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A Helping Hand in Assessing Children's Knowledge: Instructing Adults to Attend to Gesture

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The spontaneous hand gestures that accompany children's explanations of concepts have been used by trained experimenters to gain insight into children's knowledge. In this article, 3 experiments tested whether it is possible to teach adults who are not trained investigators to comprehend information conveyed through children's hand gestures. In Experiment 1, we used a questionnaire to explore whether adults benefit from gesture instruction when making assessments of young children's knowledge of conservation problems. In Experiment 2, we used a similar questionnaire, but asked adults to make assessments of older children's mathematical knowledge. Experiment 3 also concentrated on math assessments, but used a free-recall paradigm to test the extent of the adult's understanding of the child's knowledge. Taken together, the results of the experiments suggest that instructing adults to attend to gesture enhances their assessment of children's knowledge at multiple ages and across multiple domains.

It is no surprise that people gesture when they speak. However, it is not widely known that hand gestures often convey important information that goes beyond the information conveyed through speech. Experimenters trained in coding hand gestures can learn a great deal about what children are thinking by attending to their gestures. Gesture can reflect mental operations and problem-solving strategies (Goldin-Meadow, Alibali, & Church, 1993; McNeill, 1992) and at times can convey unique information that is not found anywhere in a child's speech (Alibali & Goldin-Meadow, 1993). Even untrained adults are capable of gleaning substan-

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tive information from gesture (Goldin-Meadow & Sandhofer, 1999; Goldin-Meadow, Wein, & Chang, 1992; Kelly & Church, 1998; McNeill, Cassell, & McCullough, 1994). Importantly, however, these adults do not extract all of the information that gesture offers. In this study, we investigated whether it is possible to instruct adults to glean as much as possible from the spontaneous gestures children use to accompany their speech.

PREVALENCE AND IMPORTANCE OF GESTURES IN EVERYDAY COMMUNICATION

We focus on two of the most common types of hand gesture: deictic and iconic. *Deictics,* also called *pointing gestures,* highlight objects, events, and locations in the environment. Deictic gestures have no particular meaning on their own and convey information solely by connecting a communicator to a context. *Iconic* gestures, on the other hand, can convey meaning out of context. These gestures imagistically represent information about such things as object attributes, actions, and spatial relations. For example, suppose a speaker explained how his car had been hit by another car. In speech, he could say, “I didn’t see it coming” while gesturing an image of the other vehicle blindsiding his car from the rear. In this way, gesture may reveal information about the cars’ attributes (through the hand shape and orientation of the gestures), direction of movement (through the speed and angle of the gestural movements), and spatial relations (through the relative location of the gestures)—information that is not encoded anywhere in the speech the gesture accompanies.

Deictic and iconic gestures are pervasive in children’s speech. Children produce deictic gestures before they begin to talk (Bates, 1976; Butcher & Goldin-Meadow, 2000). Shortly thereafter (usually by 18 months), children produce iconic gestures along with their speech (Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979; Butcher & Goldin-Meadow, 2000; Iverson, Capirci, & Caselli, 1994; Masur, 1983; Morford & Goldin-Meadow, 1992). Throughout childhood, deictic and iconic gestures become more complex and frequent (Jancovic, Devoe, & Wiener, 1975; McNeill, 1992), and children produce them in a number of different contexts—with friends (Azmitia & Perlmutter, 1989; Church & Ayman-Nolley, 1995), family (Bates, 1976), and teachers (Fernandez, Flevares, Goldin-Meadow, & Kurtzberg, 1996). They also use gestures while talking about a number of different topics—telling stories (McNeill, 1992), giving directions (Iverson & Goldin-Meadow, 1997), or explaining concepts (Church & Goldin-Meadow, 1986; Perry, Church, & Goldin-Meadow, 1988, 1992).

Yet how important are these hand movements? Certainly, the auto accident example suggests that iconic gestures can add richness to communication beyond uttered words. In other contexts, pointing gestures can also clarify speech (Kelly, 2001; Kelly, Barr, Church, & Lynch, 1999; Thompson & Massaro, 1994). Thus, gesture may add important information to speech.

Several recent studies suggest that the gestures children produce while speaking reveal much more about what they are thinking than does their speech alone (Alibali, 1999; Alibali & Goldin-Meadow, 1993; Church, 1999; Church & Goldin-Meadow, 1986; Church, Schonert-Reich, Goodman, Kelly, & Ayman-Nolley, 1995; Garber, 1997; Goldin-Meadow, 2000; Goldin-Meadow et al., 1993; Perry et al., 1988, 1992). For example, in a study investigating the role of gesture in children's explanations of Piagetian (1967) conservation problems, Church and Goldin-Meadow (1986) discovered that children frequently produced iconic gestures in their explanations and that those gestures conveyed different information than the spoken component of the explanations (gesture–speech mismatches). This phenomenon generalizes to more traditional educational domains as well, such as mathematics. For example, Perry et al. (1988, 1992) found that when 10-year-old children solve math problems (e.g., 3 + 4 + 5 = __ + 5), their deictic gestures often reflect different strategies than does their speech.

One of the most interesting findings in these studies (Church & Goldin-Meadow, 1986; Perry et al., 1988) was that the children who produced many gesture–speech mismatches in their explanations were precisely the ones who benefited most from instructional input in those problems. This finding suggests that speech and gesture can serve as an index of transitional, implicit knowledge in a specific domain and may be a way of determining a child's "readiness to learn." The claim that gestures reflect implicit knowledge and readiness to learn fits nicely with recent educational research arguing that teachers can better interpret a student's work by being aware of that student's underlying or implicit understanding of a topic (Ball, 1993; Carpenter, Fennema, & Franke, 1996; Carpenter, Franke, Jacobs, Fennema, & Empson, 1998). For example, Carpenter et al. (1996) argued that awareness of children's implicit understanding of mathematical concepts can allow teachers to better assess and instruct children in that domain. If hand gestures are a window into this implicit knowledge, attention to this information may make this task easier.

DO UNTRAINED ADULTS INTERPRET GESTURE?

Given the prevalence and potential importance of the gestures that accompany speech, it makes sense to ask whether ordinary, untrained adults pay attention to this information. As it turns out, adults (and even young children; see Kelly, 2001; Kelly & Church, 1997) do detect and interpret gesture, albeit imperfectly (Goldin-Meadow et al., 1992; Kelly & Church, 1998). Goldin-Meadow, Wein, and Chang (1992) asked adults to watch videotapes of children speaking and gesturing while explaining their answers to Piagetian (1967) conservation problems.

