestures—that she views the change in population as a discrete, rather than a continuous, function (cf. Alibali, Bassok, Olseth, Syc, & Goldin-Meadow, 1995; Alibali, Bassok, Solomon, Syc, & Goldin-Meadow, 1999).

Gestures of this sort have the potential to express task-relevant information, and, indeed, gesture has been found to do so in a variety of tasks taught in schools: reasoning about mathematical problems (Alibali & Goldin-Meadow, 1993; Perry, Church, & Goldin-Meadow, 1988), seasonal change (Crowder & Newman, 1993), control of variables (Stone, Webb, & Mahootian, 1991), gears (Perry & Elder, 1996), and rate of change (Alibali et al., 1995, 1999). Moreover, gesture has been observed in teacher–student interactions within the classroom (Crowder & Newman, 1993; Neill, 1991; Zukow-Goldring, Romo, & Duncan, 1994) and is particularly prevalent in classrooms of experienced teachers (Neill & Caswell, 1993).

Even though gesture is an integral part of classroom conversations, little attention has been paid to how gesture is actually used in teaching. In particular, how does the information conveyed in gesture relate to the information

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conveyed in the speech it accompanies? The goal of this study is twofold: (a) to examine how teachers use gesture and speech when asked to instruct a child in mathematics and (b) to explore the effects of these bimodal instructions on the student.

We chose to observe teachers explaining a math concept for several reasons. First, mathematical notions are often based on visual images (Hadamard, 1945), and gesture is an excellent medium for conveying such images. For example, in a technical discussion between two mathematicians, both speakers portrayed the notion "direct limit" by moving the hand in a straight line with a tensed stop and the notion "indirect limit" by looping the hand down and then up (McNeill, 1992). Second, there is presently a great deal of interest in the communication of mathematical notions within the classroom (National Council of Teachers of Mathematics [NCTM], 1989; Pimm, 1987; Stigler & Hiebert, 1997). Finally, gesture has been observed to accompany talk about mathematics among both teachers (Alibali, Sylvan, Fujimori, & Kawanaka, 1997) and children (Perry et al., 1988).

Gesture can be used in a math lesson to guide a student's attention to aspects of the problem (e.g., pointing out and tracing the perimeter of a triangle on the board while saying, "see this triangle") or to make concrete the concepts within the problem (e.g., holding two pointing hands together and then drawing a horizontal line by pulling them apart while saying, "that would be a line measurement"; Alibali, Sylvan, et al., 1997). However, gesture can do more; it can also be used to convey problem-solving strategies. For example, in solving the problem, $5 + 3 + 4 = \_\_ + 4$, children often add the numbers on the left side of the equation and put the sum in the blank, an "add-to-equal sign" strategy. When asked to explain how they solved the problem, they articulate this strategy in both speech and gesture: They say, "I added the 5, the 3, and the 4, and put 12 in the blank" while pointing at the 5, the 3, and the 4 on the left side of the equation and then at the blank on the right. It is important to note that the problem-solving strategies children convey in their gestures are not always the same as the problem-solving strategies conveyed in speech. For example, in response to this problem, a child might articulate the add-to-equal sign strategy in speech—"I added the 5, the 3, and the 4, and put 12 in the blank"—but produce gestures that convey a different strategy: Point at the 5, the 3, the 4 on the left side of the equation, point at the 4 on the right side of the equation, point at the blank (an "add-all-numbers" strategy).

At first glance, it may seem as though these pointing gestures, rather than conveying problem-solving strategies, are doing nothing more than directing the listener's attention to the numbers in the problem. However, the string of gestures, when considered as a whole, can be taken to reflect a problem-solving strategy on its own. Support for this view comes from children's ratings of solutions generated by various problem-solving strategies. For example, the child described previously who produced a different strategy in speech and in gesture was later asked which answers might be acceptable solutions to the problem, $5 + 3 + 4 = \_\_ + 4$ (children were, on the whole, willing to accept more than one answer). The child, of course, accepted 12, the answer generated by the add-to-equal sign strategy that she had conveyed in speech. More interestingly, the child also accepted 16, the answer generated by the add-all-numbers strategy that she had conveyed in gesture but not in speech. In general, children gave significantly higher ratings to answers generated by strategies that they themselves had produced *only* in gesture (and not in speech) than to answers generated by strategies that they had not produced in either gesture or speech (Garber, Alibali, & Goldin-Meadow, 1998). In other words, children recognized solutions generated by strategies that they had produced uniquely in gesture. Thus, strings of gestures can reveal knowledge about a child's problem-solving strategies (although the knowledge may be implicit and the strategy may be incorrect).

In this study, we observed the problem-solving strategies revealed in the gestures teachers produce as they talk about mathematical equivalence, the concept that the two sides of an equation must be equivalent. When asked to solve problems such as $5 + 3 + 4 = \_\_ + 4$, most fourth graders arrive at incorrect answers and use incorrect strategies to do so (Perry et al., 1988). We asked teachers in our study to instruct children on this type of addition problem and observed the problem-solving strategies that the teachers produced, in both gesture and speech, during the tutorial. Our procedures go a step beyond paradigms that have traditionally been used to explore nonverbal behavior in teaching in that our tutorials were unstaged lessons (cf. Allen & Feldman, 1973; Perry, Berch, & Singleton, 1995), and our gesture-reader (the student) was a participant in the interaction rather than an uninvolved observer (cf. Ambady & Rosenthal, 1993). Our design allowed us to assess children's reactions to gestures and speech directed specifically toward them without any artificial staging of the interaction. Note that our math tutorials resemble the one-on-one interchanges that commonly arise in American mathematics classrooms when teachers assign seat work and then circulate throughout the classroom offering each student instruction and feedback (Stigler, Fernandez, & Yoshida, 1996).

