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From Children's Hands to Adults' Ears: Gesture's Role in the Learning Process

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Children can express thoughts in gesture that they do not express in speech—they produce gesture–speech mismatches. Moreover, children who produce mismatches on a given task are particularly ready to learn that task. Gesture, then, is a tool that researchers can use to predict who will profit from instruction. But is gesture also useful to adults who must decide how to instruct a particular child? We asked 8 adults to instruct 38 third- and fourth-grade children individually in a math problem. We found that the adults offered more variable instruction to children who produced mismatches than to children who produced no mismatches—more different types of instructional strategies and more instructions that contained two different strategies, one in speech and the other in gesture. The children thus appeared to be shaping their own learning environments just by moving their hands. Gesture not only reflects a child's understanding but can play a role in eliciting input that could shape that understanding. As such, it may be part of the mechanism of cognitive change.

When children explain their answers to a problem, they convey their thoughts not only in speech but also in the gestures that accompany that speech (e.g., Alibali, 1999; Church & Goldin-Meadow, 1986; Goldin-Meadow, in press; Perry, Church, & Goldin-Meadow, 1988). Adults, too, when explaining problems to a child, convey information about those problems in both speech and gesture (Flevares & Perry, 2001; Goldin-Meadow, Kim, & Singer, 1999). Our goal here is to demonstrate that gesture may play a crucial, although typically unacknowledged, role in the learning process.

Different children come to a learning situation with different levels of understanding. In principle, an adult could interact with each child in a way that is tailored to that child's level of understanding—in Vygotsky's (1978) terms, the adult could provide input that is appropriate to each child's zone of proximal development. A child's zone of proximal development contains abilities that the child has not yet mastered but is actively working on—abilities that are ripe for change. But how is an adult to know which skills a given child is working on? For the zone of proximal development to play a role in developmental change (and be more than just a descriptive metaphor), children must be able to give off reliable cues to their cognitive state and do so in everyday social interactions. Moreover, adults must be able to interpret and respond to those cues.

Children indicate that they are having difficulty with a problem when they solve the problem incorrectly or when they offer incorrect verbal explanations for their solutions. In addition to these rather obvious cues, children can use nonverbal means to provide more subtle cues to their lack of understanding. For example, children ages 4 to 8 take longer to respond, shift their bodies more frequently, and move their hands more often to messages they do not understand than to messages they do understand (Patterson, Cosgrove, & O'Brien, 1980). First-grade children exhibit less direct eye contact with the speaker, more head tilting, excessive hand movements, and agitated body movements when listening to a difficult lesson than when listening to an easy one (Machida, 1986). Kindergarten and second-grade children produce distinctive facial, manual, and bodily expressions of puzzlement, manual vacillation, hesitations, and pauses in activity when asked to follow inadequate instructions (Flavell, Speer, Green, & August, 1981).

Nonverbal cues of this sort can tell an adult that a child is at a loss and needs help with a given task. However, these cues do not tell the adult whether the child is particularly ready to make use of instruction in the task, nor do they tell the adult which parts of the task (if any) the child is actively working on. To learn this type of information, adults can attend to gesture.

In previous work, we have found that children can express thoughts in gesture that they cannot yet express in speech (Garber, Alibali, & Goldin-Meadow, 1998). Moreover, those thoughts are at times the children's newest and most advanced ideas about the problem (Goldin-Meadow, Alibali, & Church, 1993). In addition to providing unique insights into a child's burgeoning thoughts, gesture can also index the child's cognitive stability. Children who say one thing and gesture another when explaining their answers to a task, that is, children who produce *mismatches* between their gestures and their speech, are in an unstable cognitive state with respect to that task. If provided with appropriate instruction, they will improve on the task (Church & Goldin-Meadow, 1986; Perry et al., 1988); if not, they will fall back to a less advanced but more stable state (Alibali & Goldin-Meadow, 1993).

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Why is gesture such a good index of a child's readiness to learn? One important component of the developmental process is the generation of new knowledge, and gesture offers a process by which learners can bring new information into their repertoires without disrupting the current system. Because gesture is uncodified and not susceptible to cultural approbation (speakers are rarely criticized for their spontaneous gestures), it is an ideal modality within which to work out and even consider for the first time notions that are wild, untamed, and inchoate. Moreover, because the representational formats underlying gesture are mimetic and analog rather than discrete, gesture may permit the learner to represent ideas that lend themselves to these formats and that are not yet developed enough to be encoded in speech. Consider, for example, a child who is explaining how she solved the problem $5 + 4 + 3 = \_\_\_\_ + 3$. She says, "I added the 5, the 4, the 3, and the 3 and got 15," and thus in her speech displays no awareness that the equation has two sides divided by an equal sign. However, at the same time, she moves her hand under the left side of the equation, then breaks the motion and performs precisely the same movement under the right side of the equation. Her gesture reflects a budding awareness that the two sides of the equation are in some way alike. Gesture thus offers an alternative and perhaps more accessible route in which developing ideas can be tried out and expressed.

Children who produce gesture–speech mismatches are ready to learn, more ready than children who do not produce mismatches. The question we address here is whether adults recognize that these children are particularly open to instruction, and respond accordingly. Much recent work has shown that both adults and children can interpret the spontaneous gestures that children produce when those gestures are selected for clarity and are shown twice on videotape (Alibali, Flevares, & Goldin-Meadow, 1997; Goldin-Meadow, Wein, & Chang, 1992; Kelly & Church, 1997, 1998; Kelly, Singer, Hicks, & Goldin-Meadow, 2002; see also Beattie & Shovelton, 1999; McNeill, Cassell, & McCullough, 1994; Thompson & Massaro, 1986). Indeed, adults can even read children's gestures when the gestures are unedited and observed live (Goldin-Meadow & Sandhofer, 1999). But reading gesture as an observer of an interaction is not the same as reading it as a participant in an interaction. Nor do we yet have evidence that adults profit from the information they glean from a child's gestures and use it to shape their ongoing interactions with that child.

The purpose of this study was twofold. We first asked whether adults give children who produce gesture–speech mismatches different input than they give to children who do not produce gesture–speech mismatches. We found that they do—adults provide more variable input to children who produce mismatches than to children who do not, including producing more of their own gesture–speech mismatches. This finding paves the way for our next question—what role do mismatches play in the learning process? We describe the information that is displayed in child mismatches and in adult mismatches, and we provide evidence that both child and adult listeners pay attention to that information. We explored these questions using a mathematical equivalence problem that children in the third and fourth grades have difficulty with but, with instruction, can make progress on (Perry et al., 1988).

Method

Participants

Thirty-eight children (12 boys and 26 girls) from the Chicago public schools ranging in age from 8 years 6 months to 11 years 6 months ($M = 9$ years 10 months) participated in the study. The children were either in the latter part of third grade or the early part of fourth grade.

We sought a population of adults who might be particularly adept at responding to children. We therefore asked teachers, who are routinely called upon to assess children's skills and teach to those skills, to participate in the study. Eight adults (1 man and 7 women) from the Chicago public schools were recruited through fliers and through contacts in the Department of Education at the University of Chicago. The adults currently or formerly taught math or science, 7 at the elementary school level and 1 at the secondary school level, and had between 2 and 30 years ($M = 9.75$ years) of teaching experience.