Although the adults incorporated some of the gestured information into their assessments of how much the children knew about conservation, they did not glean all of the information that could be derived from the children's gestures.

Perhaps repeated interactions with children enhance an adult's ability to extract information from children's gesture. As a test of this hypothesis, Alibali, Flevares, and Goldin-Meadow (1997) compared the assessments of untrained college students with experienced teachers in a series of vignettes of children solving math problems. Surprisingly, teachers were no better than undergraduates at interpreting information contained in the children's gestures. Both groups gleaned roughly 30% of the gestured strategies. Thus, for teachers and nonteachers alike, there is considerable room for improvement.

The goal of our set of experiments was to determine whether instruction in decoding gesture helps adults glean information from children's gestures. In three experiments, we approached this question using the same overall design: pretest, instruction in attending to gesture, and posttest. In Experiment 1, we used a questionnaire to explore whether adults benefit from instruction in interpreting gestures when assessing young (5- to 8-year-old) children's knowledge of conservation. A great deal was known about the gestures produced by children in these conditions, and the ability of untrained adults to interpret these gestures has also been described (Alibali et al, 1997; Goldin-Meadow & Sandhofer, 1999; Goldin-Meadow et al, 1992; Kelly & Church, 1997). In Experiment 2, we tested adults' ability to read children's gestures in a different knowledge domain—mathematical equivalence—and at a different age (9- to 10-year-olds). This subject matter and age range have more obvious relevance to children's everyday educational interactions with parents and teachers than does conservation, and the gestures produced by children in these tasks have also been subjected to a great deal of preliminary analysis. Finally, in Experiment 3, we employed an open-ended free-recall assay to test the effects of instruction on adults' impression of children's knowledge of mathematical equivalence. This free-recall method is both less constrained and more germane to everyday educational settings than the questionnaire.

In sum, past research suggested that (a) children frequently produced gestures spontaneously while they spoke; (b) gestures may have conveyed a great deal of information to trained investigators; and (c) untrained adults picked up on some, but far from all, of the information conveyed in child gestures. Given this, we asked whether we could instruct adults to better attend to gesture—and if so, how.

EXPERIMENT 1

In Experiment 1, we explored whether adults benefit from gesture instruction when making assessments of children's knowledge of conservation problems of number, length, and quantity. Conservation problems require children to determine whether a quantity has changed after the form of that quantity has been altered. For example, the water task requires a child to assess whether the amount of water originally presented in two identical glasses is the same or different after the contents of one glass have been poured into a shorter, wider dish. Young children do not realize that the amount stays the same even though the appearance changes (Piaget, 1967).

We chose the conservation paradigm for two reasons. First, although conservation is not a task that teachers commonly address in school, it is a well-studied and controlled task that allows children to produce explanations, and explanations are prevalent in school settings. Second, children's verbal explanations of conservation problems are frequently accompanied by gestures, and there is an established literature investigating the information that these gestures convey (Alibali & Goldin-Meadow, 1993; Church, 1999; Church & Goldin-Meadow, 1986).

Method

Participants

Sixty-three college undergraduates (40 women and 23 men) participated in the study. Participants were given course credit for taking part in the study.

Procedure

Participants were tested in groups of 3 to 5. They were told that they would be watching videotapes of children explaining their answers to a series of Piagetian (1967) conservation problems. They were then given a pretest evaluating their abilities to detect information conveyed in the children's speech and gesture. Following the pretest, each group of participants was randomly assigned to one of four instruction conditions (described later). After instruction, the experimenter told the participants that they would watch the same children again (presented in a different order) and answer the same types of questions as in the pretest. For the posttest, they were to told to use the information that they had received during the instruction session when answering the questions. The pretest, instruction, and posttest lasted approximately 35 min.

Stimulus tape. The stimulus tape consisted of 15 children solving and explaining their answers to questions about Piagetian (1967) conservation problems.[1] Recall that Piagetian conservation problems require children to determine whether a quantity (liquid, length, or number) has changed after the form of that

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[1] The vignettes were taken from videotapes collected in prior studies of children's spoken and gestured responses on Piagetian (1967) conservation tasks.

quantity has been altered. All of the children in the 15 vignettes answered the transformation question incorrectly, judging the transformed quantities to be different; the children then produced verbal explanations that justified these nonconserving judgments.

The children's verbal explanations fell into three categories:

1. Three of the explanations (one liquid, one length, and one number) were not accompanied by any gestures. For example, in one of the liquid tasks, the child expressed height information through her speech saying, "They're different because one is tall and one is short" while keeping her hands on the table in front of her. These types of stimuli comprised the speech alone vignettes. The remaining 12 stimuli contained gestural information.
2. Six of the vignettes (two liquid, two length, and two number) contained gestures that conveyed the same information as speech. For example, one child in the liquid task compared the heights of the containers through her speech (as in the speech alone vignettes) and at the same time conveyed height information through her gestures: A flat hand was held at the height of the tall, thin container and then at the height of the short, wide container. These types of stimuli comprised the matching vignettes.
3. The remaining six vignettes (two liquid, two length, and two number) contained gestures that conveyed different information from speech. For example, one child in the liquid task compared the heights of the containers through his speech while simultaneously conveying width information through his gestures: Two flat hands were held at the width of the tall, thin container and then at the width of the short, wide container. These types of stimuli comprised the mismatching vignettes (for more information on gesture–speech mismatches produced on the conservation task, see Church & Goldin-Meadow, 1986).

Two stimulus tapes were created, each containing a different randomized order of the same 15 vignettes. The order in which each participant viewed the two tapes was determined at random. No effects of order were found; data were thus collapsed across orders in the analyses.

Pretest. In the pretest, participants watched one of the stimulus tapes and after each vignette answered questions about what they saw and heard in that vignette. Four questions were presented for each vignette. For example, for the stimulus vignettes described previously, one entry on the questionnaire asked, "Did the child indicate the height of the containers?" Information about height was found in the child's speech in all three vignettes (speech alone, matching, and mismatching). As a result, a "yes" response to this question for any of the three vignettes indicated that the participant had gleaned information that had been expressed through speech. A second entry tapped detection of information conveyed uniquely in gesture by asking, “Did the child indicate the width of the containers?” Information about width was found only in the child’s gesture in the mismatching vignette. As a result, a “yes” response to this question for the mismatching vignette indicated that a participant had gleaned information that was expressed uniquely through gesture. Note that the answer to this question ought to be “no” for the speech alone and matching vignettes simply because the child did not convey width information in either modality in these two vignettes. In addition to these two entries on the questionnaire, two distracter questions, culled from explanations that children typically give on problems of this type, were included on the list. The distracter questions asked, “Did the child indicate that water was poured into the dish?” and “Did the child indicate that the water could be poured back into the glass?” Participants were expected to respond “no” to these questions.

