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Gesture's Role in the Learning Process

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. Teachers, when explaining problems to a child, also convey information in both speech and gesture. Thus, there is an undercurrent of conversation that takes place in gesture alongside the acknowledged conversation in speech. This article shows that these gestures can play a crucial, although typically unacknowledged, role in teaching and learning.

A STUDENT WAVES HER HAND wildly in the air. Another shrinks in his seat trying to stay out of sight. Both are letting the teacher know whether they want to answer her question. Such acts are part of what is called nonverbal communication. A wide-ranging array of behaviors count as nonverbal communication—the home and work environments we create, the distance we establish between ourselves and our listeners, whether we move our bodies, make eye contact, or raise our voices—all collaborate to send messages about us. But these messages, while clearly important in framing a conversation, are not the conversation itself.

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The nonverbal behavior that I focus on in this article—gesture—is, in contrast, part of the conversation. Gestures are hand movements that accompany and are directly tied to speech. They can point out referents of speech or exploit imagery to elaborate the contents of speech. Take, for example, a child who says that the way to get to her classroom is to go upstairs and illustrates the path by moving her hand in an upward arc. Gesture can convey a child's thoughts. More strikingly, gesture can at times convey thoughts that the child does not express in speech and may, as a result, play a role in learning.

This article has several goals, all designed to elucidate gesture's role in the learning process. I first explore the diagnostic value of the gestures children produce in a learning situation; that is, I ask what a teacher might learn about a child's knowledge state from observing that child's gestures. I then ask whether teachers actually take advantage of this information. Do they, for example, alter their instruction in response to the gestures that their students produce? We will find that they do, and that they adjust not only their words but also their own gestures. This finding paves the way for the next question: Do the gestures that teachers produce have pedagogical value; do they promote child learning? I end by considering whether it would be beneficial for teachers to be more aware of the gestures that crop up in a learning situation, their own and those of their students.

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What Can We Learn From Children's Gestures?

We all know that nonverbal behavior can give us away. A smile, for example, can reveal our pleasure with an outcome despite verbal protestations to the contrary. What many people do not instinctively realize is that nonverbal behavior—gesture, in particular—can reveal thoughts as well as feelings. For example, a child in a sixth-grade science lesson on the seasons used both hands to produce a symmetrical gesture, laying down temperature bands on either side of the equator and thus revealing, through her hands, knowledge of the symmetry of the hemispheres (Crowder & Newman, 1993). In general, the gestures that a child produces in a problem-solving situation often provide insight into the way that child represents the problem.

Gesture and speech encode meaning differently (Goldin-Meadow, 2003; McNeill, 1992). Gesture conveys meaning globally, relying on visual and mimetic imagery. Speech conveys meaning discretely, relying on codified words and grammatical devices. Because gesture and speech employ such different forms of representation, it is difficult for the two modalities to contribute identical information to a message. Nonetheless, the information conveyed in gesture and speech can overlap a great deal. For example, consider a child who utters the word "chair" while pointing at the chair. The word labels and, thus, classifies the object. The point indicates where the object is. Although word and gesture don't convey identical information, they do work together in this example to more richly specify the same object.

However, there are instances when gesture conveys information that overlaps very little with the information in the accompanying speech. Consider a child who says "daddy" while pointing at a chair. This child has produced a gesture for an object that is not mentioned in speech. Here, word and gesture convey information that does not overlap at all. Note, however, that taken together the two modalities convey a simple notion—"daddy's chair"—that is not conveyed in either modality on its own.

I have posited a continuum based on the overlap of information conveyed in gesture and speech (Goldin-Meadow, 2003). At one end of the continuum, gesture elaborates on a topic that has already been introduced in speech. At the other end, gesture introduces new information that is not mentioned at all in speech. Although at times it is not clear where to draw a line to divide the continuum into two categories, the ends of the continuum are obvious and relatively easy to identify. We have dubbed cases in which gesture and speech convey overlapping information "gesture-speech matches," and cases in which gesture and speech convey nonoverlapping information "gesture-speech mismatches" (Church & Goldin-Meadow, 1986).