Method

Participants

Eight teachers (6 females, 2 males) participated in the study. Teachers were recruited through fliers on display at the University of Chicago and through graduate student contacts in the Department of Education. All 8 currently or formerly taught math or science in Chicago-area schools: 6 at the elementary level and 2 at the secondary level. No differences were found between the elementary- and secondary-level teachers in the results reported later. On average, teachers had 9.6 years (range = 1–33 years) of teaching experience. In addition, 49 children (21 females, 28 males) participated in the lessons. The children ranged in age from 8 years 6 months to 11 years 6 months (mean = 9 years 10 months) and were either in the latter part of their third-grade year in school or the early part of their fourth-grade year. Each teacher individually instructed 5 to 7 children, resulting in a total of 49 interactions.

The lessons took place in a quiet room in the child's school. None of the teachers knew the children they taught. However, to give the teacher a sense of the tutee's grasp of mathematical equivalence and thus make the tutorial more comparable to an actual lesson, the teacher observed each child during a pretest given by the experimenter (see next section). Although the interplay between teacher and pupil who know each other is a central aspect of education, our goal was to understand the role of nonverbal cues in on-line tutoring. We included teachers and children who were not familiar with one another to avoid the communicative gaps that can occur when people know each other well. If teacher and pupil had been familiar with one another, there would be no way that we, as observers, could have determined whether the participants were responding to explicit communicative signals occurring on-line or to the unspoken knowledge they shared.

Procedure

The teachers were asked about their teaching experience and were familiarized with the problems they were to teach. They were told that we were studying how experienced teachers instruct children in mathematical equivalence. None of the teachers was aware of our focus on gesture. The only constraint imposed was a time limit of 20 min per lesson. Teachers spent an average of 12 min with each child (range = 5–16 min).

To give teachers control of the lesson, we did not provide a specific list of problems to use during instruction. However, we did encourage teachers to use problems comparable to those on the pretest (e.g., 4 + 5 + 6 = __ + 6; 7 + 3 + 6 = 7 + __). Eighty percent of the 488 problems that teachers used during the lessons were of this form: Each problem had a blank and one addend on one side of the equation and at least two addends on the other side of the equation. Three of the 8 teachers used only problems of this type. The other 5 used a majority of these pretest-like problems but also used some problems with no addends on the right side of the equation (e.g., 3 + 4 + 5 = __; 13% of the 488 problems) and some with no blank, two blanks, or no operation (7%). It is important to note that no differences were found in the results reported later as a function of the proportion of pretest-like problems that the teachers used.

To give the teacher an opportunity to see how the child approached the math problems before instruction, the teacher observed the experimenter giving the child a pretest designed to tap knowledge of mathematical equivalence. The child completed a series of problems independently and then explained to the experimenter at the blackboard how he or she solved six of the problems. The experimenter wrote each problem on the board, filled in the child's answer from the paper-and-pencil test, and then asked how the child had obtained that answer. The teacher watched and was given paper on which to jot notes about the child's answers and explanations. Children who solved three or more of the six pretest problems correctly were eliminated from the study immediately after the pretest. The teacher was then brought to the blackboard to instruct the child and told to use whatever techniques he or she thought appropriate for that child. After the lesson, the child was given a posttest similar to the pretest. This design encouraged teachers to focus their instruction on mathematical equivalence. The entire session was videotaped.

Coding the Instruction Sessions

All of the speech and gestures that the teachers and children produced during the lessons were transcribed. However, only communications pertaining to mathematical equivalence were coded for strategies. Speech was coded independently of gesture (with video turned off), and gesture was coded independently of speech (with audio turned off).

Each problem-solving strategy that the teacher produced was classified in two ways. First, following the system described by Perry et al. (1988), we classified each strategy according to the particular approach it took to the problem. This decision effectively determined whether the strategy was correct, incorrect, or building. Correct strategies, if implemented, lead to correct solutions; incorrect strategies lead to incorrect solutions; building strategies are described in the next paragraph. Second, we classified each strategy according to the modality in which it was produced (speech, gesture, or both).

In addition to correct and incorrect solution strategies, teachers also produced strategies that focused on only one of the two sides of the equation. These strategies were used to break the problem into parts and build up to the correct answer. We, therefore, refer to them as building strategies. A typical sequence containing building strategies might proceed as follows: The teacher first asks the child to calculate the sum for the left side of the equation (a left building strategy). In the next turn, the teacher asks the child to calculate the sum for the right side (a right building strategy). Finally, the teacher tells the child to compare the two sides and to determine whether the two sums are equal (a correct equalizer strategy). Although building strategies typically culminated in the teacher producing a correct strategy, we treated building strategies as independent for several reasons. First, teachers frequently stopped and left space for the child to respond. Second, building strategies did not always culminate in either a correct or incorrect strategy but, at times, were used on their own. Finally, we had no evidence that the children themselves considered a building strategy to be part of the correct or incorrect strategy to which it eventually led.