Participants were told that the number of correct “yes” responses on each list could vary from 0 to 4. In fact, for the questionnaires presented with speech alone and matching vignettes, there was only one possible correct response (the explanation conveyed by the child in speech alone or in both speech and gesture). For the questionnaire presented with mismatching vignettes, there were two possible correct responses (the explanation conveyed in speech and the explanation conveyed in gesture).

Instruction conditions. Following the pretest, participants were randomly assigned to one of four instruction conditions. In the first condition, the *no instruction* condition ($N = 15$), participants were required to take a 5 min break after they finished the pretest. After the break, they were told that they would be seeing the children again but this time in a different order. Participants were asked a set of assessment questions that corresponded to this new order.

In the second condition, *hint* ($N = 16$), participants were given a 5 min break after the pretest, but at the end of the break they were told that hand gestures often convey important information not found in speech. When watching the children the second time, they should pay close attention—not only to what the children said with their words but also to what they “said” with their hands.

In the third condition, *general instruction* ($N = 18$), participants were shown a 5 min instructional tape on how to interpret hand gestures. The instruction sessions were presented on videotape to control against possible variation in presentation from group to group. On the tape, the experimenter (who had recorded himself weeks earlier) talked about three parameters of hand gestures, explaining that each parameter could convey substantive information about the task. The three parameters were based on the gesture coding system created by Church and Goldin-Meadow (1986): (a) shape of a hand gesture, (b) motion of a hand gesture, and (c) placement of a hand gesture. The tape gave an example of each of these components in three novel contexts (describing an unfamiliar object, giving directions, and solving a math problem). Consider describing an unfamiliar object as an example. The experimenter described the size of an object through his speech saying, “It was a really big one” while indicating the shape of the object in his gesture—he made a two-handed gesture representing a sphere. This example highlighted the potential for conveying meaning via the shape of one’s hand. Note that this example (as well as all others on the general instruction tape) was not drawn from the conservation task. Examples were deliberately selected from tasks other than conservation so that we could determine whether participants could learn general principles of gesture coding and apply them to a novel task (recall that the experimental stimuli contained only examples from conservation tasks). Following the training videotape, participants were instructed as in the hint condition.

In the fourth condition, *specific instruction* ($N = 14$), participants were shown a 5 min instructional tape (again, created by the experimenter) that focused on the three parameters of gesture but in the specific context of conservation—that is, the instruction focused on three conservation examples that participants had seen once already in the pretest and would be seeing again on the posttest stimulus tape. Consider the water conservation problem as an example. The experimenter demonstrated how children sometimes represent multiple pieces of information when explaining that the water in a tall, thin glass has a different amount than the water in a short, wide dish. The experimenter explained that a child will sometimes say that the amount of water in the two containers is different because “one is short and one is tall” while producing a wide C-shape gesture near the dish and a narrow C-shape gesture near the glass. In speech, the child was comparing the heights of the containers, but in gesture the child focused on their widths (places a wide C-shaped gesture near the dish and a narrow C-shaped gesture near the glass). In this way, the child’s hand shapes conveyed information not found in the child’s speech.

Participants received instruction on only three of the six gesture examples on the pretest tape. This design allowed us to determine whether adults could generalize their training to totally new exemplars from the conservation task. The format of this instruction was identical to the general instruction condition—the only difference was the particular examples used in the training (conservation vs. a variety of nonconservation examples). Following the training videotape, participants were instructed as in the hint condition.

Thus, the four types of instruction represent increasingly explicit instruction (from no instruction to highly specific instruction) in how to glean substantive information from gesture.

Posttest task. Following the instruction session, participants were shown the other order of the stimulus tape and were asked the same questions as in the pretest. They were instructed to answer the questions based on whatever new information they had received.

Results and Discussion

The results focus on two issues. Our major interest was the effects of instruction on detection of information conveyed uniquely in gesture. In addition, we investigated whether focusing on gesture influenced participants' ability to detect information conveyed in speech. Previous work (Goldin-Meadow, Kim, & Singer, 1999; Goldin-Meadow & Sandhofer, 1999) has shown that adults understand a child's speech less well if that speech is accompanied by gestures that convey different information than if it is accompanied by no gestures at all. As a result, improving an adult's ability to glean information from a child's gestures has the potential to compromise that adult's ability to glean information from the accompanying speech. We therefore explored a second phenomenon in this experiment—whether instruction to attend to gesture compromised an adult's ability to glean information from the speech it accompanies.

Does Instruction Improve the Ability to Glean Information From Gesture?

We analyzed the adults' pretest and posttest responses to questions probing the explanations that children conveyed in gesture (and not in speech) on the mismatching vignettes. Figure 1 presents the percentage of times participants correctly identified a strategy conveyed uniquely in gesture in mismatching vignettes as a function of the four instruction conditions.[2] A 4 (no instruction vs. hint vs. general vs. specific) × 2 (pretest vs. posttest) split plot analysis of variance (ANOVA) on "yes" responses to gesture questions following the mismatching vignettes revealed a main effect of test, $F(1, 59) = 78.03, p < .001$, but not a main effect of instruction condition, $F(3, 59) = 1.91$, *ns*. In addition, there was a significant instruction by test interaction, $F(3, 59) = 11.29, p < .001$. As illustrated in Figure 1, this interaction was driven by significant differences among instruction conditions only in the posttest. In the posttest, all comparisons across instruction conditions differed significantly (Dunnet's test; $p < .01$) with the exception of the hint versus general instruction comparison. Overall, increasingly explicit gesture instruction resulted in more accurate performance on the questions probing the explanations children conveyed only in gesture.

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[2] To analyze the data the percentages were transformed using an arcsine formula. The text, graph, and table, however, present raw percentages. A Tukey–Kramer analysis indicated that there were no sex differences in any of the measures reported.