Procedure

Each adult taught between 4 and 6 children in individual sessions, each lasting approximately 20 min. The adults taught children they did not know. Thus, whatever reactions they had to a child could not have been based on previous interactions with that child. The entire session was videotaped.

Pretest. An experimenter gave each child a paper-and-pencil pretest consisting of six mathematical equivalence problems of the type $5 + 3 + 4 = \_\_\_\_ + 4$. After completing the test, each child explained his or her answers at the blackboard. The pretest provided a baseline measure of the child's knowledge of the task prior to instruction. No child who gave any correct solutions on the pretest was included in the study. The adult watched the entire pretest for each child and thus gained some sense of the child's level of understanding of the problem before having to instruct him or her.

Instruction. Adults were given five math problems to use in instructing each child, and each of the adults used all five. They were told to put the first of the problems on the board and to ask the child to solve it and explain the solution. The adult was then free to instruct the child in any way he or she thought appropriate.

Posttest. After instruction, the experimenter gave the child a posttest comparable but not identical to the pretest.

Coding

All of the adults' and children's speech and gestures were transcribed and coded according to a previously developed system (Perry et al., 1988). Only those gestures and spoken utterances that conveyed strategies for solving the problems were analyzed. Overall, the children and adults produced three strategies that led to correct answers, three strategies that led to incorrect answers, and two strategies that focused exclusively on one side of the equation (these strategies were used to break the problem into parts and "build up" to the correct answer; see Goldin-Meadow et al., 1999). Table 1 presents examples of each strategy in speech and its gestural equivalent.

We made two passes through the data, once coding speech and a second time coding gesture. We then compared the speech and gesture codes for a given utterance. Utterances were classified as *match* if the strategies conveyed in gesture and speech were the same, *mismatch* if the strategies were different, and *speech alone* if there was no gesture at all.[1] Reliability was assessed by having a second experimenter independently code a subset of the adults' and children's utterances. Agreement between coders was

[1] On rare occasions, the adults and children produced gestures without speech; these responses were not included in the analysis.

Table 1
Examples of Correct, Incorrect, and Building Strategies Produced in Speech and in Gesture

	Sample problem: 5 + 3 + 4 = ____ + 4	
Strategy	Speech	Gesture
	Correct strategies	
Equalizer	"Both sides have to be the same."	Flat palm first placed under the left side of the problem and then under the right
Equal-addends and grouping	"There's a 4 here and a 4 here; you can block them off and then add these two numbers to get the answer."	One flat palm covers the 4 on the left side of the problem and another covers the 4 on the right; V-hand indicates the 5 and 3 on the right side of the problem
Add–subtract	"You can get the answer by adding up all of the numbers on the left side, then taking away the 4 on the right."	Pointing hand sweeps under the left side of the problem; hand points to the 4 on the right side and retracts; hand points to the blank
	Incorrect strategies	
Add all numbers	"I added all of them up."	Points at the 5, 3, left 4, right 4, and the blank
Add to equal sign	"I added the 5, the 3, the 4 to get the answer."	Points at the 5, 3, left 4, and the blank
Carry	"I put the 5 there."	Points at the 5 and the blank
	Building strategies	
Left side	"Let's add the 5, the 3, and the 4 and put the sum here [under the left side of the problem]."	Points at the 5, 3, left 4, and at the 12 written in under the left side of the problem
Right side	"Let's add the number in the blank and the 4 and put the sum here [under the right side of the problem]."	Points at the blank, the right 4, and the 12 written in under the right side of the problem

92% ($N = 53$) for assigning strategy codes to speech, 90% ($N = 40$) for assigning strategy codes to gesture, and 97% ($N = 50$) for categorizing utterances as match, mismatch, or speech alone.

Results

Do Children Who Mismatch Profit From Instruction in a Naturalistic Interaction?

We began by dividing children into groups on the basis of their gestures. Fourteen of the 38 children (38%) produced gesture–speech mismatches on the pretest, a percentage comparable to those found in previous studies (Church & Goldin-Meadow, 1986; Perry et al., 1988). However, unlike in previous studies, the children who produced mismatches produced relatively few of them; the range was from 1 to 4 ($M = 2.1$, $SD = 1.1$). In previous work, we considered a child to be a "mismatcher" if that child produced three or more mismatches over six problems. We could not use this cutoff in the present study because only 4 children met the criterion. We consequently classified all 14 children who produced any mismatches on the pretest as mismatchers.[2] Twelve of these children continued to produce mismatches during the instruction period ($M = 3.7$, $SD = 2.5$).[3]

A second group of 12 children did not produce any mismatches during the pretest but began producing them during instruction. The mean number of mismatches they produced was 3.5 ($SD = 3.1$), a number that did not differ significantly from the number of mismatches produced by the first group of children during instruction, $t(24) = 0.31$, *ns*.

The third group of 12 children never produced any mismatches, either during the pretest or during instruction.

[2] We do not know why the children in the current study produced so few mismatches on the pretest. We did explore whether the 4 children who produced three or four mismatches differed from the 10 who produced only one or two, and we found that the two groups were equally successful on the posttest (2.3 correct vs. 3.6), $t(12) = 0.82$, *ns*. Thus, unlike in our previous work (cf. Perry et al., 1988, Note 5), there is no evidence that the number of mismatches a child produces is correlated with eventual learning. Rather, producing any mismatches at all appears to signal the child's readiness to learn.

[3] When the 2 children who produced mismatches during the pretest but not during instruction were eliminated from the analyses presented below, the pattern of results did not change.

Our first task was to determine whether children who produce mismatches are particularly likely to profit from instruction even when that instruction is provided in an unscripted, naturalistic tutorial. Figure 1 presents the mean number of correct responses that the three child groups produced on the posttest after instruction from the adult (recall that none of the children from any of the three groups produced any correct responses on the pretest). As expected, the three child groups differed significantly in their posttest performance, $F(2, 35) = 3.86$, $p = .03$. Children who produced mismatches on the pretest and during instruction gave significantly more correct responses on the posttest than did children who produced no mismatches whatsoever ($p = .01$, Dunn's test). No other differences between groups were statistically significant.[4]

It is important to note that the children in all three groups were identical on the pretest in terms of the measures traditionally used to measure child understanding—number of correct solutions and number of correct spoken explanations. The solutions that the children in our study gave to the pretest problems were all incorrect, as were all their spoken explanations. Moreover, most of the gestural explanations that the children gave on the pretest were also incorrect. As a result, the majority of the mismatches that the children produced on the pretest (69%) contained two incorrect strategies—an incorrect strategy in speech and a different incorrect strategy in gesture. The children who produced these mismatches profited from instruction, but it was not because they had displayed partially correct knowledge of mathematical equivalence. In addition, there were 6 children who produced not only incorrect–incorrect mismatches but also incorrect–correct mismatches—an incorrect strategy in speech but a correct strategy in gesture (28% of the mismatches on the pretest were of this type).[5] These children did display partial knowledge of mathematical equivalence, but we stress that this incipient knowledge was available only to adults who paid attention to child gesture. The 6 children also improved on the posttest but performed no better than the 8 children who did not produce correct strategies in gesture in their pretest mismatches ($M = 2.5$, $SD = 2.9$ vs. $M = 3.7$, $SD = 2.7$), $t(12) = 0.83$, *ns*.