After a lesson was coded for gestural problem-solving strategies and for spoken problem-solving strategies, the two sets of strategies were aligned using time codes. Two types of turns were coded: (a) those in which a strategy produced in one modality did not overlap in time with any strategies in the other modality; and (b) those in which a strategy produced in one modality did overlap in time with a strategy in the other modality. A spoken strategy that did not overlap in time with a gestured strategy was considered a speech-without-gesture turn. A gestured strategy that did not overlap in time with a spoken strategy was considered a gesture-without-speech turn. Spoken strategies that did occur simultaneously with gestured strategies were classified as follows: speech and gesture match (the turn contained both gesture and speech, and the same strategy was produced in the two modalities); or speech and gesture mismatch (the turn contained both gesture and speech, but the strategy was produced in one modality and not the other; e.g., the teacher produced an equalizer strategy in speech but an add-all-numbers strategy in gesture).

Finally, we examined the relation between the teacher's strategies and the child's response to those strategies. If the teacher paused and waited for a response from the child, we classified that turn as one on which the child had an opportunity to respond. We then determined whether the child responded, and, if so, we classified that response according to type of strategy and modality. Observing both gesture and speech, we classified the child's response as follows: (a) no response to the teacher's strategy (the child said or gestured nothing at all); (b) unrelated response to the teacher's strategy (the child's response bore no relation to the strategy conveyed by the teacher); (c) uptake of the teacher's strategy (the child's response contained the strategy conveyed by the teacher). We classified a child response as an uptake even if it did not occur in the same modality as the teacher's. For example, if the teacher produced an equalizer strategy in speech but the child responded with an equalizer strategy in gesture (or vice versa), the response was still an uptake. The modality in which the child produced the uptake was later analyzed in relation to the modality and correctness of the teacher strategy it followed.

Results

The Types of Problem-Solving Strategies Teachers Used in Their Lessons

Table 1 presents examples, in both speech and gesture, of the most common correct, incorrect, and building strategies that the teachers used in their lessons. Reliability between coders was assessed by having two individuals independently categorize the gestures and speech teachers produced in a subset of the lessons according to the types of problem-solving strategies displayed in Table 1. Cohen's kappa coefficients (Cohen, 1960) were calculated to determine the level of agreement between coders after chance agreement had been excluded. The proportion of agreement between coders and the kappa were 1.00 and 1.00, respectively, for assigning strategies to speech and .92 and .89, respectively, for assigning strategies to gesture. Note that this decision effectively determined whether a response was correct, incorrect, or building (see Table 1). The proportion of agreement between coders and the kappa were .92 and .84 for breaking the stream of behaviors into turns; .97 and .96 for determining the relation between speech and gesture codes within a turn (speech alone, gesture alone, speech–gesture match, speech–gesture mismatch); .92 and .83 for determining whether the teacher gave the child an opportunity to respond; and 1.00 and 1.00 for classifying the child's response to the teacher's strategy.

The 8 teachers produced, on average, 95 problem-solving strategies ($SD = 29$, range = 48–139) when instructing each child. In contrast, each child produced an average of 31 strategies ($SD = 15$, range = 14–56). That the teachers did most of the talking in these tutorials is consistent with previous reports of teacher–student interaction in math lessons, with either an entire class or individual students (Pimm, 1987, p. 58).

Not surprisingly given that the teacher's goal was to get the children to solve the problems, most of their strategies were correct. Teachers also produced building strategies and a relatively small number of strategies leading to incorrect solutions (Figure 1). Although the number of incorrect strategies was small, each teacher did produce at least one.

The Modalities Teachers Used to Express Problem-Solving Strategies

Next, we asked whether teachers used gesture to convey problem-solving strategies and, if so, how gesture was used. Teachers produced an average of 37 strategies in gesture ($SD = 11$, range = 28–53) per child, accounting for 38% of their total strategies. Thus, a good percentage of the teachers' problem-solving strategies were expressed nonverbally.

Our next question was how gesture and speech related to one another within a single turn. Teachers often produced strategies in speech without any gesture whatsoever (.36 of turns, white bar in Figure 2) and rarely produced strategies

Table 1
Examples of Correct, Incorrect, and Building Strategies Produced in Speech and in Gesture: Sample Problem, 3 + 4 + 5 = _ + 5

Type of strategy	Speech	Gesture
Correct strategies		
Equalizer	"Both sides have to be the same."	Flat palm perpendicular to the board, first placed under the left side of the problem and then under the right
Grouping	"You can add up these two numbers to get the answer."	V-hand indicates the 3 and 4 on the left side of the problem
Equal addends	"There's a 5 here and a 5 here; you can block them off and ignore them."	One flat palm covers the 5 on the left side of the problem and another covers the 5 on the right
Add–subtract	"You can get the answer by adding up all of the numbers on the left side, then taking away the 5 on the right."	Pointing hand sweeps under the left side of the problem and retracts; hand points to the 5 on the right side and retracts; hand points to the blank
Incorrect strategies		
Add-all-numbers	"I added all of them up."	Point at the 3, 4, left 5, right 5, and the blank
Add-to-equal sign	"I added the 3, the 4, the 5 to get the answer."	Point at the 3, 4, left 5, and the blank
Carry	"I put the 4 there."	Point at the 4 and the blank
Building strategies		
Left side	"Let's just add up the left side first; how much is the left side?"	Flat palm held under left side of problem
Right side	"Let's ignore the left side, and just look at the numbers on the right."	Flat palm sweeps from left to right under the right side of the problem

in gesture without any speech (.07, stipled bar). Approximately .60 of the teachers' turns contained both gesture and speech, .39 in which gesture conveyed the same strategy as speech (the matches, striped bar) and .19 in which gesture conveyed a different strategy from speech (the mismatches, black bar). Thus, when produced along with speech, gesture played one of two roles: Two thirds of the time, it reinforced speech by conveying the same strategy; one third of the time, it conflicted with speech by conveying a different strategy. Each of the 8 teachers produced some gestures that did not match the speech they accompanied; that is, each produced speech–gesture mismatches.