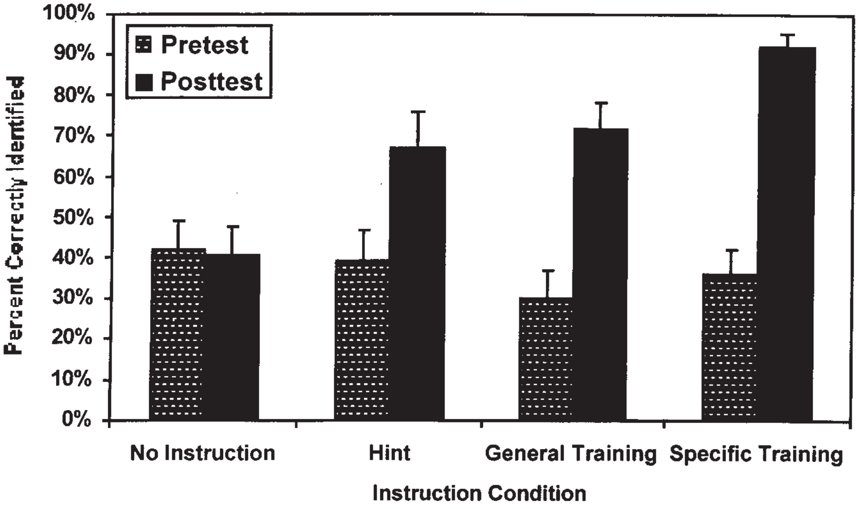

FIGURE 1 Percent of conservation explanations uniquely conveyed in a child's gestures that adults correctly identified (Experiment 1). Bars indicate standard errors.

These data are consistent with our hypothesis that instruction makes people more aware of the information contained in gesture. An alternative hypothesis, however, is that instruction to notice gesture merely increased the number of "yes" responses overall, not targeted to the questions probing the explanations that the child had actually produced. However, this alternative fails, as we found no significant differences in the proportion of "yes" responses participants gave to the distracter questions in the posttest across the four instruction conditions, $F(3, 54) = 1.27$, *ns*.

Recall that in the specific instruction condition, participants received training on some, but not all, of the explanations that the children conveyed in gesture on the vignettes. We compared the percentage of times participants correctly identified the gestured explanations explicitly taught in the specific instruction condition on the posttest to the comparable percentage for gestured explanations that were not taught. We found that participants were equally accurate on the two sets of explanations: 93% ($SD = 4\%$) correct responses for gesture explanations that were explicitly taught versus 91% ($SD = 5\%$) for gesture explanations that were not taught. Thus, the participants were able to apply the instruction they received to novel stimuli, generalizing what they had learned to stimuli on which they had not been specifically trained.

Does Instruction in Gesture Detract From Attention to Speech?

We performed three separate 4 × 2 (Instruction × Test) split plot ANOVAs on the correctly identified spoken strategies produced in speech on its own, speech with a matching gesture, and speech with a mismatching gesture. We found no effect of training on speech detection for any of the three types of stimuli: The ANOVAs did not reveal a main effect of test, $F(1, 59) = 0.62$, *ns,* for speech alone vignettes; $F(1, 59) = 0.12$, *ns,* for matching vignettes; $F(1, 59) = 0.26$, *ns,* for mismatching vignettes or instruction condition, $F(3, 59) = 1.33$, *ns;* $F(3, 59) = 1.16$, *ns;* $F(3, 59) = 2.22$, *ns,* for the three vignettes, respectively; and there was no Instruction by Test interaction, $F(3, 59) = 1.43$, *ns;* $F(3, 59) = 0.89$, *ns;* $F(3, 59) = 0.77$, *ns,* for the three vignettes, respectively. The reason that we did not find a difference is simple. In all of the conditions, across all of the training sessions, participants were near ceiling (between 88% and 100%) at correctly identifying speech information. This was true for both the pretest and the posttest.

The fact that participants were almost perfect at identifying speech on the pretest made it impossible for them to have improved over time. However, competition for limited resources could have caused them to become worse with instruction to attend to gesture. They did not. Gesture instruction appeared to increase participants' sensitivity to information conveyed in gesture without compromising their ability to pay attention to speech.

These results may have relevance to educational interactions. Because gestures have been shown to reflect substantive, task-related information about what children know, heightening attention to gesture could help teachers make better and more informed assessments of children's knowledge of concepts. This deeper understanding of children's states of awareness, in turn, could result in teaching that is better targeted to a child's level of understanding (Ball, 1993; Carpenter et al., 1996, 1998).

How much can we extrapolate from Experiment 1 to everyday teaching situations? After all, conservation is a task that children learn without any explicit instruction. Do our findings generalize to topics that are frequently found in the classroom? Experiment 2 was designed to answer this question.

EXPERIMENT 2

In Experiment 2, we explored a different domain—children's mathematical knowledge, and in particular, their understanding of mathematical equivalence problems such as 3 + 4 + 5 = __ + 5. Problems of this kind are usually taught in fourth- or fifth-grade classrooms in the United States. Past research has shown that children younger than 10 years old often solve problems of this sort incorrectly and subsequently provide verbal justifications for their incorrect solutions (Alibali, 1999; Alibali & Goldin-Meadow, 1993; Garber, 1997; Goldin-Meadow et al., 1993; Perry et al., 1988, 1992). Moreover, the gestures these children produce in their justifications often convey information about the problem that is not conveyed in their speech.

In this experiment, we instructed adults to glean information from the kinds of gestures that typically accompany mathematical equivalence problems. Experiment 2 resembled Experiment 1 in all but three features. First, we showed adults videotapes of children solving and explaining mathematical equivalence problems rather than conservation problems. Second, the gestures used in this experiment were deictic rather than iconic. Third, because we found in Experiment 1 that the specific instruction condition was particularly effective in inducing change, we included only two instructional conditions in this study: no instruction and specific instruction.

Method

Participants

Twenty college undergraduates (11 women and 9 men; different from those participating in Experiment 1) participated in the study and were paid for their participation.

Procedure

Participants were tested individually. They were told that they would be watching videotapes of a series of children explaining their answers to math problems. Before watching the pretest videotape, they were given a general introduction to the math problems that the children on the tape would be solving. They were then given a pretest evaluating their abilities to glean information from children's speech and gesture. Following the pretest, participants were randomly assigned to a control or instruction condition. After instruction, the experimenter told the participants that they were to watch the same children again and answer the same types of questions as in the pretest. The pretest, instruction, and posttest lasted approximately 35 min.

Stimulus tape. The stimulus tape consisted of eight children solving and explaining their answers to mathematical equivalence problems (e.g., $3 + 4 + 5 = \_\_ + 5$). Four of the children in the eight vignettes answered the math problems correctly, and four answered them incorrectly; the children produced verbal explanations that justified these correct and incorrect solutions, respectively.