As an example of a gesture-speech match, consider the response given by a school-aged child when asked to explain his incorrect solution to the mathematical equivalence problem, $7 + 6 + 4 = 7 + \_\_$. The child indicated that he solved the problem by adding up the numbers on the left side of the equation in both speech ("I added 7 plus 6 plus 4 and got 17") and gesture (point at the left 7, the 6, the 4, and the blank). As an example of a gesture-speech mismatch on this same problem, another child indicated in speech that she also solved the problem by adding up the numbers on the left side of the equation ("I added 7 plus 6 plus 4 and got 17"). However, in gesture, this child indicated all of the numbers in the problem (point at the left 7, the 6, the 4, the right 7), thus making it clear that she did, at some level, know that the 7 on the right side of the equation was there and might be important. Note that this second child seems to have an understanding (however implicit) of two pieces of information: (a) there are two distinct sides to the equation, reflected in the add-to-equal-sign strategy the child conveyed in the speech component of her mismatch; and (b) there is an additional addend on the right side of the equation, reflected in the add-all-numbers strategy she conveyed in the gesture component of her mismatch. These two pieces of information are not yet integrated into a single framework but will need to be for the child to solve the problem correctly.

As another example of gesture-speech match and mismatch, consider a younger child asked first whether the number of checkers in two identical rows is the same, and then whether the number of checkers in one of the rows changes after the checkers in that row have been spread out. The child says that the number of checkers in the two rows is the same at the beginning, but that they are different after the spreading-out transformation. When asked to explain this answer, this particular child focuses on the teacher's movements in both speech and gesture. He says that the number of checkers is different "cause you moved them out" while producing a spreading-out motion with his hands. The child is thus conveying a justification in speech that overlaps a great deal with the justification in gesture—a gesture-speech match (see Figure 1a).

In contrast, another child gives precisely the same explanation in speech (it's different "cause you moved them") but conveys the principle of one-to-one correspondence in gesture—he moves a pointing hand between the checkers in one row and the checkers in the other row (Figure 1b). This child is focusing on the teacher's movements in speech but on checker pairs in gesture. He has produced a gesture-speech mismatch. Here again, the child does not yet seem to have integrated the pieces of information conveyed in his gesture and speech. At some point, however, he must come to understand the relation between these pieces of information—that the pairing of checkers does not change when the checkers are moved—in order to master conservation of number.

Children who produce mismatches in their explanations of a task have information relevant to solving the task and could, as a result, be on the cusp of learning the task. If so, they may be particularly susceptible to instruction. To explore this hypothesis, we gave 9- to 10-year old children instruction on problems of the 4 + 5 + 3 = __ + 3 variety. Prior to instruction, all of the children solved the problems incorrectly and all of their spoken explanations were incorrect. However, the children differed with respect to their gestures: some produced gestures that did not match their speech, whereas others produced matching gestures. After the instruction period, we gave the children a second test to see how much they learned. We found that children who produced mismatches prior

(a)

(b)

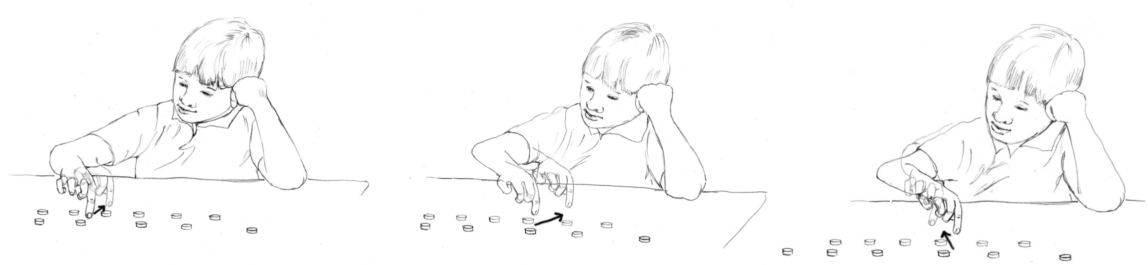

Figure 1. Examples of Children Explaining Why They Think the Number of Checkers in the Two Rows is Different. Both children say that the number is different because the experimenter moved the checkers in one row. The child in the top picture (a) conveys the *same* information in gesture (he produces a "spreading-out" motion); he has produced a gesture-speech match. The child in the bottom pictures (b) conveys *different* information in gesture (he aligns the checkers in one row with the checkers in the other row); he has produced a gesture-speech mismatch.

to instruction were more likely to profit from instruction than children who produced no mismatches (Alibali & Goldin-Meadow, 1993; Perry, Church, & Goldin-Meadow, 1988). To test the generality of this finding, we conducted a comparable study with 5- to 8-year-old children. We gave children, none of whom had mastered conservation, instruction in conservation. We found once again that children who produced mismatches prior to instruction were more likely to profit from instruction than children who produced matches (Church & Goldin-Meadow, 1986)—they were ready to learn. Gesture-speech mismatch can therefore serve as an index of a child's readiness to learn a particular task. Moreover, because the gestures in a mismatch convey substantive information that is *not* found in speech (e.g., one-to-one correspondence in Figure 1b), mismatches provide insight into children's newest and not-yet-digested notions, notions that their teachers might want to consider teaching next.