Next, we looked at the modalities teachers used to convey correct, incorrect, and building strategies. Figure 3 presents the proportion of correct strategies, incorrect strategies, and building strategies that appeared in a speech–gesture match, a mismatch, or in speech or gesture on its own. In each graph, strategies are displayed along the x-axis according to whether that strategy was produced in both modalities (speech–gesture match), in speech only (either in speech without gesture or in the speech component of a mismatch), or in gesture only (either in gesture without speech or in the gesture component of a mismatch). The important point to note is that teachers relied on different modalities to convey correct, building, and incorrect strategies.

Teachers used speech with *matching gesture* very frequently when conveying correct and building strategies (striped bar in top and bottom panels in Figure 3) and speech with *no gesture* almost as often when conveying correct strategies (white bar, top panel, Figure 3). In other words, teachers used speech—either alone or with gesture—when providing the child with correct information. However, when attempting to build up or scaffold the lesson for the child, teachers rarely spoke without gesturing, and those gestures tended to reinforce the message conveyed in the accompanying speech.

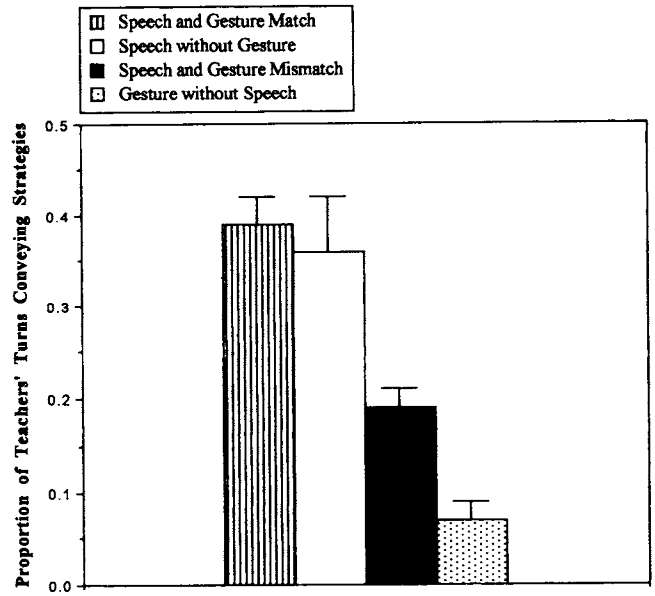

Figure 2. Mean proportion of teacher turns classified according to the modality (or modalities) within which the strategies were expressed: speech and matching gesture; speech without gesture; speech and mismatching gesture; gesture without speech. Bars indicate standard errors.

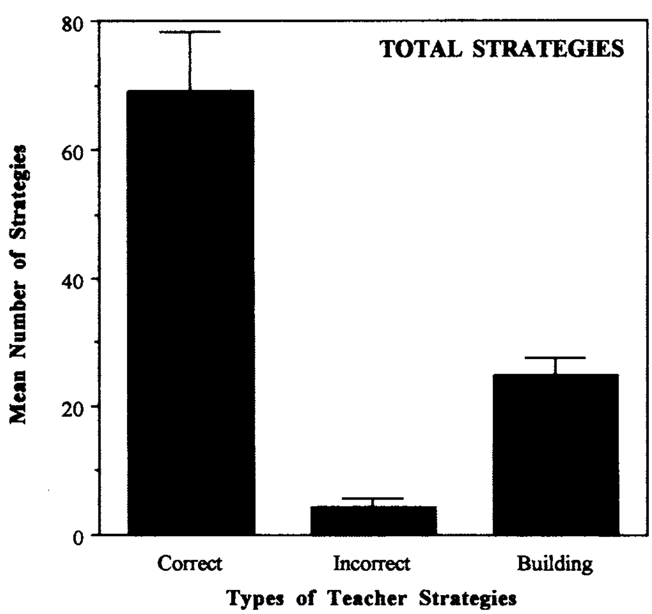

Figure 1. Mean number of correct, incorrect, and building problem-solving strategies that the teachers produced during a lesson with an individual child. Bars indicate standard errors.

When conveying their few incorrect strategies, the teachers again rarely spoke without gesturing. However, in this case, the teachers tended to use speech with *mismatching gesture* (black bars, middle graph, Figure 3). The incorrect strategy did not appear exclusively in gesture but was found in the speech component of the mismatch as often as the gesture component (compare the heights of the two black bars in the middle graph of Figure 3). For example, on the problem, $3 + 7 + 9 = \_\_ + 9$, one teacher said, "so 3 plus 7 is 10, plus 9 is 19" (an incorrect add-to-equal sign strategy) while pointing at the 3 and the 7, the two numbers that, if grouped and summed, produce the correct answer (a correct grouping strategy). It is interesting that the few incorrect strategies teachers produced were so strongly associated with mismatches, and that the incorrect strategy in the mismatch appeared as often in speech as it did in gesture. As noted later, the teachers' incorrect strategies, although infrequent, were noticed by the children.