The children's explanations fell into two categories:

1. Four of the explanations contained gestures that conveyed the same information as speech (matching vignettes). For example, for the problem 3 + 4 + 5 = __ + 5, the child said, “I added the 3, the 4, and the 5 to get 12 for my answer,” while at the same time pointing to the 3, 4, and 5 on the left side of the equation and then the blank. Both speech and gesture thus conveyed an *add to equal sign* strategy.

2. Four explanations contained gestures that conveyed different information than was conveyed in speech (mismatching vignettes). For example, on the same problem, a different child said, “3 plus 4 is 7, and 7 plus 5 equals 12” (an add to equal sign strategy), while at the same time pointing at all four of the numbers in the problem and then the blank (an *add all numbers* strategy). Thus speech conveyed one strategy, whereas gesture conveyed another strategy.

Introduction to the math problems. All participants watched a tape that introduced them to the types of problems and solution strategies that they were to see on the stimulus tape. They were given examples of four correct strategies and three incorrect strategies that children typically use to solve problems of this type, all described by the experimenter in speech without gesture.

Pretest. During the pretest, participants watched the stimulus tape and after each vignette responded to a questionnaire about what they saw and heard in that vignette. The questionnaire for each vignette listed seven different strategies, along with a description of each strategy. The adults were asked to indicate which of these seven strategies the child on the videotape had considered when solving the problem. There was only one correct response on the list for the matching vignettes (the strategy the child expressed in both gesture and speech) but two correct responses on the list for the mismatching vignettes (the strategy the child expressed in speech and the strategy the child expressed in gesture).

Instruction conditions. Following the pretest, participants were randomly assigned to one of two conditions. The first condition involved no instruction at all ($N = 10$) and was identical to the no instruction condition in Experiment 1. The second condition, the specific instruction condition ($N = 10$), followed the same format as Experiment 1 using math rather than conservation problems. For example, for the problem 3 + 4 + 5 = __ + 5, the experimenter explained that a child’s gesture could indicate an understanding of the *equalizer* strategy (that the left side and the right side of the equation must equal each other). One way to do this is to simultaneously place the left hand (whole hand, spread out) under the left side of the equation, and place the right hand (again whole hand, spread out) under the right side. The fact that two hands are used suggests that the child notices that there are two parts to the equation. The fact that the child uses the same hand shape when indicating each part suggests that the child may understand that the two parts should be treated in the same way. This example illustrates how children can convey meaning via gesture hand shape and location. The experimenter on the videotape also stressed that, at times, children indicate different information in gesture than they indicate in speech. She demonstrated this phenomenon by producing an add all numbers strategy in speech ("I added the 3, the 4, the 5, and the 5 to get 17") and an *add–subtract* strategy in gesture (left hand points to the 3, 4, 5, pauses, and then does a flicking motion at the right 5, which is roughly translated as "add up the numbers on the left side of the equation and subtract the number on the right"). By using a different hand shape and motion to indicate the right 5 than she used to indicate the numbers on the left side of the equation, the experimenter illustrated how gesture can be used independently of speech to highlight a break in the equation.

The instruction contained three strategies as vehicles to explain how to interpret gesture on math problems, two of which the participants had already seen on the pretest and would be seeing again on the posttest. The other two gestured examples that appeared on the pretest stimulus tape and would appear again on the posttest stimulus tape were not mentioned at all during instruction. As in Experiment 1, this design allowed us to determine whether the participants could generalize their training to new exemplars within the mathematical domain.

Posttest task. Following the instruction session, participants were shown the stimulus tape and were given the same questionnaires as in the pretest. They were instructed to answer the questions based on whatever new information they had received.

Results

To anticipate the results, we found no effect of instruction on identification of speech or gesture information. A 2 (no instruction vs. specific instruction) × 2 (pretest vs. posttest) split plot ANOVA on gesture identification revealed no main effects of test, $F(1, 18) = 0.12$, *ns,* or instruction condition, $F(1, 18) = 2.67$, *ns,* and no Instruction × Test interaction, $F(1, 18) = 2.92$, *ns.* In the pretest, participants identified gesture information 6% ($SD = 2\%$) in the no instruction condition and 7% ($SD = 2\%$) in the specific instruction condition. There was no improvement after training. In the posttest, participants identified no gesture information at all in the no instruction condition and only 12% ($SD = 4\%$) in the specific instruction condition. These data suggest that participants were unable to glean information from the children's gestures during the pretest, and their skills did not improve after instruction.

Moreover, instruction did not affect speech identification. We performed two separate 2 × 2 (Instruction × Test) split plot ANOVAs—one for the matching vignettes and one for the mismatching vignettes. For speech in both matching and mismatching vignettes, there was no main effect of test, $F(1, 18) = 0.04$, *ns,* and

F(1, 18) = 0.06, *ns,* respectively, or instruction condition, *F*(1, 18) = 0.79, *ns,* and *F*(1, 18) = 1.43, *ns,* respectively, and there was no Instruction × Test interaction, *F*(1, 18) = 0.95, *ns,* and *F*(1, 18) = 1.64, *ns,* respectively. As in Experiment 1, participants were at ceiling (between 88% and 100%) in correctly identifying the strategies children conveyed in speech. Instruction in how to interpret gesture did not impair these skills.

Discussion

Experiment 2 did not confirm Experiment 1. Instruction in how to read a child's gestures did not increase adults' ability to glean information from the gestures children produced when explaining math problems. Why might this be?

Two possible explanations arise—one task related, the other technique related. The gestures that children produce on the math task are much less transparent than the gestures they produce on the conservation task. Gestures in conservation explanations tend to be iconic and relatively easy to interpret. For example, a palm held at the height of the water level on the tall glass transparently conveys the meaning "tall." In contrast, gestures in math explanations tend to be strings of points that require some interpretation. For example, pointing at all four numbers and then the blank in a mathematical equivalence problem conveys the add all numbers strategy (see Garber, Alibali, & Goldin-Meadow, 1998, for evidence that strings of pointing gestures do indeed convey problem-solving strategies—not only to experimenters but also to the speakers themselves). It may be that a few moments of instruction are insufficient to teach adults—who are not routinely called on to interpret children's math gestures—the skills to do so.

