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Brief article

Gesturing makes learning last

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Abstract

The gestures children spontaneously produce when explaining a task predict whether they will subsequently learn that task. Why? Gesture might simply reflect a child's readiness to learn a particular task. Alternatively, gesture might itself play a role in learning the task. To investigate these alternatives, we experimentally manipulated children's gesture during instruction in a new mathematical concept. We found that requiring children to gesture while learning the new concept helped them retain the knowledge they had gained during instruction. In contrast, requiring children to speak, but not gesture, while learning the concept had no effect on solidifying learning. Gesturing can thus play a causal role in learning, perhaps by giving learners an alternative, embodied way of representing new ideas. We may be able to improve children's learning just by encouraging them to move their hands.

Keywords: Gesture; Learning; Problem-solving; Instruction; Embodied cognition; Cognitive development; Mathematics

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1. Introduction

People of all ages and cultures spontaneously gesture with their hands when they speak (Feyereisen & deLannoy, 1991). Even blind individuals who have never seen gesture move their hands as they talk (Iverson & Goldin-Meadow, 1998). Moreover, the gestures learners produce when explaining a task predict whether they will soon master that task (Church & Goldin-Meadow, 1986; Perry, Church, & Goldin-Meadow, 1988; Pine, Lufkin, & Messer, 2004), and learners who gesture spontaneously on a task are more likely to retain what they have learned about the task than learners who do not gesture (Alibali & Goldin-Meadow, 1993; Cook & Goldin-Meadow, 2006). These findings suggest that gesturing can promote learning. And, indeed, instruction that includes gesture has been found to facilitate learning (Church, Ayman-Nolley, & Mahootian, 2004; Singer & Goldin-Meadow, 2005; Valenzeno, Alibali, & Klatzky, 2003), perhaps by encouraging learners to produce gestures of their own (Cook & Goldin-Meadow, 2006).

However, all of the work to date that has explored gesture's role in learning has looked exclusively at gestures that learners produce spontaneously, leaving open the possibility that gesture is associated with factors that cause change, rather than being directly involved in the change itself. As a result, it is unclear whether gesturing merely reflects a readiness to learn new knowledge, or is itself actively involved in the construction of new knowledge.

There is some evidence to suggest that gestures can play a role in constructing new knowledge. Meaningful gestures are more frequent when speakers are spontaneously constructing sentences than when they are reciting rehearsed sentences (Chawla & Krauss, 1994). Gestures are also more frequent when speakers are made to reason about a set of objects than when they are instructed to simply describe those objects (Alibali, Kita, & Young, 2000). Gestures have also been shown to be important in accessing stored knowledge. Children who are instructed to gesture while recalling an event report more details about the event than children who are instructed not to gesture (Stevanoni & Salmon, 2005).

However, no experimental work has examined the gestures that learners produce when encoding new information, and whether those gestures influence subsequent recall of the information. If hand gestures merely reflect (and do not alter) one's existing knowledge, then whether or not a learner gestures when encoding new information should have no effect on the acquisition of that new knowledge. In contrast, if gestures play a role in the creation and retention of knowledge, then gesturing when encoding new information should have a demonstrable effect on the acquisition of the new knowledge. In particular, learners should be more likely to acquire a concept if told to produce gestures instantiating that concept during the learning than if told to articulate the concept in speech without accompanying gesture. To explore this prediction, we gave children instruction in a mathematical problem and told them to produce gestures that displayed a strategy for solving the problem. We then compared their improvement after instruction to the progress made by children told to produce spoken words reflecting the same problem-solving strategy.

2. Methods

2.1. Participants

Eighty-four third and fourth grade children were included in the study.

2.2. Pretest

Children completed a pretest consisting of six addition problems with identical addends on each side of the equal sign (e.g., $4 + 3 + 6 = \_\_ + 6$) and were then asked to explain how they solved each of the problems to an experimenter at a board. Only children who did not produce any correct answers or explanations in speech or gesture on the pretest were included in the study.

