Research Report

Children Learn When Their Teacher's Gestures and Speech Differ

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ABSTRACT—***Teachers gesture when they teach, and those gestures do not always convey the same information as their speech. Gesture thus offers learners a second message. To determine whether learners take advantage of this offer, we gave 160 children in the third and fourth grades instruction in mathematical equivalence. Children were taught either one or two problem-solving strategies in speech accompanied by no gesture, gesture conveying the same strategy, or gesture conveying a different strategy. The children were likely to profit from instruction with gesture, but only when it conveyed a different strategy than speech did. Moreover, two strategies were effective in promoting learning only when the second strategy was taught in gesture, not speech. Gesture thus has an active hand in learning.***

People gesture when they talk. Even teachers routinely produce gestures as they instruct children in both individualized tutorials (Goldin-Meadow, Kim, & Singer, 1999) and the classroom (Crowder & Newman, 1993; Flevares & Perry, 2001; Neill, 1991; Roth & Welzel, 2001; Zukow-Goldring, Romo, & Duncan, 1994). And children pay attention to those gestures, often gleaning substantive information from gesture that cannot be found anywhere in the teacher's speech (Goldin-Meadow et al., 1999). Gesture is thus present and salient in teaching situations. The question we addressed in this study is whether gesture promotes learning.

Gesture conveys information in a visuospatial format (McNeill, 1992). Previous work suggests that when visual images are presented simultaneously with a spoken message, listeners do better at remembering the message (Baggett, 1984) or solving problems with information contained in the message (Mayer & Anderson, 1991). Because gesture is produced simultaneously with speech, it allows speakers to present visual information at the same time as, indeed synchronized with, their words (Kendon, 1980; McNeill, 1992; Morrel-Samuels & Krauss, 1992). One might therefore expect gesture to be effective in getting a message across to learners, particularly when gesture reinforces the message conveyed in speech. And, indeed, researchers have found that spoken instruction presented with gesture promotes learning better than the same spoken instruction presented without gesture (Church, Ayman-Nolley, & Estrada, 2004; Perry, Berch, & Singleton, 1995; Valenzeno, Alibali, & Klatzky, 2003).

However, the information conveyed in gesture does not always match the information conveyed in the speech it accompanies (Goldin-Meadow, 2003; Goldin-Meadow, Alibali, & Church, 1993). For example, when giving a child instruction in how to solve the problem $7 + 6 + 5 = \_\_ + 5$, a teacher articulated the equalizer problem-solving strategy in speech: "We need to make this side equal to this side." At the same time, she conveyed a grouping strategy in gesture: She pointed at the 7 and the 6 on the left side of the equation and then at the blank on the right side (7 and 6 are the two numbers that, if grouped and added, give the correct answer). The two strategies lead to correct solutions yet do so via different routes and, in this sense, constitute a "mismatch." Gesture-speech mismatch occurs when gesture conveys information that is different from (although not necessarily contradictory to) the information conveyed in the speech it accompanies (Goldin-Meadow, 2003). Gesture-speech mismatches are produced by speakers of all ages and in a variety of tasks (Alibali, Bassok, Olseth, Syc, & Goldin-Meadow, 1999; Garber & Goldin-Meadow, 2002; Gershkoff-Stowe & Smith, 1997; Pine, Lufkin, & Messer, 2004; Schwartz & Black, 1996; Stone, Webb, & Mahootian, 1991) and are frequently found in teaching situations. In fact, teachers spontaneously increase the number of gesture-speech mis-

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TABLE 1
Examples of the Strategies Taught in Speech and Gesture

Sample problem: 6 + 4 + 3 = __ + 3
Equalizer in speech: "We can add 6 + 4 + 3, which equals 13. We want to make the other side of the equal sign the same amount, and 10 + 3 also equals 13, so 10 is the answer."
Equalizer in gesture: Sweep with palm under left side of problem, drop hand, sweep with palm under right side.
Add-subtract in speech: "We can add 6 + 4 + 3, which equals 13. We then subtract the other 3 from 13 and get 10 as the answer."
Add-subtract in gesture: Point at the 6, the 4, and the left 3, then produce a flick-away gesture near the right 3.

Note. On all trials, the experimenter gave the correct answer in her explanation but did not write it in the blank.

matches in their instruction when teaching children who are on the cusp of learning the task (Goldin-Meadow & Singer, 2003). But just because mismatches are found in teaching situations does not mean they are good for learning.