When teachers convey incorrect strategies in a math lesson, it is likely that they are doing so to indicate what not to do. Thus, we might expect many of the teachers' incorrect strategies to be negated (e.g., the teacher might say, "we don't add up all of the numbers in the problem to get the answer to put in the blank"). Indeed, when the teachers produced incorrect strategies in *speech,* they often (although not always) negated those strategies: Eighty-two percent of the 34 incorrect strategies teachers produced uniquely in speech, as well as 71% of the 14 incorrect strategies they

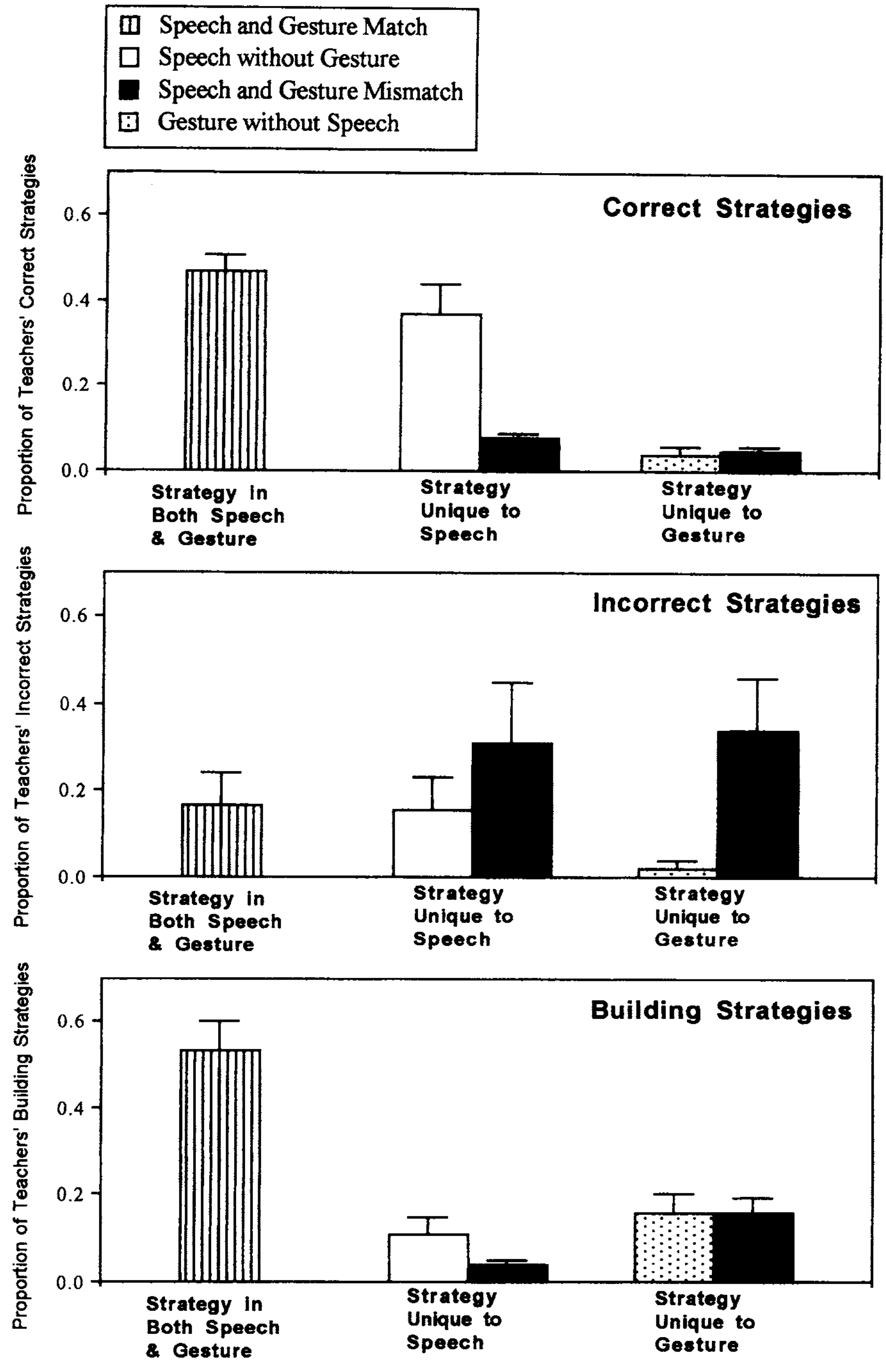

Figure 3. Mean proportion of teachers' correct (top graph), incorrect (middle graph), and building (bottom graph) strategies classified according to the modality within which each strategy was expressed. In each graph, strategies are displayed along the x-axis according to whether that strategy was produced in both modalities (speech–gesture match), in speech only (either in speech without gesture, or in the speech component of a mismatch), or in gesture only (either in gesture without speech, or in the gesture component of a mismatch). Bars indicate standard errors.

produced in speech accompanied by a matching gesture, were negated. Of course, the child may or may not notice that the teacher has signaled that the incorrect strategy is not to be used on these problems. We address this issue later.

In contrast to incorrect strategies in speech, none of the 27 incorrect strategies produced uniquely *in gesture* was negated; that is, teachers never shook their heads or produced a wiping-away movement while gesturing an incorrect strategy. For example, on the problem, 3 + 4 + 5 = __ + 5, the teacher pointed at the 3, the 4, the left 5, the 4 again, and the blank (an incorrect add-to-equal sign strategy) while in speech she talked about equivalence, making no reference to the incorrect strategy displayed in her gestures: "Okay, how can we check to see if they are the same on both sides?" This pattern suggests that the incorrect strategies teachers produced in gesture may have been unintentional.