Alternatively, the questionnaire technique we used to gauge the adults' improvement in interpreting gesture may not have been sufficiently fine grained. The adults may have been able to glean some information from the children's gestures but were unable to translate this information onto the questionnaire that we provided. To explore this second possibility, we repeated the protocol of Experiment 2 but employed a free-recall technique after both the pretest and posttest to assess the adults' interpretations. In this way, the adults were able to express in their own words the message they thought each child was conveying.

EXPERIMENT 3

In Experiment 3, we used a free-recall procedure, rather than a questionnaire, to determine whether adults glean substantive information from the gesture and speech children produce on mathematical equivalence problems. In addition to being much less constraining than the questionnaire probe, the free-recall probe comes much closer to the way teachers actually assess children's knowledge in the classroom. Thus, the findings from Experiment 3 may have more direct relevance to teaching interactions than those from Experiment 2.

Method

Participants

Twenty college undergraduates (12 women and 8 men) participated in the study and were paid for their participation.

Procedure

The procedure was identical to Experiment 2 with the exception that free recall was used rather than a questionnaire in both the pretest and posttest. The pretest, instruction, and posttest lasted approximately 40 min.

Tapes. The stimulus tape, instruction tape, and introduction to the math problems tape were identical to those used in Experiment 2.

Pretest. As in Experiment 2, participants first watched a tape that introduced them to the seven types of problem-solving strategies that they were to see on the stimulus tape. Participants then watched the stimulus tape. After each vignette, the experimenter wrote on the blackboard the problem that the child had solved on the videotape and asked the adult to describe the strategies that the child had considered when solving this problem. The adult was permitted to refer to the problem on the board when describing the child's strategies. A list of the seven strategies that children typically use on these problems was displayed on the blackboard so the adults did not have to memorize them. The entire procedure was videotaped.

The adults' responses were coded according to a system developed to identify problem-solving strategies that children convey in speech and gesture when explaining mathematical equivalence problems (Perry et al., 1988). If adults repeated the strategy that the child conveyed on the videotape, they were credited with correctly identifying that strategy. A paraphrase expressed in speech, gesture, or in both modalities was counted as a correct identification. For example, after viewing a child who conveyed an add to equal sign strategy, one adult said, "She used the add to equal sign strategy because she only added the numbers on the left side of the equal sign" while at the same time pointing to the numbers on the left side of the equation. This adult was credited with correctly identifying the strategy that the child had expressed and with doing so in her own speech and gesture.

Adults received credit for correctly identifying the child's strategy even if they expressed that strategy only in gesture. For example, after viewing a child who expressed an add to equal sign strategy in speech and an add all numbers strategy in gesture, one adult said, "Well, she added all of the numbers to the equal sign" while at the same time pointing to all four of the numbers in the problem (those on the left and right sides of the equation). This adult was credited with correctly identifying two strategies: the add to equal sign strategy that the child expressed in speech and the adult paraphrased in speech and the add all numbers strategy that the child expressed in gesture and the adult reiterated in gesture.

Often adults translated strategies that the children expressed uniquely in gesture into their own speech. For example, after viewing a child who produced an add all numbers strategy in speech and an *equalizing* strategy in gesture, an adult said, "Speech was add all numbers, and gesture was equalizing." This adult was credited with correctly identifying two strategies, one that the child had expressed uniquely in speech and one that the child had expressed uniquely in gesture. The adult, however, had expressed both strategies in her own speech.

Thus, adults were credited with correctly identifying the child's strategy regardless of the modality in which the adults reproduced that strategy (speech, gesture, or both gesture and speech).

Instruction conditions. Following the pretest, participants were randomly assigned to one of two conditions: no instruction ($n = 10$) and specific instruction ($n = 10$).

Posttest task. Following the instruction session, participants were reshown the stimulus tape and were asked the same questions as in the pretest. The posttest was videotaped and adult responses were coded as in the pretest.

Results

Gleaning Information From Gesture

Figure 2 presents the proportion of times participants correctly identified a strategy that a child had conveyed uniquely in gesture (i.e., responses to mismatching vignettes). A 2 (instruction) × 2 (test) split plot ANOVA revealed main effects of test, $F(1, 18) = 24.69, p < .001$; instruction condition, $F(1, 18) = 19.27, p < .001$; and an Instruction × Test interaction, $F(1, 18) = 20.74, p < .001$. As in Experiment 2, participants were unable to glean information from children's gestures during the pretest even though free recall was used to measure their assessments of the children. However, unlike Experiment 2, participants were able to identify strategies that the children expressed uniquely in gesture after training and did so at a rate significantly higher than their pretest rate. Moreover, the rate at which adults incorrectly attributed strategies to the children after instruction did not differ between the no instruction condition (7%, $SD = 2\%$) and specific instruction condition (12%, $SD = 4\%$), $t(19) = 0.50$, *ns*. Thus, instruction did not create an overall

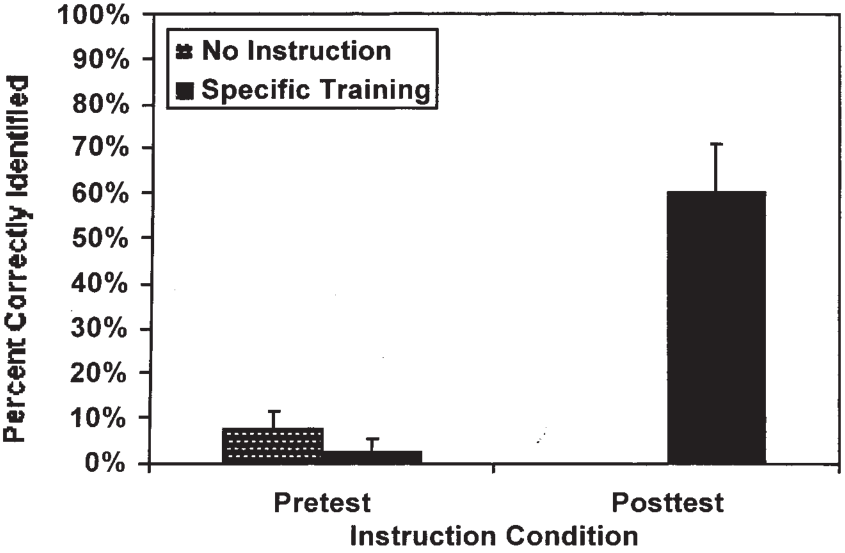

FIGURE 2 Percentage of math strategies uniquely conveyed in a child's gestures that adults correctly identified using free recall (Experiment 3). Bars indicate standard errors.

increase in rate of reporting strategies but rather a selective increase in the strategy the child had actually produced in gesture.