Why might one expect gesture-speech mismatch to promote learning? Mismatching gesture allows speakers to add a second problem-solving strategy to an instruction. Given that having a variety of approaches to a problem is positively associated with cognitive change (Siegler, 1994), it might be beneficial for learners to be exposed to multiple problem-solving strategies. Indeed, studies of teaching across nations have found that students in Japan are exposed to more alternative methods for solving math problems than are students in America, and they learn more (Stigler & Hiebert, 1999)—although there is as yet no evidence of a causal link between multiple approaches in instruction and children's outcomes.

We asked two questions in this study: (a) Does teaching children more than one strategy for solving a problem facilitate their mastery of the problem? (b) Does it matter whether those strategies are presented in speech, in gesture, or in both speech and gesture? To address these questions, we presented children with one or two strategies for solving mathematical equivalence problems and varied whether the spoken instruction was accompanied by matching gesture, mismatching gesture, or no gesture at all.

METHOD

One hundred sixty children (58 boys, 102 girls) who were finishing the third grade or beginning the fourth grade (ages 8–10) in Chicago public and parochial schools participated. The children were randomly assigned to one of six instruction conditions. Each child participated individually in a pretest, an instruction session, and a posttest. During the pretest, the child was given a paper-and-pencil test containing six addition problems and asked to explain at the chalkboard how he or she solved each problem. If the child solved any of the pretest problems correctly, he or she was eliminated from the study. A second experimenter then gave the child instruction in mathematical equivalence using four additional problems. Two instructional trials were given on each of the four problems; after each trial, the child was asked to solve and explain the problem again. After the instruction period, the first experimenter returned and gave the child a posttest comparable to the pretest.

Two problem-solving strategies spontaneously used by teachers when instructing children in mathematical equivalence (Goldin-Meadow et al., 1999; Goldin-Meadow & Singer, 2003) were used to teach the children: (a) equalizer, a strategy highlighting the principle underlying the problem, and (b) add-subtract, a strategy highlighting a procedure for solving the problem. We determined the gestural equivalents of these spoken strategies by examining the gestures children typically produce when expressing equalizer and add-subtract in speech (Perry, Church, & Goldin-Meadow, 1988; Goldin-Meadow, 2003, describes the general procedure used to attribute meaning to gesture). Table 1 presents examples of the two strategies in speech and gesture.

Instruction was organized around two factors, resulting in six conditions (see Table 2). The first factor was the number of strategies taught in speech: In half the conditions, children were taught one strategy in speech, equalizer. In the other half, children were taught two strategies in speech, equalizer and add-subtract. The second factor was the relation between speech and gesture: In the two no-gesture conditions, the experimenter produced no gestures during the instruction. In the two matching-gesture conditions, she produced in gesture a strategy that was the same as the spoken strategy it accompanied. In the two mismatching-gesture conditions, she produced in gesture a strategy that was different from the spoken strategy it accompanied. There were approximately 27 children in each condition (range: 24–31).

Table 2 displays for each condition the strategies taught on the two instructional trials for each problem. In all six conditions, the experimenter taught children the equalizer strategy in speech on a problem's first instructional trial. Depending on the child's condition, the experimenter produced either no gesture, matching gesture (equalizer in gesture), or mismatching gesture (add-subtract in gesture) along with the spoken equalizer strategy. On the problem's second instructional trial, children in the one-strategy-in-speech conditions received the same strategies in speech and gesture as they received on the first trial. Children in the two-strategies-in-speech conditions were taught their second spoken strategy (add-subtract) on the second instructional trial and, depending on their condition, received no

TABLE 2
Design of the Six Instruction Conditions

Gesture condition and trial on each problem	Number of strategies taught in speech: One		Two	
	Speech	Gesture	Speech	Gesture
No gesture				
Trial 1	Equalizer	—	Equalizer	—
Trial 2	Equalizer	—	Add-subtract	—
Matching gesture				
Trial 1	Equalizer	Equalizer	Equalizer	Equalizer
Trial 2	Equalizer	Equalizer	Add-subtract	Add-subtract
Mismatching gesture				
Trial 1	Equalizer	Add-subtract	Equalizer	Add-subtract
Trial 2	Equalizer	Add-subtract	Add-subtract	Equalizer

gesture, matching gesture (add-subtract in gesture), or mismatching gesture (equalizer in gesture) along with this second spoken strategy.