2.3. Pre-instruction

A second experimenter, the instructor, then demonstrated a behavior and asked the child to mimic that behavior three times. The behavior that the child was asked

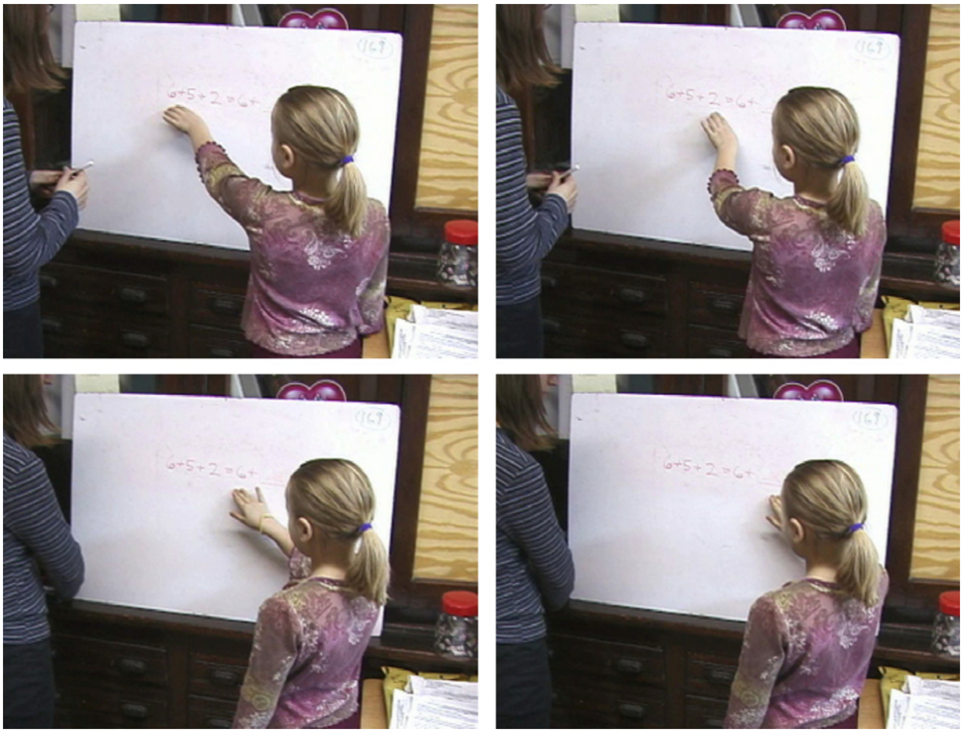

Fig. 1. A child in the *Gesture* group performing the hand movements she had been taught prior to instruction. She moves her left hand under the equation's left side (top two pictures), pauses, then moves her right hand under the equation's right side (bottom two pictures).

to mimic varied across conditions, and was based on the sorts of speech and gestures that are commonly produced by children who solve the math problems successfully. Children were randomly assigned to one of three conditions. In the *Speech* condition ($N = 29$), the instructor said, "I want to make one side equal to the other side," and asked the child to repeat her words. In the *Gesture* condition ($N = 30$), the instructor moved her left hand under the equation's left side, paused, then moved her right hand under the equation's right side, and asked the child to repeat her hand movements (see Fig. 1 for an example of a child reproducing the movements). In the *Gesture + Speech* condition ($N = 25$), the instructor said, "I want to make one side equal to the other side," while moving her left hand under the left side of the equation and then her right hand under the right side of the equation, and asked the child to simultaneously repeat her words and hand movements. During this pre-instruction phase, the instructor did not provide answers to any of the problems, and children did not solve any math problems.