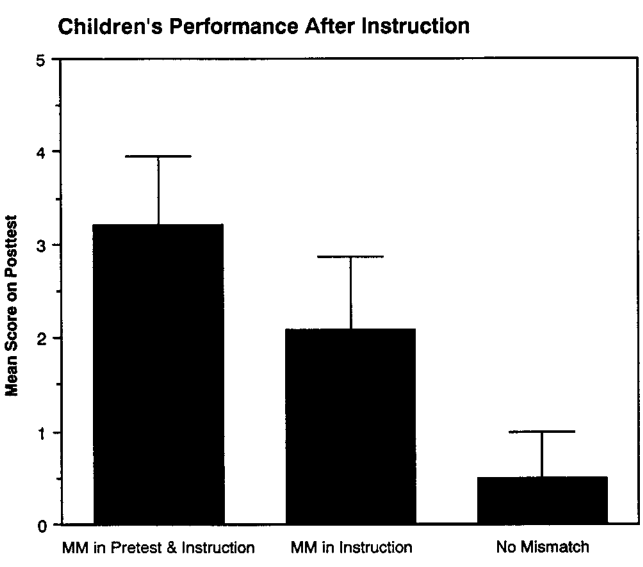

Figure 1. Children who mismatch are more likely to learn than children who do not. The figure displays the mean number of correct responses children produced on the posttest after instruction. Children who produced mismatches during the pretest and instruction produced significantly more correct responses than children who produced no mismatches at all. Error bars represent standard errors. MM = mismatch.

We have thus replicated work showing that children who produce mismatches prior to instruction are ready to profit from that instruction. However, unlike previous studies in which instruction was administered by an experimenter and was deliberately held constant across all children (Church & Goldin-Meadow, 1986; Perry et al., 1988), in this study instruction was administered by adults who had no set script to follow. The adults' instruction quite likely varied across the children and thus contributed in unequal ways to the children's improvement on the posttest. Indeed, this is our primary hypothesis—that the adults were sensitive to the fact that some of the children produced mismatches whereas others did not and that the adults adjusted their instruction as a result. To test this hypothesis, we examined the instruction that the adults offered to each of the three child groups.

Do Adults Give Different Instruction to Children Who Produce Mismatches?

In this section we ask whether the adults noticed (not necessarily consciously) that some but not all of the children produced mismatches and, if so, whether they altered their instruction accordingly. The answer appears to be yes.

Adults alter the amount of variability in their instruction. Figure 2 presents the mean number of different types of correct (top graph) and incorrect (middle graph) strategies that the adults presented to children who did and did not produce mismatches. We gave adults credit for having produced a particular strategy if they produced it in either speech or gesture. In all cases, the adults used their incorrect strategies to instruct children in what *not* to do (e.g., "You don't add up all of the numbers in the problem") or to comment on what a child had just done ("You just added up all of the numbers in the problem"). These incorrect strategies thus seemed to be part of the adult's instructional plan. We found that the adults differed in the total number of types of strategies they presented to the three child groups, $F(2, 35) = 10.47$, $p < .0003$. They produced significantly more different types of strategies when instructing children who produced mismatches on both the pretest and instruction ($p = .02$, Scheffé test) or on the instruction alone ($p = .0003$, Scheffé test) than when instructing children who did not produce mismatches at all. There were no significant differences in the adults' strategies when we compared the two groups of children who produced mismatches.

Figure 2 (bottom graph) presents the mean proportion of gesture–speech mismatches that the adults presented to children

[4] There were no significant differences on the posttest between the boy and girl learners, $F(1, 36) = 0.07$, *ns*, nor were there any differences in the way the adults responded to the boy and girl learners: $F(1, 36) = 1.93$, *ns*, for types of strategies; $F(1, 36) = 0.23$, *ns*, for mismatches.

[5] In addition, 1 child produced an incorrect strategy in speech accompanied by a building strategy in gesture on the pretest.

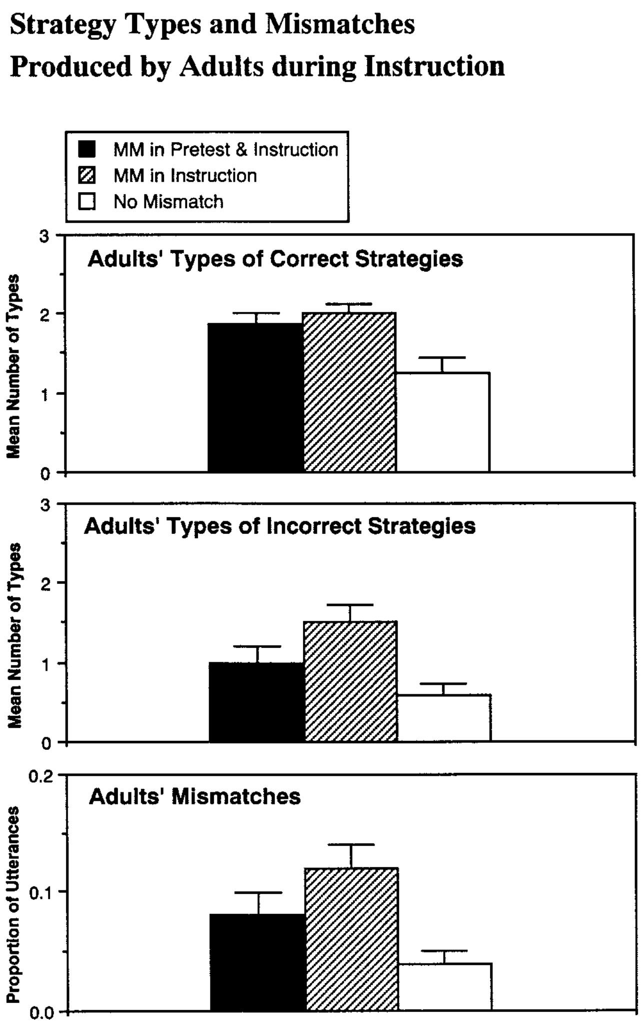

Figure 2. Adults offer different instruction to children who produce mismatches. The figure displays the mean number of different types of correct (top graph) and incorrect (middle graph) strategies and the mean proportion of mismatches (bottom graph) that adults used when instructing the children. Adults produced significantly more different types of correct and incorrect strategies and more mismatches when teaching children who produced mismatches during the pretest and instruction (black bars) and during instruction only (striped bars) than when teaching children who produced no mismatches (white bars). MM = mismatch.

who did and did not produce mismatches. As before, the adults responded differently to the three child groups, $F(2, 35) = 6.54$, $p < .004$ (proportions were arcsine transformed before analysis). The adults produced significantly more mismatches with children who produced mismatches during either the pretest or the instruction than with children who produced no mismatches at all, $F(2, 35) = 6.93$, $p < .05$, Scheffé test. There were no significant differences in the adults' productions of mismatches when we compared the two groups of children who produced mismatches.