As in Experiment 1, participants in the specific instruction condition received training on some, but not all, of the explanations that the children conveyed in gesture on the vignettes. We compared the percentage of times participants correctly identified the gestured explanations explicitly taught in the specific instruction condition on the posttest to the comparable percentage for gestured explanations that were not taught. We found that participants were equally accurate on the two sets of explanations: 60% (*SD* = 20%) correct responses for gesture explanations that were explicitly taught versus 60% (*SD* = 23%) for gesture explanations that were not taught. Thus, the participants were able to apply the instruction they received to novel stimuli, generalizing what they had learned to stimuli on which they had not been specifically trained.

Gleaning Information From Speech

Table 1 presents the proportion of times participants correctly identified a strategy conveyed uniquely in speech in mismatching vignettes or in speech and gesture in matching vignettes. We performed two separate 2 × 2 (Instruction × Test) split plot ANOVAs, one for the matching vignettes and one for the mismatching vignettes. For matching vignettes there was no main effect of test, $F(1, 18) = 3.24$,

TABLE 1
Proportion of Math Strategies Conveyed in a Child's Speech That Adults Identified Correctly Using Free Recall in Experiment 3

	No Instruction		*Specific Instruction*	
Pretest and Posttest	*M*	*SD*	*M*	*SD*
Speech with gesture conveying the same information (matching vignettes)				
Pretest	.99	.04	.96	.08
Posttest	1.00	.00	.98	.04
Speech with gesture conveying different information (mismatching vignettes)				
Pretest	.93	.12	.98	.08
Posttest	1.00	.00	.85	.21

ns, or instruction condition, $F(1, 18) = 0.87$, *ns,* and there was no Instruction × Test interaction, $F(1, 18) = 0.36$, *ns.*

For mismatching vignettes there was no main effect of test, $F(1, 18) = 0.34$, *ns,* or instruction condition, $F(1, 18) = 1.76$, *ns.* However, there was a significant Instruction × Test interaction, $F(1, 18) = 5.43$, $p < .05$. Participants reported significantly fewer of the strategies conveyed in speech on the mismatching vignettes after instruction than before. Taken alone, this finding suggests that specific instruction in gesture decreased the amount of information the participants were able to glean from the children's words. However, when information gleaned from speech is considered in relation to information gleaned from gesture, a different picture is obtained. On the posttest participants in the specific instruction conditions extracted 85% (6.8) of the 8 strategies conveyed in speech and 60% (4.8) of the 8 strategies conveyed in gesture, a total of 11.6 strategies in all. In contrast, participants in the no instruction condition gleaned 100% of the 8 strategies conveyed in speech but none of the 8 strategies conveyed in gesture, a total of 8 strategies in all. Thus, participants in the specific instruction condition gleaned on average 3.6 more strategies (11.6–8.0) from the mismatching vignettes than did participants in the no instruction condition. Despite a slight decrement in strategies inferred from speech during the specific instruction condition, adults more than compensated by increasing their uptake from gesture. Future work will be required to explore instructional techniques to improve interpretation of gesture without deleteriously affecting interpretation of speech.

Discussion

Why did the participants' ability to interpret gesture improve after instruction in Experiment 3 but not Experiment 2? We suspect that the difference lies in the way we chose to measure the adults' interpretations of the child's gestures. In Experiment 2, the adults were forced to choose among seven strategies listed on the questionnaire. They found it easy to map their interpretations of the child's speech onto the choices we gave them on the questionnaire (they were at ceiling when interpreting speech). They did not, however, find it easy to map their interpretations of the child's gesture onto the choices given on the questionnaire (they were at floor when interpreting gesture). When given the opportunity to use their own words—and gestures—on the free-recall task in Experiment 3, the adults demonstrated that they had indeed profited from the instruction.

The open-ended format of the free-recall technique allowed the adults to express themselves in whatever way suited their knowledge. Indeed, in roughly 25% of correct identifications, the adults did not even put their interpretations of the child's gestures into words but relied exclusively on gesture. On these occasions, the adults may not even have been consciously aware of detecting the child's gestures. It is important to note, however, that when the adults reiterated a child's gestured strategy in their own gestures (and not in words), they did not mimic the hand shape, movement, or place of articulation that the child had actually used. Rather, they got the "gist" of the child's meaning and created their own gestures to express that meaning. For example, after viewing a child who expressed an add to equal sign strategy in speech and an add all numbers strategy in gesture (by pointing to each number), one adult said that the child's explanation was that he added all the numbers. At the same time, the adult swept under all the numbers. Note that not only were the adult's words different from the child's words, but the adult's gestures were different from the child's gestures.

In addition, when the adults correctly inferred a strategy the child had expressed uniquely in gesture (identified from mismatching vignettes), the adults frequently expressed their understanding in words, not gestures, of their own. Indeed, 75% of strategies inferred solely from the child's gestures were not mimicked by adults in gesture but rather were translated by the adults into their own speech.

In sharp contrast to these frequent translations of the strategies that the children had expressed in gesture, when the adults correctly identified strategies that the children had expressed in speech, they rarely expressed that strategy in gesture without words. They never reproduced the child's spoken strategies in mismatching vignettes in gesture alone and did so for the child's spoken strategies in matching vignettes only 3% of the time. Rather, they reproduced the child's spoken strategies in speech alone 41% of the time for mismatching vignettes and 53% for matching vignettes. Also, they reproduced the child's spoken strategies in both speech and gesture 59% of the time for mismatching vignettes and 44% for matching vignettes. Thus, not surprising, the adults relied on speech to reiterate children's spoken problem-solving strategies; they did, however, supplement that speech with gesture approximately half of the time. Note, however, that when the adult reproduced in speech and gesture modalities the strategies that the children had expressed uniquely in speech (which they did on 41% of the mismatching vignettes), they were, in effect, translating the children's speech into gestures of their own.

In sum, the free-recall probe allowed the adults to express more comprehensively the knowledge they had gleaned from the children's gestures and speech using whichever modality felt appropriate. The adults most frequently expressed knowledge that the child conveyed in one modality in that same modality—gesture if it were produced in gesture and speech if it were produced in speech. However, they also translated between modalities—transferring roughly 50% of the strategies that the child had produced in speech into gesture and over 75% of the strategies that the child had produced in gesture into speech. These observations reveal that adults had not merely imitated the child's words or gestures but had comprehended the underlying meaning of the words and gestures.