2.4. Instruction

The instructor then taught the child how to use the equalizer strategy to solve six more problems of the same type. For example, after putting the correct answer in the blank for the problem $4 + 9 + 3 = 4 + \_\_$, the instructor said, "I want to make one side (while sweeping the left hand under the left side of the equation) equal to the other side (while sweeping the right hand under the right side); so four plus nine plus three equals sixteen, and four plus twelve equals sixteen; one side (gestures under the left side) is equal to the other side (gestures under the right side)." Note that the experimenter repeated the equalizer strategy in speech and gesture twice on each of the 6 problems, just before and just after adding up the numbers on each side of the equation and arriving at the same sum. Children in all three conditions were thus exposed to the equalizer strategy 12 times in speech and 12 times in gesture during instruction. Providing instruction ensured that all children were exposed to the same spoken and gestured representations of mathematical equivalence, and increased the chances that at least some children would learn how to solve the math problems; without instruction, children usually become entrenched in their incorrect solutions to problems of this type (Goldin-Meadow & Alibali, 2002).

After each of the instructor's 6 problems, the children were given a problem of their own to solve. They were asked to reproduce the behavior they had earlier mimicked (*Speech*, *Gesture*, or *Gesture + Speech*) before solving each of their problems and then again after solving the problem. Children who attempted to produce behav-

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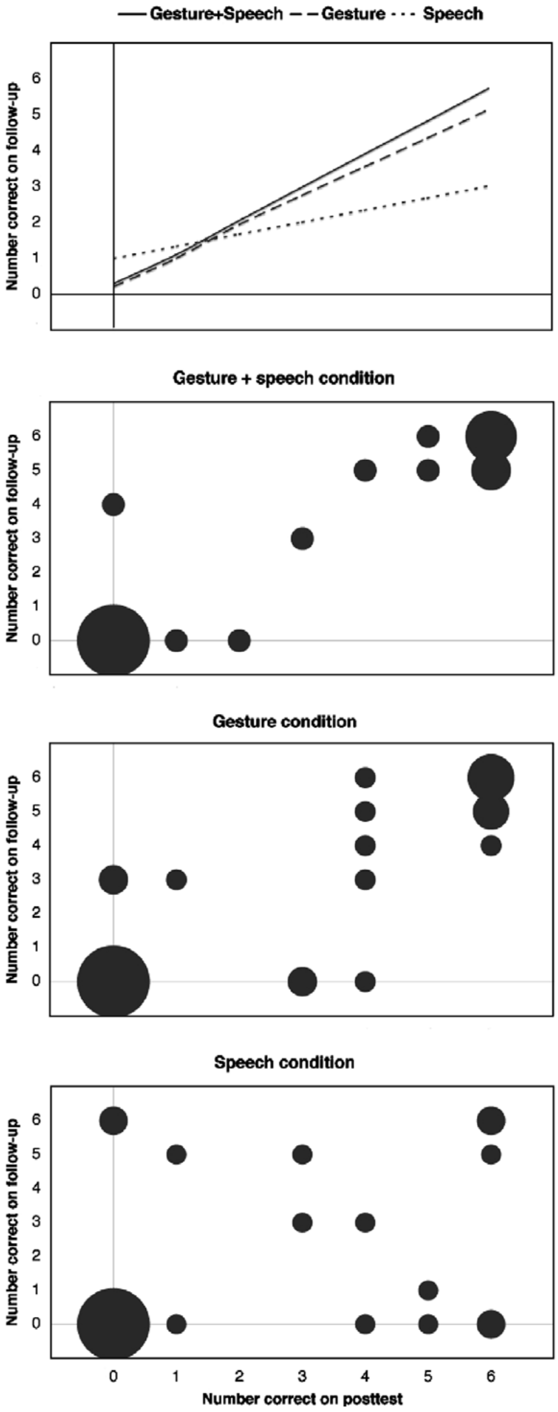
Fig. 2. The top panel displays regression lines relating performance on the 4-week follow-up to performance on the immediate posttest. The bottom three panels display scatterplots of the number of problems solved correctly on the follow-up test and the posttest by condition (*Gesture + Speech*, *Gesture*, *Speech*). The size of the dot at each point represents the number of children who fell at that point. Follow-up performance could be predicted from posttest performance in the *Gesture + Speech* and *Gesture* conditions, but not in the *Speech* condition, suggesting that children retained their new knowledge only when they gestured during learning.