Do Teachers Use the Information Conveyed in a Child's Gestures?

Gesture-speech mismatches are not limited to a particular age or task, nor are they characteristic of particular individuals. Moreover, gesture-speech mismatch is not a personality trait—the same child who produces many mismatches on one task can produce none on another (Perry et al., 1988). Gesture-speech mismatch indicates when a particular child is ready to profit from instruction on a particular task. In this way, gesture offers information that could prove useful to teachers when instructing children. Can teachers take advantage of the information conveyed in gesture?

We know that researchers are able to interpret a child's gestures and make inferences about what that child knows. But researchers are armed with video-cameras and plenty of time. In order for gesture to be useful in the classroom, teachers have to be able to read gestures in real time without benefit of instant replay. Do teachers notice their students' gestures? To find out, we observed eight teachers instructing children individually in the concept of mathematical equivalence (Goldin-Meadow & Singer, 2003; see also Goldin-Meadow, Wein, & Chang, 1992, and Alibali, Flevares, & Goldin-Meadow, 1997). As we expected, the children's gestures often revealed knowledge that they did not seem to know they had. Consider, for example, a child explaining how he solved the math problem 4 + 5 + 3 = __ + 3. The child said, "I added 4 plus 5 plus 3 plus 3 and got 15," demonstrating no awareness that this is an equation bifurcated by an equal sign. His gestures, however, offered a different picture: He swept his left palm under the left side of the equation, paused, then swept his right palm under the right side. His gestures clearly demonstrated that, at some level, he knew that the equal sign breaks the string into two parts. The question we asked was whether teachers offer a different type of instruction to children who produce gesture-speech mismatches than to children who do not.

The answer is yes. The teachers gave more variable instruction to children who produced mismatches than to children who produced no mismatches in two respects (Goldin-Meadow & Singer, 2003). First, they presented more different types of strategies for solving the math problem in their instructions to children who produced mismatches. Second, they produced more of their own mismatches (i.e., more instructions containing two different strategies, one in speech and one in gesture) to children who produced mismatches than to those who didn't. Most of the teachers' mismatches contained correct strategies in both gesture and speech. For example, on the problem 7 + 6 + 5 = __ + 5, one teacher expressed an equalizer problem-solving strategy in speech ("we need to make this side equal to this side") while conveying a grouping strategy in gesture (point at the 7, the 6, and the blank; the two numbers that give the correct answer if grouped and added together). Both strategies lead to correct solutions, yet do so via different routes.

It is not difficult to imagine why a teacher might instinctively provide a variety of approaches to a problem when instructing a child who is on the cusp of grasping that problem. Indeed, the literature suggests that having many approaches to a problem in one's repertoire is associated with cognitive change (Siegler, 1994, 1996). It is more difficult to imagine why a teacher would produce mismatches. In general, a mismatch reflects the fact that a speaker is holding two ideas in mind that have not yet been integrated into a single unit (Garber & Goldin-Meadow, 2002; Goldin-Meadow, Nusbaum, Garber, & Church, 1993). Certainly the teachers all understood the principle of mathematical equivalence. However, they may have been uncertain about how best to *teach* this principle, particularly in light of the multiple strategies that their mismatching pupils were producing. It is this uncertainty that may be reflected in a teacher's mismatches.

We do not know why teachers produce mismatches. But the fact that they produce mismatches differentially when teaching children who themselves produce mismatches makes it clear that the teachers do notice, and react to, their student's gestures. In addition, we have found instances where a teacher's next instructional strategy seems to be in direct response to the student's gestures. For example, one child solved the problem 7 + 6 + 5 = __ + 5 incorrectly and produced the following gesture-speech mismatch to explain his solution. 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). The teacher responded by ignoring the child's incorrect spoken explanation and focusing on the child's gestures. She 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 teacher appeared to use the child's gestures as the basis for her next instructional step. She covered the two numbers that the child had indicated (two numbers that give the correct answer if added together), thereby forcing the child to notice that there was a 5 on each side of the problem.