In sum, the adults offered instruction that contained more variability, with more different types of strategies and more mismatches, to children who produced mismatches than to children who did not. Several additional points with respect to the adults' adjustments are also important.

First, all 8 adults taught children who produced mismatches on the pretest and during instruction; all but 1 taught children who produced mismatches during instruction only; and all but 2 taught children who never produced mismatches. Thus, the phenomenon shown in Figure 2 is not tied to individual adults or children. Most of the adults had the opportunity to teach all three types of children.

Second, the adults adjusted the variety of correct and incorrect strategies they gave to the children, not the tokens of correct and incorrect strategies. We looked at the proportion of correct and incorrect strategies that the adults produced, counting each token of a correct and incorrect strategy rather than each type. Not surprisingly, the adults produced many more correct than incorrect strategies when teaching the children. The important point, however, is that the adults used the same distribution of strategies when teaching all of the children—the proportion of correct strategies they produced did not differ across the three child groups ($M = 0.43$, $SD = 0.13$; $M = 0.44$, $SD = 0.13$; $M = 0.38$, $SD = 0.11$), $F(2, 35) = 0.99$, *ns*, nor did their proportion of incorrect strategies ($M = 0.04$, $SD = 0.05$; $M = 0.06$, $SD = 0.06$; $M = 0.02$, $SD = 0.02$), $F(2, 35) = 2.28$, *ns*. The remaining strategies that the adults produced were building strategies. All of the adults used two different types of building strategies with each child they taught; as a result, there was no variability across groups in types of building strategies. There were also no differences in the proportion of building strategies that the adults used with each group, $F(2, 35) = 2.01$, *ns*, and no differences in the total number of utterances they used with each group, $F(2, 35) = 2.07$, *ns*.

Third, the adjustments that the adults made in terms of mismatches did not extend to other types of utterances. The adults varied their proportion of gesture–speech mismatches—that is, utterances containing more than one strategy, one in speech and a different one in gesture. However, they did not vary their proportion of utterances containing a single strategy, either the same strategy presented in speech and gesture (gesture–speech matches; $M = 0.49$, $SD = 0.11$; $M = 0.47$, $SD = 0.10$; $M = 0.49$, $SD = 0.13$) or a single strategy presented in speech in an utterance containing no gesture (speech-alone utterances; $M = 0.36$, $SD = 0.10$; $M = 0.33$, $SD = 0.09$; $M = 0.36$, $SD = 0.11$). There were no differences across the three child groups for either matches, $F(2, 35) = 0.29$, *ns*, or speech without gesture, $F(2, 35) = 0.37$, *ns*. Thus, the adults made adjustments in certain types of utterances—those that contained a variety of strategies within a single response—not in all utterances.

Is it really child mismatch that elicits variable instruction from adults? We divided the children in our study into three groups on the basis of their mismatch production during the pretest and instruction. We then found that adults instructed children who produced mismatches differently from children who produced no mismatches. It is possible, however, that there were other factors that correlated with child mismatch and that the adults were responding to those factors rather than to child mismatch. Recall that we have already eliminated the two most likely candidates: (a) number of correct solutions on the pretest (there were none for any child) and (b) number of correct explanations on the pretest (again, there were none for any child). One remaining candidate is the number of correct strategies produced during instruction—perhaps children who produced mismatches also produced more different types of correct strategies or more correct strategies overall during the instruction period. If so, the adults could have altered their instruction on this basis.

To explore this hypothesis, we calculated the number of different types of correct ($M = 2$, $SD = 0.5$; $M = 1.6$, $SD = 0.8$; $M = 1.5$, $SD = 0.7$) and incorrect ($M = 2$, $SD = 0.7$; $M = 1.7$, $SD = 0.6$; $M = 1.4$, $SD = 0.8$) strategies that the children in each of the three groups produced during instruction, and we found no significant differences across the groups for either correct strategies, $F(2, 35) = 1.99$, *ns*, or incorrect strategies, $F(2, 35) = 2.15$, *ns*. We also calculated the proportion of correct ($M = .30$, $SD = .24$; $M = .32$, $SD = .24$; $M = .37$, $SD = .25$) and incorrect ($M = .17$, $SD = .10$; $M = .18$, $SD = .12$; $M = .14$, $SD = .10$) strategies that the children produced during instruction and again found no differences: $F(2, 35) = 0.27$, *ns*, for correct; $F(2, 35) = 0.36$, *ns*, for incorrect.

Lending additional support to the hypothesis that the adults were responding to child mismatch is the fact that the variables that the adults altered during instruction (their own mismatches, and the number of different types of strategies they produced) correlated with child mismatch. The more mismatches a child produced during instruction, the more mismatches ($r_s = .58$, $p < .001$) and more different types of strategies ($r_s = .39$, $p = .01$) an adult was likely to produce during instruction. This relation did not hold, however, for the number of different types of strategies the children produced—child types of strategies during instruction were not significantly correlated with adult mismatch ($r_s = .13$, *ns*) or adult types of strategies ($r_s = .18$, *ns*).

Adult mismatch during instruction thus correlated only with child mismatch during instruction. However, the mismatches that the adults produced did not seem to be direct imitations, that is, immediate responses to the mismatches that the children produced. Only 10 of the 221 (.04) mismatches that the adults produced during instruction were preceded by a child mismatch. Indeed, in only 39 mismatches (.18 of 221) could the adult's strategies be traced back to a strategy in the child's preceding utterance. The adults' mismatches were therefore not immediate responses to child utterances.

There is, however, one other child factor that the adults might have been responding to—whether the child was gesturing at all. The three child groups produced precisely the same number of utterances without gestures, that is, speech-alone utterances ($M = 20.5$, $SD = 9.8$; $M = 19.1$, $SD = 10.0$; $M = 19.7$, $SD = 10.8$), $F(2, 35) = 0.06$, *ns*. Thus, the essential difference between the groups was the amount of talk produced with gesture. Perhaps not surprisingly, the three child mismatch groups differed significantly in the proportion of their utterances that contained gesture, $F(2, 35) = 11.64$, $p = .0001$. Children who produced mismatches during pretest and instruction produced gesture in .41 ($SD = .18$) of their utterances, and children who produced mismatches only during instruction produced gesture in .43 ($SD = .22$) of their utterances. In contrast, children who never produced mismatches produced gesture in only .12 ($SD = .13$) of their utterances,[6] a proportion significantly different from both mismatch groups ($p < .01$, Tukey's honestly significant difference [HSD] test). Thus, it remains possible that the adults were responding not to mismatch per se but to the fact that the mismatching children were gesturing at all.

To test this hypothesis, we examined how often the children produced gestures that matched their speech (child matches) and how often they produced gestures that mismatched their speech (child mismatches), and we used these proportions as child factors in a multiple regression analysis predicting adult mismatch. We found that there was indeed a relation between the gesture–speech child factors and adult mismatch ($r = .56$, $p = .001$). However, only child mismatch significantly predicted adult mismatch ($p = .001$); child match did not. Thus, it was the relation between the children's gesture and speech, and not the mere presence of gesture with speech, that seemed to be key in predicting adult mismatch.