GENERAL DISCUSSION

Traditionally, researchers investigating child and teacher communication in the classroom have focused on verbal aspects of the process. However, the importance of children's nonverbal behaviors in the classroom has been increasingly appreciated (for a review, see Woolfolk & Galloway, 1985). To be sure, such obvious behaviors as scratching doodles on the desk or throwing wads of paper at other children can blatantly let a teacher know what children are (or are not) thinking. However, more subtle nonverbal behaviors may allow teachers to understand what and how much a child understands.

For example, children's facial expressions and tone of voice can reveal how they feel about a given topic (Woolfolk & Galloway, 1985). Children's eye gaze can tell a teacher just how often they are paying attention to what is going on in class (Cazden, 1981). Signals of how comfortable students are with a teacher can be sent through children's body posture and movements (M. Patterson, 1983). Some nonverbal behaviors can even reveal general information about how well children understand a concept. For example, researchers have shown that children display how certain they are about a concept through body posture (C. J. Patterson, Cosgrove, & O'Brien, 1980), body movements and eye contact (Machida, 1986), and facial expressions (Flavell, Speer, Green, & August, 1981).

In addition to conveying a child's general affect, nonverbal behaviors—specifically the spontaneous hand gestures that accompany speech—can convey substantive information about cognitive aspects of a task (Goldin-Meadow, 2001;

McNeill, 1992). Moreover, McNeill (1992) and others (Alibali & Goldin-Meadow, 1993; Goldin-Meadow et al., 1993) have shown that hand gestures can convey information that is not found anywhere in the speaker's verbal repertoire. This unique information can provide privileged insight into children's thought processes. In this way, speech and gesture together can often provide a clearer and more accurate picture of what children really know about a given concept than either modality alone.

For example, recall the child on the stimulus tape in Experiment 1 who believed that the amount of water in a tall, thin glass changed when its contents were poured into a short, wide dish. She justified this belief in her speech by focusing on the heights of the containers, which did differ. However, her gestures, which focused on the widths of the containers, suggested that she had at least some sense that this second dimension might also be relevant to the problem. In this way, the child demonstrated—to those who attended to both the gestural and verbal modalities—that she had knowledge (albeit perhaps unconscious) of precisely the dimensions of the containers that are necessary to understand the concept of conservation.

By noting a child's gestures, an adult can have access to knowledge that the child possesses but is not yet able to articulate in words. The assessments that adults form on the basis of a child's gestures could then influence how they go about instructing that child (cf. Singer & Goldin-Meadow, 2001). For example, if a child's gestures prompt an adult to think about a particular strategy, that strategy may be at the top of the adult's agenda when he or she then decides how to instruct that child.

The way an adult responds to a child may be affected by the child's gestures even if the adult is not aware of having noticed those gestures. Recall that in Experiment 3 adults reiterated the child's gestures uniquely in gesture 25% of the time. For example, one adult paraphrased the child's add to equal sign strategy in speech while at the same time reiterating the child's add all numbers strategy in gesture, and only in gesture. We know that children do pay attention to the gestures their teachers produce (Goldin-Meadow et al., 1999). When an adult "seconds" or gesturally elaborates on a child's gestures, it may serve to reinforce the meaning of those gestures for the child—an outcome that, in this case, may not be the desired result because the strategy is an incorrect one. Making teachers more aware of what their students—and they themselves—do with their hands may create new avenues for teachers to exploit in instructing their students about math (and likely other areas as well).

In these studies, we demonstrated that nonexpert adults benefit from instruction in attending to gesture in two different domains. Instruction was effective in increasing adult sensitivity to child gesture in both a conservation task and a math task—although improvement in the math task was evident only when we used a free-recall probe (i.e., only when adults were asked to describe in their own words what the child knew about the problem). In a sense, this finding makes it much more likely that our study will have implications for naturalistic teaching situations. Teachers are rarely called on to fill out a checklist type questionnaire to assess a student's knowledge, but they are often asked to assess student knowledge using their own words.

Instructing an adult to attend to gesture thus appears to significantly increase the amount of accurate information that the adult is able to glean from a child's gestures. What is particularly striking about this improvement is that the instruction session in our study lasted only 5 min. Moreover, for both conservation and math, the improvement was not limited to the specific stimuli on which the participants were trained. That is, participants generalized the instruction to stimuli that they had never seen.

How might instruction have improved the ability to gain insight from gestures? Perhaps the adults simply did not notice gestures on the pretest, or alternatively, did notice gestures but did not take them seriously. Exit interview data from Experiment 1 provide support for both these hypotheses. Roughly half of the adults in the instruction conditions said they had noticed that children gestured in the pretest but did not pay attention to it until after the instruction. The other half of the participants claimed not to have noticed gesture at all in the pretest but did become aware of gesture after instruction.

Merely hinting that adults should pay attention to a child's gestures significantly improved their ability to glean information from conservation gestures (from 39% on the pretest to 67% on the posttest in Experiment 1). However, giving the adults explicit and specific instruction in how to read the gestures produced greatly improved performance (from 36% on the pretest to 92% on the posttest in Experiment 1) on conservation gestures they had been explicitly taught, as well as those they had not been taught. Explicit instruction in how to read gestures produced on the math task resulted in an equally impressive change from pretest to posttest in Experiment 3 (from 3% on the pretest to 60% on the posttest). Again, this was true on both gestures they had seen during instruction and those they had not. Thus, gently prodding adults to attend to gesture can increase the amount of information they glean from a child's gestures, as one might expect given that we are all natural gesture readers (cf. McNeill, 1992). However, a brief tutorial on how to interpret those gestures can clearly improve performance a great deal—and improving a teacher's ability to read the unspoken thoughts children express in gesture even a little might make a big difference.

Regardless of how gesture instruction worked to make people perform better on our task, the fact that people did get better at detecting gesture after instruction has clear implications for the classroom. Although there is much research on the educational relevance of several other types of nonverbal behaviors (Jecker, Maccoby, & Breitrose, 1965; Koch, 1971; Neill, 1991; Neill & Caswell, 1993; M. Patterson, 1983; Smith, 1984; Woolfolk & Galloway, 1985), children's hand gestures remain a relatively untapped resource for teachers in the classroom. The results from this study suggest that it would probably be quite easy to advise teachers to pay attention to the task-specific information that children typically convey through their gestures. This type of instructional advice may be exactly what teachers need to make use of the valuable information that children's hands have to offer in the classroom.

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