Each session was videotaped, and the experimenter's speech and gestures were spot-checked to be certain they conformed to the child's condition.[1] Because no children solved any problems correctly on the pretest, number of problems correct on the posttest was taken as a measure of learning. Data were analyzed using an analysis of variance with two between-subjects factors: number of strategies in speech (one, two) and relation between gesture and speech (no gesture, matching gesture, mismatching gesture).

RESULTS

Figure 1 presents the number of problems solved correctly on the posttest in each condition.[2] Children performed better on posttest when taught one strategy in speech than when taught two, $F(1, 154) = 4.25$, $p = .04$. The relation between gesture and speech also had an impact on learning, $F(2, 154) = 4.44$, $p = .01$, and did not interact with number of strategies taught in speech, $F(2, 154) = 0.27$, $p = .76$. Mismatching gesture was significantly better as a teaching device than no gesture ($p = .01$, Newman-Keuls) and was also better than matching gesture ($p = .04$). There was no reliable difference between matching gesture and no gesture ($p = .39$).

Surprisingly, teaching children two problem-solving strategies in speech was significantly worse than teaching one strategy (i.e., adding add-subtract to equalizer was less effective than teaching equalizer on its own), suggesting that children may have been overwhelmed by the additional spoken strategy. Note, however, that including a second strategy in instruction was effective when that strategy was presented in gesture. Children in all of the one-strategy-in-speech conditions were taught one spoken strategy; however, those who received mismatching gestures along with their one spoken strategy were actually exposed to a second strategy—but only in gesture. The fact that children in this group did so well on posttest, significantly better than children in all other groups (even those exposed to two spoken strategies), suggests that instruction containing a second strategy can indeed

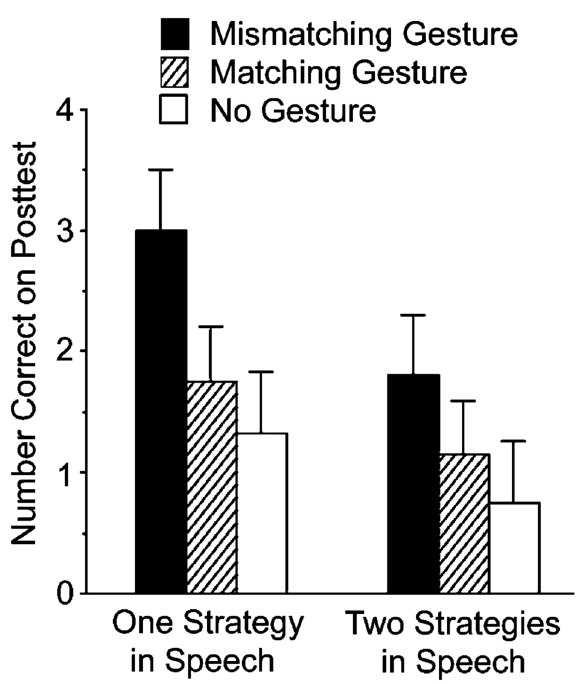

Fig. 1. Number of problems children solved correctly after receiving instruction that contained either one or two strategies in speech and that was accompanied by no gesture, gesture matching the strategy in speech, or gesture mismatching the strategy in speech.

[1]To determine whether the experimenter not only used the same words, but also took the same amount of time to present the spoken strategies in each condition, we calculated time taken to deliver the strategies to 6 children randomly chosen from each of the six conditions; we found no differences in either the one-strategy condition, $F(2, 17) = 0.69$, n.s., or the two-strategy condition, $F(2, 17) = 2.33$, n.s.

[2]Girls performed significantly better than boys on posttest (2.0 vs. 1.2), $F(1, 148) = 3.99$, $p < .05$, but gender did not interact with any of the other factors; data were therefore collapsed across genders for all analyses.

promote learning—as long as that second strategy is produced in gesture and not in speech.

Not only was gesture effective as a teaching device when it conveyed information not found in speech, but it was also effective when it conveyed the same information packaged differently. Note in Table 2 that within the two-strategies-in-speech conditions, children given matching and mismatching gesture were exposed to precisely the same information. The only difference between the two groups was how the information was packaged. In the matching condition, each of the spoken strategies was presented along with the same strategy in gesture. In the mismatching condition, each spoken strategy was presented along with a different strategy in gesture. The mismatching group performed better on posttest, suggesting that mismatch in instruction can promote learning even when type and amount of information are held constant.