There is no particular reason to believe that this type of teacher responsiveness is limited to the gestures children produce in math lessons. It is therefore likely that children's gestures play a role in shaping the type of instruction they receive in a variety of subject areas, at least when that instruction takes place in one-on-one tutorials. But what about the classroom? Could the gestures that children produce have an impact on what teachers choose to teach groups of children? A teacher cannot take the needs of every student in a class into account when deciding what to teach and how to teach it. Nonetheless, if teachers are relying on the verbal reactions they get from their students to calibrate their instruction to the group, they can at the same time pay attention to the *gestures* that their students produce. Indeed, asking children for verbal explanations during a lesson could be an excellent teaching tool, effective not only in giving students an immediate opportunity to react to the lesson but also in eliciting gestures from those students. In our current work, we have begun to explicitly ask children to move their hands as they explain a problem. Children have no trouble doing so and, in fact, express more different types of problem-solving strategies than they did before they were asked to move their hands (Broaders & Goldin-Meadow, 2002). Whether this influx of strategies means that the children will be more ready to profit from instruction in the task is a question for future research. However, at the least, we know that asking children (alone or in groups) to move their hands as they explain a problem can provide teachers with a window into their students' burgeoning thoughts.

Do Teachers' Gestures Promote Learning?

Teachers can use their students' gestures to discover the thoughts those students are unable to express in words. But students are not the only ones who gesture; teachers gesture, too. Do teachers' gestures play a role in teaching and in learning?

The first question is, do teachers use gesture in their classrooms? Gesture crops up in talk about topics that are frequently taught in schools; for example, counting (Graham, 1999), addition (Alibali & Goldin-Meadow, 1993; Perry et al., 1988), control of variables (Stone, Webb, & Mahootian, 1991), gears (Perry & Elder, 1997), rate of change (Alibali, Bassok, Olseth, Syc, & Goldin-Meadow, 1999). It should come as no surprise, then, that gesture also crops up in classrooms, particularly in classrooms of experienced teachers (Neill & Caswell, 1993). Consider a history teacher who describes where a set of trenches were dug during World War I in speech, but indicates the zig-zagging course the trenches took in gesture (Neill & Caswell, 1993). Teachers gesture in classrooms. But is gesture used often enough to make a difference?

We have found that in a one-on-one math tutorial situation, teachers express 40% of the problem-solving strategies they convey to their students in gesture (Goldin-Meadow, Kim, & Singer, 1999), which is quite a lot. And gesture is equally frequent in the classroom. Flevares and Perry (2001) found that math teachers used from five to seven nonspoken representations of mathematical ideas per minute (almost one every 10 seconds), and gesture was by far the most frequent nonspoken form for all of the teachers (the others were pictures, objects, and writing). Moreover, when the teachers combined two or more nonspoken representations, one of those forms was always a mathematically relevant gesture. Gesture was the glue that linked the different forms of information to one another and to speech. Interestingly, the teachers often used their nonspoken representations strategically, responding to a student's confusion with a nonspoken representation. The teachers would repeat their own speech while clarifying the meaning of their utterance with gesture. And it seemed to work; the children would frequently then come up with the correct answer.

Thus, teachers use gesture in the classroom (at least in science and math classrooms and probably in all classrooms), and they seem to use it to good effect to clarify and correct misconceptions. However, we don't yet know whether the gestures that teachers produce on a task lead children to improve their performance on that task the next time around. The few experimental studies that have been done suggest that a lesson accompanied by gesture is more effective than that same lesson not accompanied by gesture (Church, Ayman-Nolley, & Mahootian, 2004; Perry, Berch, & Singleton, 1995; Valenzeno, Alibali, & Klatzky, 2003). But much more work needs to be done before we fully understand the conditions under which gesture promotes learning. Take, for example, the role of gesture-speech mismatches in instruction. We might have guessed that gesture would get in the way of learning when it conveys information that is different from the information conveyed in speech; that is, when it mismatches speech. But the teachers in our math study frequently produced gesture-speech mismatches when teaching children who produced their own mismatches, and those children were the ones who profited from their instruction (Goldin-Meadow & Singer, 2003). These findings suggest that mismatch isn't necessarily bad for learning and may even be good for it.