Gesture + speech condition

Gesture condition

Speech condition

iors other than the behavior they had been shown during pre-instruction were immediately stopped and reminded to produce only the behaviors they had been told to repeat. Thus, children in the *Gesture* and *Gesture* + *Speech* groups produced the equalizer strategy in gesture 12 times during instruction (twice on each of 6 problems); children in the *Speech* group never produced the equalizer strategy in gesture but produced it in speech 12 times (as did the *Gesture* + *Speech* group).

2.5. Posttest

Immediately after the instruction period, children completed a posttest similar to the pretest and administered by the first experimenter.

2.6. Follow-up test

Approximately four weeks later, children completed a follow-up test similar to the pre- and posttest but in a new context. This test was administered by the child's classroom teacher over the course of a normal school day. Teachers were instructed not to mention the experiment when administering the test and not to assist the students in solving the problems.

3. Results

All of the children improved with instruction (recall that none had solved any of the problems correctly on the pretest). Children in the three groups solved comparable numbers of problems correctly during instruction (*Gesture* 2.3, *Gesture* + *Speech* 2.8, *Speech* 1.8, $F(2, 82) = 1.12$, ns) and on the immediate posttest (*Gesture* 2.6, *Gesture* + *Speech* 2.7, *Speech* 2.0, $F(2, 82) = 0.52$, ns). Thus, the behaviors that children learned during pre-instruction and reproduced during instruction did not reliably affect children's understanding of the experimenters' instructions. However, the three groups did differ in how well they maintained the knowledge gained during instruction.

If children retained the knowledge learned during the math lesson, we should be able to predict their performance on the follow-up test 4 weeks after instruction from their performance on the posttest immediately following instruction. We used a regression model to predict follow-up test performance, using posttest performance and condition (*Speech*, *Gesture*, *Gesture* + *Speech*) as factors.[1] As is evident in Fig. 2, regression coefficients differed across the three groups ($F(2, 78) = 5.79$, $p = .0045$).

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[1] We used multiple regression to explore our data, rather than an ANOVA with condition and time of test as factors, because treating the data in this way increases statistical power. Because the regression coefficients between posttest and follow-up are less than 1, including posttest in the regression decreases the size of the error term, in comparison with a traditional repeated measures analysis (see Girden, 1992, p. 58), albeit at the cost of a degree of freedom. In addition, this type of model seemed to better capture the shape of the data.

The unique predictive power was significantly greater for the *Gesture* ($\beta = .80$, $t(28) = 7.94$, $p < .0001$) and *Gesture* + *Speech* ($\beta = .92$, $t(23) = 12.00$, $p < .0001$) groups than for the *Speech* group ($\beta = .33$, $t(27) = 1.89$, $p = .069$); $t(78) = 2.64$, $p < .01$ and $t(78) = 3.22$, $p < .01$, respectively. Reiterating the instructor's words did not appear to be particularly effective in helping children retain knowledge they had apparently learned – unless those words were accompanied by gesture. Interestingly, the unique predictive power was not reliably different for the *Gesture* and *Gesture* + *Speech* groups ($t(78) = 0.69$, ns). In both of these groups, there was a strong relation between posttest and follow-up performance; children in these conditions who improved on posttest tended to maintain their gains on follow-up. And the effect was robust – children told to gesture during instruction retained 85% of their posttest gains, on average, compared to 33% for children told to speak and not gesture.

In the *Speech* group, the relation between instruction and learning was relatively weak. In this condition, many children who had improved after instruction failed to maintain their gains on follow-up (lower-right dots in bottom scatterplot, Fig. 2). In addition, there were children who improved on follow-up but had not improved immediately after instruction (upper-left dots in bottom scatterplot, Fig. 2), suggesting that, although these children were ready to learn the concept, our lesson and the instructions to mimic speech had little to do with their improvement.[2] These two patterns are not seen in either of the groups instructed to produce gestures.