DISCUSSION

Teachers gesture when they teach, and those gestures do not always convey the same information as the speech they accompany. Gesture thus offers students a second approach to the problem at hand. Our findings make it clear that children can take advantage of the offer—children profit from gesture when it conveys information that differs from the information conveyed in speech.

Previous research led us to expect that gesture would have a hand in promoting learning. Producing speech with gesture requires less effort on the speaker's part than producing speech without gesture (Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001; Wagner, Nusbaum, & Goldin-Meadow, 2004); gesture might therefore be expected to reduce the effort that listeners expend. Moreover, when children are at a transitional point in acquiring a concept, they often find it easier to produce ideas relevant to that concept in gesture than in speech (Church & Goldin-Meadow, 1986); those same ideas might therefore be expected to be easier to understand in gesture. However, in the present study, gesture per se did not promote learning—only gesture that conveyed mismatching information led to improved performance.

Why might mismatching gesture be such an effective teaching tool? We begin to tackle this question by examining the two strategies used in instruction. These strategies represent different, albeit complementary, approaches to mathematical equivalence. Add-subtract offers an algorithm for solving the problem; equalizer articulates the principle underlying the correct solution. Previous work has found that these two strategies are not equally effective teaching tools—children are more likely to succeed on mathematical equivalence problems when taught the equalizer principle than when taught the add-subtract algorithm (Perry, 1991). Interestingly, however (and as is consistent with our findings), children do less well if taught both principle and algorithm than if taught the principle on its own (Perry, 1991). Offering children a step-by-step algorithm seems to prevent them from attending to the principle they could have profited from. Indeed, when asked to explain their answers to the posttest problems, children in our study were more likely to express the equalizer principle if it was the only strategy taught in speech than if it and add-subtract were both taught in speech (1.74 vs. 0.36 equalizer explanations produced on the posttest per child in the one-strategy-in-speech conditions vs. the two-strategies-in-speech conditions).

But gesture changes the picture. An algorithm detracts from the principle it accompanies only when it is taught in speech—not when it is taught in gesture. Algorithms presented in gesture provide children with a step-by-step procedure to follow but (unlike algorithms presented in speech) do not encourage children to rely exclusively on that procedure. Perhaps because gesture is not as explicit as speech, the information it conveys is less intrusive than information conveyed in speech. In our study, children expressed equalizer in their postinstruction explanations more often if they had been taught equalizer along with add-subtract presented only in gesture (2.54 equalizer explanations in the one-strategy-in-speech condition with mismatching gesture) than if they had been taught equalizer along with add-subtract presented in speech (0.36 in the two-strategies-in-speech condition, with or without gesture)—and, interestingly, also more often than if they had not been taught add-subtract at all (1.27 in the one-strategy-in-speech condition with matching or no gesture). Thus, when an algorithm is taught only in gesture, rather than overpowering the principle it accompanies, it appears to enhance it and render it more accessible to learners.

Gesture seems to be good at making children aware of the synergistic relation between principle and algorithm, perhaps because it allows the two to be presented simultaneously and not sequentially, as would be required by speech on its own. In our study, not only did the equalizer principle benefit from occurring simultaneously with the add-subtract algorithm, but add-subtract also benefited from co-occurring with equalizer. Children were more likely to express add-subtract in their explanations after instruction when add-subtract was taught simultaneously with equalizer, that is, when it was taught in speech (i.e., in the two-strategies-in-speech condition) with mismatching gesture (1.77 add-subtract explanations), than when it was taught in speech with matching gesture (0.81) or no gesture (0.54).[3] Principles and algorithms are interconnected approaches. Presenting them simultaneously—as only speech and gesture can do—highlights the relation between the two and seems, as a result, to facilitate learning.

Whatever the purported mechanism, the phenomenon reported here remains robust. Presenting students two different

[3]Children expressed add-subtract 0.13 times in their posttest explanations when it was not taught at all (i.e., one-strategy-in-speech condition with matching or no gesture), and 0.93 times when it was taught only in gesture and not in speech (i.e., one-strategy-in-speech condition with mismatching gesture).

explanations—one in speech and one in gesture—facilitates their mastery of mathematical equivalence problems compared with presenting either one or two strategies in speech without gesture. Given previous work establishing the breadth and depth of gesture production across many tasks and ages, these data open the possibility for a heretofore unappreciated technique to improve learning in and out of the classroom.

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