Note also that the presence of gesture per se conveys little information about a child's knowledge state. In contrast, the mismatches that children produce often provide information about their knowledge states, information that is not found anywhere else in their repertoires. There is consequently diagnostic value to child mismatch, as we discuss in the next section.

The Diagnostic Value of Child Mismatch

Child mismatch conveys information not found elsewhere. An utterance containing a gesture–speech mismatch by definition includes more than one strategy. Thus, mismatches convey more strategies than matches or speech-alone utterances. The question we address next is whether the children's mismatches also convey more different types of strategies than either matches or speech-alone utterances. We found that the two groups of children who produced mismatches during instruction did indeed produce different numbers of types of strategies in their mismatching, matching, and speech-alone utterances, $F(2, 48) = 4.06$, $p = .02$. The children produced more different types of strategies in their mismatching utterances ($M = 2.4$, $SD = 1.2$) than in their matching ($M = 1.5$, $SD = 1.1$) or speech-alone ($M = 1.8$, $SD = 1.2$) utterances, $F(2, 48) = 3.71$, $p = .03$; there were no significant differences between the two groups of children, $F(1, 24) = .56$, *ns*, and no interaction, $F(2, 48) = 1.4$, *ns*. Thus, the children conveyed more information in mismatches than in other types of utterances.

In addition, the information that the children conveyed in their mismatches was often unique, that is, not found anywhere else in their repertoires. The children who produced mismatches on the pretest and during instruction, as a group, produced a number of strategies that did not appear in their speech-alone utterances or in their gesture–speech matches; that is, these strategies could be found only in their gesture–speech mismatches—10 strategies in their 28 pretest mismatches (9 in gesture and 1 in speech) and 14 in their 43 instruction mismatches (9 in gesture and 5 in speech). The children who produced mismatches only during instruction also produced strategies in their mismatches that did not appear anywhere else in their repertoires—9 in their 39 instruction mismatches (3 in gesture and 6 in speech). Both groups thus produced unique information in their mismatches. However, the first group produced their unique strategies in gesture more often than in speech, whereas the second group produced them in speech more often than in gesture. Nevertheless, for both groups of children, it was essential to pay attention to the children's mismatches in order

[6] Four of the children who never produced mismatches also produced no gestures during the instruction period. However, even after omitting these children, the proportion of utterances that this group produced with gestures was low (.18).

to discover the complete set of strategies that the children had in their repertoires.

What types of mismatches did the children produce during the instruction session? Recall that in the pretest, the children produced primarily one type of mismatch—an incorrect strategy in speech and a different incorrect strategy in gesture. Some children also produced an incorrect strategy in speech accompanied by a correct strategy in gesture, but this type of mismatch was relatively infrequent. Interestingly enough, the types of mismatches the children produced during instruction were much more varied and did not differ across the two mismatch groups (those who began producing mismatches during the pretest and those who did not begin until the instruction period). The children produced incorrect–incorrect mismatches (.10), incorrect–building mismatches (.23), incorrect–correct mismatches (.27), correct–building mismatches (.21), and correct–correct mismatches (.13); the remaining mismatches (.06) were building–building combinations in which the child gestured about one side of the problem and spoke about the other. Overall, .61 of the children's mismatches during instruction contained correct strategies, and .60 contained incorrect strategies. Moreover, .44 of the correct strategies that the children produced appeared in the gesture component of a mismatch, whereas only .30 appeared in the speech component. Thus the children were more likely to express their first ideas about how to solve the problem correctly in the gestural half of their mismatches.

Further evidence that mismatch is a useful diagnostic of the child's state comes from the fact that the children's mismatches changed after instruction. Sixteen of the 24 children who produced mismatches during instruction produced a smaller proportion of mismatches on the posttest than they produced during instruction. But more important, the types of mismatches that the children produced changed over the course of the study. Only 28% of the children's mismatches contained a correct strategy on the pretest. The percentage increased to 61% during instruction, and it increased again to 100% on the posttest. Thus, the changes that occurred in the children's understanding of mathematical equivalence were reflected in their mismatches.

Adults pay attention to child gestures. We have shown that there is useful information about children's knowledge in their gestures. The fact that adults provide different instruction to children who produce mismatches than to children who do not suggests, but certainly does not prove, that adults are sensitive to the gestures that children produce. Is there direct evidence that adults pay attention to child gestures?

To explore this question, we first asked whether the gestures that accompanied a child's speech affected the message that the adult took from that speech. If, for example, gesture conveyed a different message than speech, the adult might be less likely to receive the spoken message than if speech were accompanied by no gesture at all. Conversely, if gesture conveyed the same message as speech, the adult might be more likely to receive that message than if speech were accompanied by no gesture at all. To test these predictions, we needed a measure of the adult's reception of the message conveyed by the child in speech. We chose a conservative one—we counted a spoken strategy as "received" if the adult repeated that strategy in his or her own words or in gestures in the next utterance.

Figure 3 presents the proportion of adult responses that were

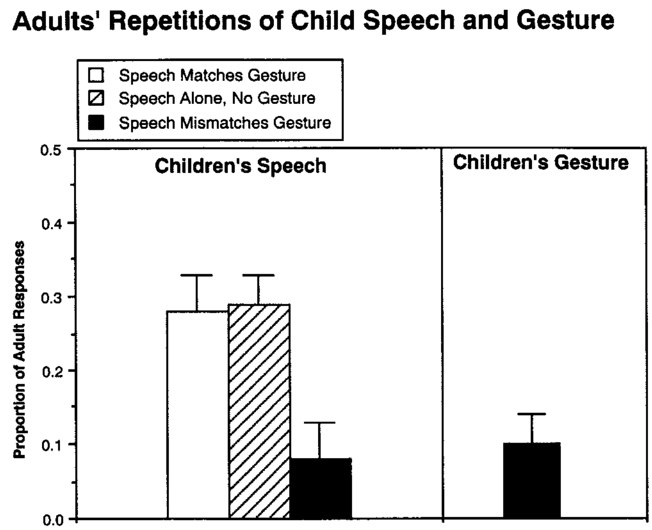

Figure 3. Adults react to and take meaning from a child's gestures. The figure displays the mean proportion of responses in which the adult repeated the child's speech (left graph) and gesture (right graph). Adults were significantly less likely to reiterate a strategy in speech when that speech was accompanied by gesture conveying different information (black bar) than when it was accompanied by no gesture at all (striped bar). However, they were no more likely to reiterate a strategy in speech when that speech was accompanied by gesture conveying the same information (white bar) than when it was accompanied by no gesture at all (striped bar). In addition, the adults reiterated the strategy conveyed in the gestural component of a mismatch as often as they reiterated the strategy conveyed in the speech component of a mismatch (compare the two black bars). Error bars represent standard errors.

repetitions of a preceding child utterance. The strategy that the child expressed in speech was classified according to whether it (a) matched the strategy expressed in gesture (white bar), (b) was accompanied by no gesture (striped bar), or (c) did not match the strategy expressed in gesture (black bar on left). We found that the adults varied their repetitions as a function of type of child utterance, $F(2, 7) = 16.19$, $p = .0002$.[7] They were significantly less likely to repeat a child's spoken strategy if it was accompanied by a mismatching gesture than by no gesture at all ($p < .01$, Tukey's HSD test).[8] However, they were no more likely to repeat a child's spoken strategy when it was accompanied by a matching gesture than when it was accompanied by no gesture at all. The adults seemed to take note of the children's mismatches but not their matches.