We see the same pattern of performance when we look at children's maintenance of learning over time categorically. We categorized children as learners if they solved more than half of the posttest problems correctly.[3] We then asked how many of these learners retained their newly formed knowledge through to the follow-up. (i.e., how many solved more than half of the problems correctly on the follow-up test). We used Fisher's Exact Test to explore whether there were differences in the likelihood of retaining learning across conditions, and found a significant difference across conditions ($N = 33$, $p < .01$). Children in the *Gesture* + *Speech* (11 of 11) and *Gesture* (11 of 13) conditions were more likely to retain their learning than children in the *Speech* condition (3 of 9; $G + S$ vs. S, $p < .01$; G vs. S, $p = .026$), and were not reliably different from one another ($G + S$ vs. G, ns). Thus, children who performed well at posttest and had gestured during instruction were more likely to consolidate and retain the knowledge they had gained than children who performed well at posttest and had not gestured during instruction.

It is possible, however, that it was not the instructed gesture that led children to retain their new knowledge, but rather the children's natural inclination to gesture.

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[2] The difference between conditions is comparable and statistically reliable when those children who made progress during the period between the posttest and follow-up (and apparently not from our instruction, at least as measured by their performance on the immediate posttest) are eliminated from the study.

[3] We chose this criterion because, in order to solve over half of the problems correctly, children had to be correct on at least some problems of the $a + b + c = \_\_ + c$ form and some of the $a + b + c = a + \_\_$ form; they therefore could not be relying on a narrow, and potentially incorrect, algorithm.

On this account, the children who learned in the gesture conditions may have been precisely those children who were likely to gesture spontaneously. In other words, our instructions may have done nothing more than induce the performance of a behavior that would have been produced without instruction. In order to investigate this possibility, we divided children into two groups based on whether or not they gestured spontaneously on the pretest, and reanalyzed the data. In both groups, there was a reliable effect of condition on the relation between posttest and follow-up (Non-gesturers at pretest, $F(2,9) = 4.47$, $p = .05$; Gesturers at pretest, $F(2,63) = 3.76$, $p = .03$). In both groups, the *Gesture* and the *Gesture + Speech* conditions were associated with significantly more retention than the *Speech* condition (Non-gesturers: $G + S$ vs. S, $t(9) = 2.72$, $p = .02$, G vs. S, $t(9) = 2.55$, $p = .03$; Gesturers: $G + S$ vs. S, $t(63) = 2.65$, $p = .01$, G vs. S, $t(63) = 1.98$, $p = .05$).[4] Thus, our instructions to gesture were effective in promoting lasting learning, even for those children who did not produce the behavior spontaneously prior to instruction.

4. Discussion

4.1. Gesturing makes learning last

Recent research has suggested that the body can play a significant role in interpreting meaning (Barsalou, 1999; Glenberg & Robertson, 2000). Even understanding sentences about fairly abstract concepts has been shown to engage bodily motor processes (Glenberg & Kaschak, 2002; Zwaan & Taylor, 2006). Our findings add to this literature by showing that when children are asked to instantiate a new concept in their hands, learning is more lasting than when they are asked to instantiate it in words alone. Indeed, in our data, it was primarily when children were encouraged to produce gestures (with speech or without it) that they retained what they had learned from the instruction. Many children who expressed the equalizer strategy only in words during learning evidenced only a fleeting memory for the new concept. These findings suggest that using the body to represent ideas may be especially helpful in constructing and retaining new knowledge.