Children's Responses to the Teachers' Strategies

The teachers produced a number of strategies that were embedded within the lesson and to which they did not expect a response. Overall, teachers gave children an opportunity to respond on 61% of the 3,192 problem-solving strategies they presented. We analyzed only strategies on which teachers expected a response. We calculated how likely children were to reiterate in their next turn the teacher's strategy, thus explicitly reflecting uptake of the idea that the teacher had presented.

We first examined children's responses to strategies that the teachers conveyed in speech (Figure 4, left panel). Because gesture, at times, reinforced the message conveyed in speech and, at other times, differed from that message, we calculated the proportion of child uptakes separately for problem-solving strategies presented by the teacher in speech with a matching gesture (striped bar), speech without any gesture at all (white bar), and speech with a mismatching gesture (black bar). We entered child uptake data into an analysis of variance with type of teacher presentation as a within-participant factor. The proportional data were transformed before statistical analysis (Zar, 1984). Child uptakes differed significantly as a function of teacher presentation, $F(2, 7) = 39.15$, $p < .0001$. Children were significantly more likely to uptake the strategy that teachers presented in speech when it was accompanied by a gesture that conveyed the same strategy ($p < .01$, Newman–Keuls) than when it was accompanied by no gesture at all. All 8 teacher–student dyads displayed this pattern. Conversely, children were significantly less likely to uptake the strategy that teachers presented in speech when it was accompanied by a gesture that conveyed a different strategy ($p < .01$, Newman–Keuls) than when it was accompanied by no gesture at all. Seven of the 8 teacher–student dyads displayed this pattern. Thus, gesture aided child comprehension of teacher speech when it matched that speech, and hurt child comprehension of teacher speech when it mismatched speech.

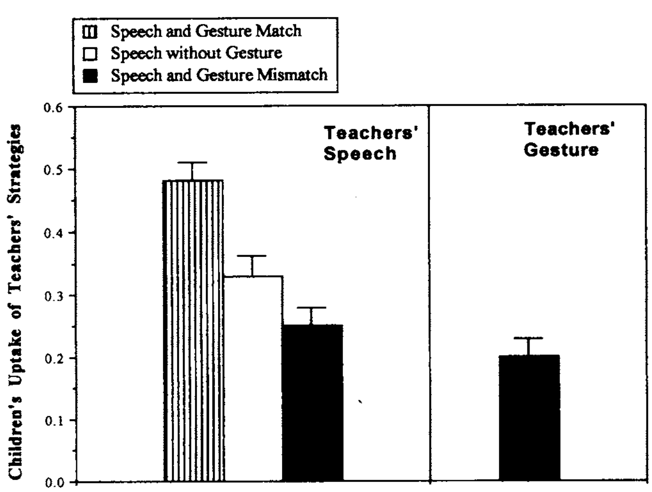

Figure 4. Mean proportion of child uptakes following teacher's speech (left panel) when accompanied by a matching gesture, by no gesture, or by a mismatching gesture, and child uptakes following teacher's gesture (right panel) when accompanied by mismatching speech. On average, teachers gave each child an opportunity to respond to 15 speech–gesture match turns (and each child responded with an uptake to an average of 6.9), to 20 speech without gesture turns (and each child responded with an uptake to 6.9), and to 4 speech–gesture mismatch turns (and each child responded with an uptake to 1.6). Bars indicate standard errors.

It is clear, then, that the teachers' gestures did have an effect on what children took from the teachers' speech. Did, however, the children actually comprehend the teachers' gestures; that is, did they glean substantive information from the gestures themselves? To answer this question, we examined the children's responses after the problem-solving strategies that the teachers produced in the gesture component of a mismatch. In these productions, gesture conveyed a different strategy from speech; if the child were to reiterate the strategy conveyed in gesture, it could only be because the child was able to "read" that gesture. We found that child uptakes followed strategies produced in the gesture component of a teacher mismatch .20 of the time (Figure 4, black bar in right panel; child uptakes also followed .17 of teacher strategies produced in gesture without speech, not shown in Figure 4). Although this may seem like a small proportion, note that child uptakes followed teacher strategies produced uniquely in speech only .25 of the time (Figure 4, black bar in left panel). Children were indeed able to glean substantive information from teachers' gestures.

It is important to note that the phenomenon we are describing is not restricted to a small set of teachers or children. All of the teachers provided the children they taught with opportunities to respond to speech–gesture matches, speech without gesture, and speech–gesture mismatches. Moreover, 48 of the 49 children responded with at least one uptake to teacher matches; 43 responded with at least one uptake to teacher speech without gesture; and 38 responded with at least one uptake to teacher mismatches.

We are assuming that a child uptake of a teacher strategy reflects child comprehension of that strategy. However, when children reiterated in gesture a strategy that the teacher produced only in gesture, they may have done so by merely imitating the teacher's hand movements. This "miming without comprehension" hypothesis loses credibility if, in reiterating a gestured strategy, the child translates that strategy into speech. We therefore examined the modality in which a child reiterated a teacher's strategy as a function of the modality in which that strategy was presented by the teacher. Not surprisingly, when children reiterated a strategy that teachers produced uniquely in speech, 98% ($N = 383$) of their reiterations were also in speech, 1% were in both speech and gesture, and less than 1% were in gesture alone.