Gesture seems to affect how adult listeners interpret a child's words. But do those listeners also glean substantive meaning from

[7] The unit for this analysis is the adult. We present responses given by a particular adult to the speech and gesture produced by all of the children he or she taught in Figure 3 and the responses given by all of the children taught by a particular adult to that adult's speech and gesture in Figure 4. In this way, we were able to conduct an analysis of variance with type of utterance as a within-subjects factor.

[8] Adults repeated speech accompanied by a mismatching gesture less often than speech accompanied by no gesture whether that speech conveyed a correct strategy, an incorrect strategy, or a building strategy.

the gestures themselves? In a gesture–speech mismatch, the child is conveying a strategy in gesture that is not conveyed in the accompanying speech. If the adult listener were to repeat that strategy (in gesture or in speech), we would have evidence that the adult was gleaning meaning from the child's gestures. The data are presented in the right-hand panel in Figure 3. Although the adults repeated the strategy conveyed in the gesture component of a mismatch relatively infrequently, they did so as often as they repeated the strategy conveyed in the speech component of a mismatch (compare the two black bars in Figure 3). Thus, the adults were able to glean substantive information from child gesture in a mismatch, and in equal measure to the information gleaned from speech in a mismatch.

To summarize thus far, the adults responded differently to the children's mismatches than to their matches or speech-alone utterances. Overall, adults were less likely to reiterate the information conveyed in a mismatch than the information conveyed in a match or speech alone, but they did glean information from both the gesture and speech components of a mismatch—and in equal measure. Moreover, the adults were more likely to pick up the correct strategies that children produced in their mismatches than to pick up the incorrect strategies (.30 vs. .08). For example, consider a child who explained his incorrect solution to the problem $7 + 6 + 5 = \_\_\_\_ + 5$. The child said "I added 13 plus 10 equals 23" (an incorrect add-all-numbers strategy) while holding his whole hand under the 7 and the 6, pointing at the blank, and then pointing at the 7 and 6 (a correct grouping strategy). In response, the adult said, "I am going to cover this up [while covering up the 7 and 6 with her hand]. Now what do you see on both sides? Five and five, right?" The adult ignored the child's incorrect solution and spoken explanation and used the child's gestures as the basis for her next instructional step. She covered the two numbers that the child had indicated (the two numbers which, if added together, gave the correct answer), thereby forcing the child to notice that there was a 5 on each side of the problem (equal addends).

The adults were able to interpret the mismatches that the children produced, which was quite fortunate because the children often conveyed strategies in those mismatches that were not found anywhere else in their repertoires. Indeed, 17 of the 24 children who produced mismatches during instruction conveyed strategies in those mismatches that they did not convey at any other time. It was essential to pay attention to mismatch in order to figure out what these children knew, and the adults in our study seemed quite capable of doing just that.

The Pedagogical Value of Adult Mismatch

When instructing children who produced mismatches on the mathematical equivalence task—children who were ready to learn the task—adults produced a relatively large number of different types of strategies and a relatively large proportion of their own gesture–speech mismatches. It is not difficult to imagine why an adult (particularly one who is a trained educator) might instinctively increase the range of approaches to a problem when instructing a child who is on the cusp of grasping that problem. It is less easy to imagine why the adult would produce a large proportion of mismatches. To get a handle on this question, we took an in-depth look at the mismatches the adults produced during instruction and asked what their pedagogical value might be.

Adult mismatch is different from child mismatch. The first point to note is that the mismatches the adults produced during instruction were different from the mismatches the children produced. Recall that the children produced more different types of strategies in their mismatching utterances than in their matching or speech-alone utterances. In contrast, the adults produced the same number of different types of strategies in all of their utterances, $F(2, 74) = 1.04$, *ns*: $M = 1.97$ ($SD = 1.26$) in mismatching utterances, $M = 1.94$ ($SD = 0.93$) in matching utterances, and $M = 2.16$ ($SD = 1.00$) in speech-alone utterances.

In addition, the children often produced strategies that were found only in their mismatches and not in other types of utterances. But the adults rarely did so. Only 8 strategies in the 221 mismatches the adults produced during instruction were found uniquely in mismatch, and all of these strategies were in speech, not gesture. In other words, the adults never produced a strategy in the gesture component of a mismatch that they did not also produce in speech in some other utterance. Thus, there was nothing unique about the adults' mismatches in terms of content.

In terms of types of mismatches, the adults produced the same range as the children but in a different distribution. Not surprisingly, they produced fewer mismatches with incorrect strategies and more with correct strategies: incorrect–incorrect, .03; incorrect–building, .04; incorrect–correct, .10; correct–building, .49; and correct–correct, .14. They also produced a large proportion of building–building mismatches (.21). Overall, the adults produced correct strategies in .72 of their mismatches and incorrect strategies in only .17 of their mismatches. Moreover, even in their mismatches, the adults produced correct strategies in gesture (.42) as often as in speech (.42). For example, on the problem $7 + 6 + 5 = \_\_\_\_ + 5$, one adult expressed an equalizer strategy in speech ("We need to make this side equal to this side") while conveying a grouping strategy in gesture (pointing at the 7, the 6, and the blank). Both strategies lead to correct solutions yet do so via different routes.

Thus, the strategies that the adults produced in their mismatches were for the most part correct. But the adults produced those correct strategies in other places besides mismatches—gesture–speech matches and speech-alone utterances. What then was the advantage (if any) of conveying a strategy in a mismatch? At least two possibilities present themselves. Strategies conveyed in gesture may be particularly accessible to children who have not yet mastered the task. Moreover, the fact that two different strategies are occurring side by side may bring the strategies themselves into focus. If so, adult mismatch might have pedagogical value. Of course, for adult mismatch to be of use in an instructional setting, children must pay attention to adult gestures. In the next section, we show that they do.