Indeed, in our current work we are finding that presenting two strategies in a gesture-speech mismatch (one strategy in speech and a different strategy in gesture) is much more effective than presenting those same two strategies in speech alone (Singer & Goldin-Meadow, in press). More generally, recommendations for math curricula encourage teachers to present ideas through a variety of representations—diagrams, physical models, written text (NCTM, 1989). Shavelson, Webb, Stasz, and McArthur (1988), among others, recommend that teachers translate among alternative symbolic representations of a problem (e.g., math symbols and number line) rather than working within a single symbolic form. Gesture can serve as one of these representational formats, one that has a strong visual component. Gesture is unique, however, in that unlike a map or a diagram, it is transitory—disappearing in the air just as quickly as speech. But gesture also has an advantage—it can be, indeed *must* be, integrated temporally with the speech it accompanies. And we know that it is important for visual information to be timed appropriately with spoken information in order for it to be effective (Baggett, 1984; Mayer & Anderson, 1991). Thus, gesture used in conjunction with speech may present a more naturally unified picture to the student than a diagram used in conjunction with speech. If gesture were to become recognized as an integral—and inevitable—part of conversation in a teaching situation, it could offer teachers an excellent vehicle for presenting to their students a second perspective on the task at hand.

Should Teachers Be Made Aware of Gesture?

The gestures that children produce can signal to their teachers what they know and don't know about a task. We have shown that teachers can glean information from these gestures and adjust their teaching accordingly. But they don't do it all of the time. Moreover, some teachers may be better at gesture-reading than others. Can we help teachers improve their rates of gesture-reading which, in turn, might help them get as much as they can out of their students' hands?

There have been some successful attempts to train teachers to pay attention to their students' nonverbal cues in general (Jecker, Maccoby, & Breitrose, 1965; Machida, 1986) and gestures in particular (Kelly, Singer, Hicks, & Goldin-Meadow, 2002). For example, in a series of studies, we gave adults instruction in how to read the gestures that children produce on either conservation or mathematical equivalence tasks (Kelly et al., 2002). In some studies, we tested the adults' ability to read gesture by giving them a checklist on which they were to indicate the information the child on a videotape had expressed. In others, we asked them to tell us what they thought the children knew about the task. We gave the adults a pretest, then gave them instruction, and finally tested them once again on a posttest. We varied our instruction from just giving a hint ("pay close attention not only to what the children on the videotape say with their words, but also to what they express with their hands"), to giving general instruction in the parameters that experts use when describing gesture (handshape, motion, placement), to giving specific instruction in the kinds of gestures children produce on that particular task.

We found that the adults improved with instruction, even with just a hint. They picked up 30% more explanations that the child had expressed uniquely in gesture after getting a hint to attend to gesture, and 50% more after getting specific instruction in the gestures on the task. Moreover, the adults were able to generalize the instruction they received to new gestures they had not seen during training. It is particularly promising that merely suggesting to adults that they pay attention to a child's gestures improves their ability to get information from them. At the least, it seems worthwhile to make teachers aware of the fact that their students may convey useful information in their gestures. It may even be worthwhile to give teachers specific instruction in how to glean information from gesture, although this approach might require an understanding of how gesture is used on particular tasks.

The flip side of the question is whether teachers should be made aware of the gestures they themselves produce in the classroom. We know that children pay attention to their teachers' gestures, often picking up task-relevant information from those gestures (Goldin-Meadow et al., 1999). But there are times when a teacher's gestures can lead a child astray. Take the following interchange that occurred when we asked teachers to instruct children individually in mathematical equivalence. The teacher had asked the child to solve the problem $7 + 6 + 5 = \_\_ + 5$ and the child put 18 in the blank, using an incorrect add-to-equal-sign strategy to solve the problem. In her speech, the teacher pointed out the strategy that the child was using; she said "so you got this answer by adding these three numbers." However, in her gestures, she produced an add-all-numbers strategy. She pointed at the 7, the 6, the 5 on the left side of the equation *and* the 5 on the right side of the equation. After these gestures, the teacher went on to try to explain how to solve the problem correctly but, before she could finish, the child offered a new solution, 23, precisely the number you would get if you added up all of the numbers in this problem. The teacher was genuinely surprised at her student's answer, and was completely unaware of the fact that her hands might have given him the idea to add up all of the numbers in the problem. In this instance, the teacher's instruction might have been more effective had she monitored her own gestures.

Although rarely acknowledged in the course of conversation, gesture is always out there. Gestures are concrete manifestations of ideas for all of the world, including the world of education, to see. Students produce gestures that can reveal to their teachers thoughts that are on the edge of their competence. And teachers produce gestures that can have an impact on what their students take from a lesson. What we need to find out is whether asking teachers to focus on their gestures will make them more likely to use those gestures to good effect. It is time to acknowledge that the hands have a role to play in teaching and learning.

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