When children reiterated a strategy that teachers produced in both speech and gesture, 97% ($N = 331$) of their reiterations were in speech alone, 2% were in speech and gesture, and 1% were in gesture alone. The crucial analysis for this hypothesis asks whether the tendency for children to reiterate strategies in speech was also found after gestured strategies. When children reiterated a strategy that the teachers produced uniquely in gesture, 91% ($N = 57$) of their reiterations were in speech alone and only 9% were in gesture alone. Thus, children translated the information conveyed uniquely in gesture into speech in almost all of their uptakes; they were not merely miming teacher hand movements without understanding them.

Our final analysis concerns the teachers' few incorrect strategies. Teachers gave children an opportunity to respond to only 28% of the 75 incorrect strategies they produced, far fewer opportunities than the children were given overall. We examined child uptakes after those few incorrect strategies on which the children were given an opportunity to respond. We might expect that children would be less likely to reiterate an incorrect strategy if it were negated by the teacher ("You don't add the numbers up to the equal sign to get the answer") than if it were not, simply because the teacher is explicitly signaling to the child that this strategy should not be used on these problems. Children reiterated 25% ($N = 12$) of the teachers' incorrect strategies when they were not negated. Surprisingly, however, children also reiterated 22% ($N = 9$) of the teachers' incorrect strategies when they were negated (all in speech). It is important to point out that when children reiterated teachers' incorrect strategies, they did not negate them; that is, they presented the incorrect strategies as viable options to be used on the problem.

Nine of the teachers' 12 incorrect strategies that were not negated were produced uniquely in gesture, and child uptakes followed 3 of these 9. For example, for the problem, $3 + 7 + 5 = \_\_ + 5$, a teacher conveyed the correct grouping strategy in her speech ("You want to add the 3 and 7 to make both sides equal") while conveying—and not negating—the incorrect add-to-equal sign strategy in her gestures (point at the 3, the 7, the left 5, and the blank). In response, the child asked, "I add the 3 plus 7 plus 5 to get 15?," thus picking up on the teacher's incorrect gestured strategy and ignoring her correct spoken strategy. Although the numbers are small, it is clear that when teachers produced incorrect strategies in gesture and allowed children time to respond, the children picked up on those strategies—and did so about as often as they generally picked up on teacher strategies produced uniquely in gesture (cf. Figure 4, right panel).

Discussion

Teachers Gesture When Teaching

We have found, in tutorials on mathematical equivalence, that teachers frequently use gesture to convey substantive information relevant to the lesson, in this case, strategies for solving the math problems. Indeed, approximately 40% of the problem-solving strategies that the teachers conveyed were expressed in gesture. Thus, nonverbal behavior is used in instruction not only to reflect the teacher's attitude toward subject and pupil (cf. Neill, 1991) but also to express information relevant to the lesson itself.

The types of problem-solving strategies that the teachers conveyed in gesture were precisely the same as those they conveyed in speech, most strategies leading to correct solutions, some to incorrect solutions (albeit rarely), and some allowing the child to build up an answer in small steps (see Table 1). However, the two modalities distributed themselves differently across these types; correct strategies were conveyed primarily in speech with or without a matching gesture, building gestures were conveyed primarily in speech with a matching gesture, and incorrect strategies were conveyed in either modality but primarily when the other modality conveyed a different strategy (i.e., in a speech–gesture mismatch). All 8 teachers produced mismatches and did so about 20% of the time.

Why might a teacher present one strategy in one modality and a different strategy in the other modality? Children produce a large number of speech–gesture mismatches on a task when they are in transition with respect to that task; that is, when they are ready to profit from instruction and improve their performance on the task (Church & Goldin-Meadow, 1986; Perry et al., 1988). Children who produce many mismatches are in a state of cognitive uncertainty, possessing knowledge about the task that they cannot quite organize into a coherent whole (Alibali & Goldin-Meadow, 1993; Goldin-Meadow et al., 1993). Although the teachers in our study were obviously not at all uncertain about the principle of mathematical equivalence that underlies the problems they taught, they may have been somewhat uncertain about how best to go about teaching the principle. Recall that the teachers' small number of incorrect strategies tended to be produced in speech–gesture mismatches. It may be that the teachers were uncertain about the best way to relate strategies that lead to incorrect solutions to strategies that lead to correct solutions. This uncertainty may have been reflected in their mismatches.

Children Respond to the Gestures Teachers Produce

Whatever the motivation behind teacher speech–gesture mismatches, it is clear that children notice them. Children were significantly less likely to reiterate the teacher's spoken strategy when it was produced in conjunction with gesture that conveyed a different strategy (a mismatch) than when it was produced with no gesture at all. Gesture, when it differs from speech, can hurt comprehension of that speech. However, gesture can help as well. Children were significantly more likely to reiterate the teacher's spoken strategy when it was produced in conjunction with gesture that conveyed the same strategy (a match) than when it was produced with no gesture at all. Thus, gesture aids the child's comprehension of speech when it reinforces the information conveyed in speech and hinders the child's comprehension of speech when it differs from the information conveyed in speech.

Interestingly, gesture did not merely influence how much information the children gleaned from the teacher's speech. It also conveyed substantive information on its own, information that the children were able to read off of the teachers' gestures. The children reiterated strategies that the teachers conveyed uniquely in gesture 20% of the time, about as often as they reiterated strategies that the teacher conveyed in speech when it was accompanied by a mismatching gesture. Note that we may well be underestimating the child's ability to glean information from the teacher's gesture or speech; children may understand what the teacher produces even when they do not reiterate it. Reiteration is probably a conservative estimate of child uptake, but one that does suggest that children are able to glean substantive information from teachers' gestures and that the information they glean from those gestures affects how they interpret the accompanying speech.