Children pay attention to adult gestures. We conducted precisely the same analysis on the adults' gestures that we conducted on the children's gestures. The strategy that the adult expressed in speech was classified according to whether it (a) matched the strategy expressed in gesture (white bar), (b) was accompanied by no gesture (striped bar), or (c) did not match the strategy expressed in gesture (black bar on left). We analyzed the proportion of child responses that were repetitions of adult utterances. Figure 4 presents the data. Children varied their repetitions as a function of

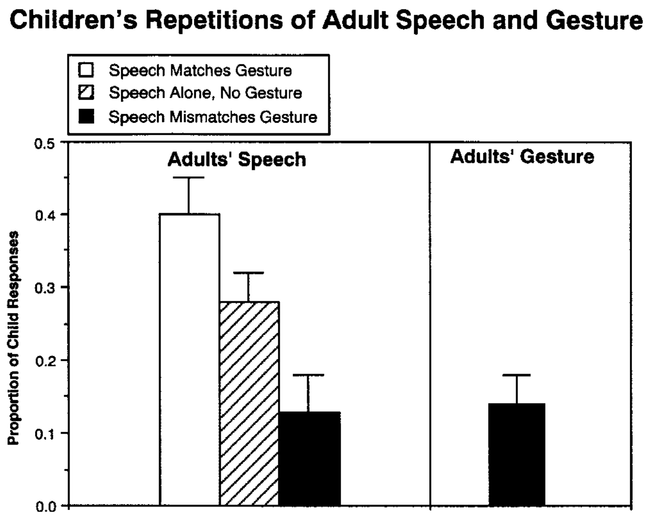

Figure 4. Children react to and take meaning from adults' gestures. The figure displays the mean proportion of responses in which the child repeated the adult's speech (left graph) and gesture (right graph). Children were significantly less likely to reiterate the strategy in speech when that speech was accompanied by gesture conveying different information (black bar) than when it was accompanied by no gesture at all (striped bar). Moreover, they were also significantly more likely to reiterate the strategy in speech when that speech was accompanied by gesture conveying the same information (white bar) than when it was accompanied by no gesture at all (striped bar). In addition, the children reiterated the strategy conveyed in the gestural component of a mismatch as often as they reiterated the strategy conveyed in the speech component of a mismatch (compare the two black bars). Error bars represent standard errors.

type of adult utterance, $F(2, 7) = 30.69$, $p < .0001$. Like the adults, the children were significantly less likely to repeat a spoken strategy when it was accompanied by a mismatching gesture than when it was accompanied by no gesture at all ($p < .01$, Tukey's HSD test).[9] However, unlike the adults, the children were also significantly more likely to repeat a spoken strategy when it was accompanied by a matching gesture than when it was accompanied by no gesture at all ($p < .01$, Tukey's HSD test). The children paid attention not only to adult mismatches but also to adult matches.

In addition, like the adults, the children were able to glean substantive information from gesture. Children repeated the strategy that the adults produced in the gesture component of a mismatch in .14 of their responses—as often as they repeated the strategy that the adults produced in the spoken component of a mismatch (compare the two black bars in Figure 4).

Note that the children did get less information out of speech that was accompanied by a mismatching gesture than they got out of speech that was accompanied by no gesture at all. However, this decrement was offset by the information that the children got out of the gesture component of the mismatch (the two black bars together equal the striped bar in Figure 4). Moreover, when the children reiterated a strategy (either spoken or gestured) in an adult mismatch, that strategy was correct 49% of the time. For example, consider an adult who was using the problem $3 + 7 + 9 = \_\_\_\_ + 9$ to teach the child the equalizer strategy. The adult said, "We're going to do it like before. We're going to make this side equal to this side" (a correct equalizer strategy) while holding her whole hand under the 3 and the 7, the two numbers which, if added, gave the correct answer (a correct grouping strategy). In response, the child exclaimed "Oh!" and solved the problem correctly. When asked to explain her solution, the child said, "We have the 9's so we need the same (equal addends) and we can't put two numbers so I just added these two and put it here and it equaled 10" (grouping) while gesturing the same information: She pointed at the 9 on the left side of the problem and the 9 on the right side of the problem (equal addends) and then pointed between the 3 and the 7 twice and then at the blank, the 3, and the 7 (grouping). The child had picked up the correct strategy that the adult displayed uniquely in gesture, which thus makes it clear that children can glean information from adult mismatch.

Discussion

Gesture Offers Adults an Accessible Cue to a Child's Knowledge State

In previous work, we have established that children who produce gesture–speech mismatches when explaining a problem are at a transitional point with respect to that problem. When provided with scripted instruction from an experimenter, children who produce mismatches are more likely to make progress on a problem than are children who do not produce mismatches (Church & Goldin-Meadow, 1986; Perry et al., 1988). Moreover, the information that these transitional children convey in their gesture–speech mismatches is often not found anywhere else in their repertoires. In that sense, this information is at the edge of the child's knowledge. Consequently, a child's gesture–speech mismatches offer one accessible (and spontaneous) index of the child's zone of proximal development, indicating not only that the child is ready to learn but also in which areas the child is ready to receive instruction.

This study constitutes an important extension of the original phenomenon. We have shown here that children who produce mismatches prior to instruction are likely to profit from instruction even when that instruction is provided by adults choosing their own teaching agenda. Our results thus demonstrate the robustness of mismatch in a seminaturalistic teaching situation. Note, however, that unlike in previous experimental studies in which all of the children received the same instruction, in this study the adults were free to alter their instruction according to their impression of the child's initial state. The adults could therefore have contributed to who learned and who did not. In fact, our study was designed to explore just this question—is gesture–speech mismatch an index that someone spontaneously interacting with a child can take advantage of? Our findings suggest that the answer to this question is yes.

[9] If the spoken component of a mismatch always conveyed a correct strategy, the children might have failed to reiterate the strategy simply because correct strategies were not yet in their repertoires. However, the children were less likely to reiterate a spoken strategy when it was accompanied by a mismatching gesture than when it was accompanied by no gesture at all, whether that strategy was a correct, an incorrect, or a building strategy.

Adults Pay Attention to Gesture and Adjust Their Instruction Accordingly

Our results make it clear that the gesture–speech signal children in transition emit is accessible not only to researchers armed with videocameras and slow-motion replay devices but also to adults who are charged with the task of instructing a child on the spot. Adults provide more variable instruction to children who produce gesture–speech mismatches, that is, to children who are themselves variable. This adult variability takes two forms. The adults are more likely to provide a variety of problem-solving strategies (both correct and incorrect) in the instruction overall and a variety of strategies (one in speech and a different one in gesture) within a single utterance.

In previous work on mathematical equivalence, we found that it did little good to instruct children who did not produce mismatches—very few made progress on the task. In contrast, it was quite profitable to offer instruction to children who did produce mismatches (Perry et al., 1988). Interestingly enough, the adults in our current study seemed to know this intuitively. They chose not to flood the unprepared no-mismatch children with too much diversification in their lessons. At the same time, they seemed to understand that the children who produced mismatches were more advanced in their knowledge of mathematical equivalence and could handle—indeed, profit from—variable instruction.

It is possible that this sensitivity to child mismatches is limited to adults who are teachers and who have had experience assessing children's skills and teaching to those skills. However, we think this unlikely. When asked to view videotapes of children solving either math (Alibali et al., 1997) or conservation (Goldin-Meadow et al., 1992) problems, teachers turned out to be no better (and no worse) than undergraduate students at using gesture to assess children's understanding. Thus, it is likely that most adults, regardless of their experience with children, will demonstrate the effect described here and provide more variable instruction to children who produce mismatches than to children who do not.