Our findings indicate that teachers use gesture, albeit not necessarily consciously, to convey task-relevant information in a math tutorial with an unfamiliar child—and the child notices. Future work is needed to determine whether these findings generalize in three important ways. First, do teachers use gesture in relation to speech in the same way in a classroom situation as they do in tutorials, and do these gestures have an impact on student learning? Second, does gesture play the same role in instruction when teacher and pupil know one another? Finally, do teachers use task-relevant gestures when providing instruction in subjects other than math?

Training Teachers to Attend to Their Hands

As a lesson progresses, alongside the acknowledged conversation in speech, an undercurrent of conversation about the task takes place in gesture. The underground information conveyed in gesture is integrated with the information conveyed in speech at both ends of the dyad. Speakers integrate the gestures they produce with the speech they utter, and listeners integrate the gestures they see with the speech they hear (McNeill, 1992), although the integration need not be conscious. Indeed, speakers are often not aware that they are moving their hands when they speak, and listeners rarely know whether the information they glean from a conversation comes from the speaker's hands or mouth (cf. Alibali, Flevares, & Goldin-Meadow, 1997; Goldin-Meadow & Sandhofer, 1999).

Given that gesture is an unavoidable part of classroom activity, teachers might do well to increase their awareness of the way they (and their students) use their hands. There have been some successful attempts to train teachers to pay attention to their students' nonverbal cues in general (Jecker, Maccoby, & Breitrose, 1965; Machida, 1986) and gestures in particular (Kelly & Goldin-Meadow, 1999). However, aside from an occasional training manual (e.g., Neill & Caswell, 1993), no systematic efforts have been made to increase teacher awareness of how they themselves use their hands.

The teachers did produce gestures of which they appeared to be unaware. Unlike the incorrect strategies that they produced in speech, which they usually negated, the teachers never negated the incorrect strategies that they produced in gesture, suggesting that these strategies were unintentional. Whether intended or not, however, teachers' gestured incorrect strategies did capture children's attention; these strategies were reiterated (and not negated) by children one third of the time. Thus, it may be worthwhile for teachers to increase the attention they pay to how they move their hands when they teach, noting whether they convey the same information in gesture as they do in speech and what that information is.

Gesture Can Provide a Second Representational Format

A priori, one might assume that it is not a good idea to produce information in gesture that is different from the information expressed in speech. However, this is not necessarily the case. When the two modalities are used to complement one another, a combined speech–gesture communication can be highly effective. The additional information conveyed in gesture may be more easily captured in the manual modality and may work together with the information conveyed in speech. For example, Neill and Caswell (1993, p. 113) described a teacher who mimed in gesture the zigzagging course of the trenches dug between Belgium and Switzerland during World War I. The teacher's hands conveyed details about trench topography that would have taken many words to convey and that, in all likelihood, would have been conveyed less precisely in speech (cf. Huttenlocher, 1976).

Gesture is particularly good at capturing the visual and imagistic features of an idea (Goldin-Meadow & McNeill, 1999; McNeill, 1992). Indeed, gesture's power comes from the fact that its strengths are different from, and complementary to, speech. Thus, it may be worth considering how gesture can be consciously used in conjunction with speech. For example, Margolin, Nesbit, and Pearson (1970) recommended that a teacher make circular motions with the hand while talking about the circular nature of spheres in a lesson on geometric shapes. The teacher's gesture makes concrete the notion described abstractly in words (see also Alibali, Sylvan, et al., 1997). Gesture can thus be used to provide a second representation, one that overlaps with but is not identical to the representation conveyed in speech. Indeed, the matching gestures that teachers produced in our study constitute a second, overlapping representation of the problem-solving strategy expressed in speech, and our data suggest that such overlapping and concrete instantiations can have a beneficial effect on child uptake.

Current recommendations for math curricula encourage teachers to present ideas through a variety of representations (diagrams, physical models, written text; NCTM, 1989). For example, Shavelson, Webb, Stasz, and McArthur (1988) recommended that teachers translate among alternative symbolic representations of a problem (e.g., math symbols and number line) rather than working within a single symbolic form. Gesture can serve as one of these representational formats, one that has a strong visual component. Gesture is unique, however, in that, unlike a map or a diagram, it is transitory, disappearing in the air just as quickly as speech. Gesture's advantage lies in the fact that it can be, indeed must be, integrated with the speech it accompanies. Thus, gesture used in conjunction with speech may present a more naturally unified picture to the student than a diagram used in conjunction with speech.

In sum, we showed that teachers use gesture in math tutorials to convey substantive ideas, primarily correct ideas but occasionally incorrect ones. At times, teachers' gestures convey information that reinforces the information conveyed in speech, but at other times, they convey information that differs from the information conveyed in speech. Gesture thus offers students a second window onto the task, one that students do take advantage of. Students are able to glean substantive information from teachers' gestures. Moreover, they understand teachers' speech more, or less, easily as a function of the gestures that teachers produce with that speech. If gesture were to become recognized as an integral—and inevitable—part of conversation in a teaching situation, it could perhaps be harnessed, offering teachers an excellent vehicle for presenting to their students a second perspective on the task at hand.

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