Were the adults responding to the children's mismatches and not to other child properties? We think so but cannot be certain. The number of different types of strategies and the proportion of mismatches that the adults produced did correlate with the proportion of mismatches the children produced during instruction (and, importantly, not with the number of different types of strategies that the children produced). However, the adults could have been responding to the fact that the mismatching children were gesturing rather than to the fact that those gestures conveyed a different strategy from the one conveyed in the accompanying speech. Although this is possible, we did find that only child mismatch—and not child match—predicted adult mismatch during instruction. Thus, it was the mismatch between gesture and speech, not the presence of gesture with speech, that was related to the adults' instructional adjustment. This observation, combined with the fact that the adults paid attention to the children's mismatches (gleaning information equally from gesture and speech), makes it at least plausible that the adults were reacting to child mismatch.

It is clear why an adult might produce a variety of different strategies when instructing a child. But why would an adult present one strategy in one modality and a different strategy in the other modality? In other words, why would an adult produce a gesture–speech mismatch? Children produce a large number of gesture–speech 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. Children who produce mismatches are in a state of cognitive uncertainty, possessing knowledge about the task that they cannot quite organize into a coherent whole. The adults conducting the math tutorials were obviously not at all uncertain about the principle of mathematical equivalence underlying the problems they taught. This difference in cognitive state between adult and child was manifested in the types of mismatches the two produced. Children frequently conveyed information in their mismatches that was not found anywhere else in their repertoires—the adults rarely did. Moreover, the children produced more different types of strategies in their mismatching utterances than in their matching and speech-alone utterances—the adults produced the same number of different types of strategies in all of their utterances. Finally, the children's mismatches contained an equal number of correct and incorrect strategies—the adults' mismatches contained primarily correct strategies.

What then does adult mismatch reflect? Although the adults were not uncertain about the principle underlying mathematical equivalence, they may have been uncertain about how best to teach this principle, particularly in light of all the inconsistent strategies that their mismatching pupils were producing. It is this uncertainty that may then have been reflected in the adults' mismatches. In general, a mismatch reflects the fact that the speaker is holding two ideas in mind—two ideas that the speaker has not yet integrated into a single unit (see Garber & Goldin-Meadow, 2002; Goldin-Meadow, Nusbaum, Garber, & Church, 1993), in this case, a single instructional unit. This way of describing mismatch is, at least plausibly, as applicable to adults when teaching as it is to children when explaining.

Does the Adults' Instruction Promote Learning?

If provided with no instruction whatsoever, children do not make progress on this mathematical equivalence task, whether they produce gesture–speech mismatches or not (Alibali, 1999; Goldin-Meadow & Alibali, 2002). Obviously, the instruction that the adults in our study gave the children had some impact on their progress. The question is whether the instruction the adults gave mismatching children was particularly effective in promoting learning. Offering many different types of solution strategies to a child seems intuitively to be good for learning. Indeed, the literature suggests that having a variety of approaches to a problem in one's repertoire is associated with cognitive change (Siegler, 1994, 1996).[10] But what good can come of offering a child gesture–speech mismatches? Mismatches do expose children to strategies in the gestural modality, and the gestural modality might be more accessible to a child who has not yet mastered the task. However, the gestural strategy could always be presented in a gesture–speech match, which would give the child an opportunity to see the strategy in both the spoken and gestural modalities. Indeed, our

[10] Research on teaching across nations has shown that Japanese students are exposed to more alternative solution methods to math problems than are American students and that they learn more (Stigler & Hiebert, 1999). However, there is as yet no evidence of a causal link between variable instruction and child outcome.

evidence suggests that children pay attention to adult matches and reiterate a spoken strategy more often when it is accompanied by a matching gesture than when it is accompanied by no gesture at all. Perhaps teachers ought to consider increasing the proportion of matches that they produce when instructing children who are on the cusp of learning.

Gesture–speech mismatch does have one unique feature—it makes the contrast between strategies salient by placing two different strategies side by side within a single utterance. Perhaps the contrast highlights the fact that different approaches to the problem are possible—an important concept for children who are grappling with mathematical equivalence. A naturalistic training study of the sort we conducted here cannot determine whether increasing or decreasing mismatches in instruction is good for learning, nor can it tell us whether increasing the number of different types of strategies in instruction promotes learning. In future work, our plan is to return to an experimental training study design and expressly provide children with variable versus nonvariable input to explore the effect of each on learning. Our goal would be to determine whether variability within a modality (i.e., many different types of strategies expressed in speech across problems) and variability across modalities (i.e., a gesture–speech mismatch in which gesture presents one strategy type and speech presents another on a single problem) are equally effective in promoting learning.

There are hints from the data we collected in this study that both types of variability may promote learning. We divided children into those who received more different types of strategies than the average (four and above) or fewer than the average (below four) and calculated their scores on the posttest. Children receiving many types performed better on the posttest than children who received few (2.75 vs. 1.17). We did the same analysis for mismatches and found that children who received a larger proportion of mismatches (.08 and above) performed better on the posttest than children who received a smaller proportion (2.54 vs. 1.72). Moreover, children who received many types *and* many mismatches did better on the posttest (3.00) than children who received many types *or* many mismatches (2.00), who, in turn, did better than children who received few types and few mismatches (1.31). The fact that adult instruction and child initial state were confounded in this study—precisely the phenomenon reported here—makes it impossible to draw any firm conclusions about the effect of variability in instruction on learning. Nevertheless, the trends in our data suggest that an experimental study in which variability of instruction is manipulated would be of great interest.

Conclusion

At first glance, it may seem that the phenomenon we have described here—that adults react to child mismatch—is no different from adults reacting in a constructive way to a child's explicitly saying "I don't know." However, the phenomenon goes beyond this rather obvious process in two ways. First, the mismatching child is not really conveying ignorance—rather, the child is in effect saying "I know two different ways of solving this problem," one explicitly expressed in speech and the second conveyed through gesture. Adults respond to this variability in strategies with variability of their own. Note, however, that the phenomenon we have described can take place only if adults are attuned to children's gesture. Thus, the second way in which our phenomenon differs from a child's saying "I don't know" is that the information about the child's cognitive state is conveyed sub rosa— below the surface of ordinary conversation. Nonetheless, gesture–speech mismatch may well have consequences for learning.

Although it is rarely acknowledged explicitly in the course of conversation, gesture is always "out there." Gestures are concrete manifestations of ideas for all the world to see. When a child's gestures convey information that is different from the information found in the child's speech, those gestures can inform an adult of thoughts that the child has but cannot (or at least does not) express in speech. Gesture may therefore be one of the best ways that we have of discovering thoughts that are on the edge of a child's competence—the child's zone of proximal development (Vygotsky, 1978).

Gesture is an excellent tool for researchers to use in making inferences about a child's up-to-the-minute knowledge of a task. But gesture can have a wider reach, as we have shown here. Adults interacting with children are sensitive to the signal available in those children's gestures and alter their instruction accordingly— they offer more variable instruction to children who are ready to learn. Children are thus able to shape their own learning environments just by moving their hands. In this way, gesture not only reflects a child's understanding of a task but also plays a role in eliciting input that could shape that understanding. Gesture may be part of the mechanism that brings about cognitive change.

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