Another possibility, however, is that it was the novelty of our instructions to gesture that led the children to retain what they had learned. But if the children had been differentially engaged across our experimental conditions, we should have found differences in performance during instruction and on the immediate posttest, and not just on the follow-up. Moreover, there were no differences on the follow-up between the entirely novel condition in which children were instructed to gesture without speech (*Gesture*) and the more familiar condition in which they were instructed to gesture along with speech (*Gesture + Speech*). The lack of difference between these two conditions also suggests that learning was not due to producing

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[4] This same pattern of performance is also seen when the children are divided into equal sized groups according to a median split of amount of gesture on the pretest.

multiple representations. Children in the *Gesture* + *Speech* condition produced two representations of the problem-solving strategy; children in the *Gesture* condition produced only one. Yet children in both groups retained what they had learned equally well. Moreover, children in the *Gesture* condition and in the *Speech* condition each produced a single representation of the equalizer strategy. Yet the *Gesture* group retained significantly more of what they had learned than the *Speech* group.

One unexpected finding of our study was that gesturing seemed to promote learning on the follow-up test but not the posttest. In fact, we believe that the gestural script we gave children did help them perform well on the posttest. However, gesture's beneficial effects were obscured by the fact that the verbal script also helped children hold onto the knowledge they gained. Indeed, 14 of the children given the verbal script in our study achieved success during instruction and 9 of those children (.64) maintained their success through to the posttest, compared to 8 out of 21 (.38) in a comparable study where children were exposed to speech but *not* required to follow a verbal script (Cook & Goldin-Meadow, 2006). The effects of the verbal script were short-lived, however. Only 3 of the 14 (.21) children successful on the verbal script in our study continued to be successful on follow-up; by that point, the children looked just like those who had never had a verbal script. Thus, children who used the verbal script had the appearance of having mastered mathematical equivalence. But only children who used the gestural script truly learned the concept and were able to continue solving the problems correctly one month later.

The children in our study may have been able to retain the knowledge gained during instruction for at least a month because they slept during the intervening period. Sleep has been shown to consolidate learning in a variety of domains (Drosopoulos, Wagner, & Born, 2005; Fenn, Nusbaum, & Margoliash, 2003; Fischer, Hallschmid, Elsner, & Born, 2002; Karni, Tanne, Rubenstein, Askenasy, & Sagi, 1994). Note, however, that in our study gesturing during learning seemed to play a role in helping bring the consolidation about.

4.2. How does gesture lead to learning that lasts?

The data reported here provide strong evidence that gesture can play a causal role in knowledge change. Yet they do not tell us *how* gesture plays this role. One possibility is that gesture offers a representational format that requires relatively little effort to produce, thereby freeing resources that can then be used to encode new information in a more lasting format. Indeed, expressing information in speech and gesture has been shown to place less demand on working memory than expressing the same information in speech alone (Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001; Wagner, Nusbaum, & Goldin-Meadow, 2004). And representing information in ways that minimize demands on working memory has been shown to be associated with learning (Brunken, Steinbacher, Plass, & Leutner, 2002; Mayer & Moreno, 1998).

Another possibility is that gesturing directly facilitates encoding in long-term memory. Expressing information in gesture may produce stronger and more robust memory traces than expressing information in speech because of the larger motor movements involved or because of the potential for action-based, bodily encoding. Indeed, when speakers are asked to use their hands to act out an event conveyed in a sentence, their memory for the event is better than if they merely read the sentence or translate it into another spoken language (Cohen, 1981; von Essen & Nilsson, 2003). Similarly, children understand stories better when they enact the story with objects or imagine enacting the story with objects than when they read the story twice (Glenberg, Gutierrez, Levin, Japuntich, & Kaschak, 2004), and actors recall the lines they produce while moving better than the lines they produce while standing still (Noice & Noice, 1999, 2001).

Gesture may also affect learning by engaging the external environment. Gestures, particularly pointing gestures that indicate objects and locations in the world, may make it easier for learners to link developing mental representations to relevant parts of the external environment. This type of grounding could then decrease errors in encoding and lighten processing demands (Ballard, Hayhoe, Pook, & Rao, 1997), while at the same time facilitating new insights into the problem (Grant & Spivey, 2003).

4.3. How general is gesture's effect on learning?

Is the effect we found for gesture a general one? We cannot tell from our study because we taught children only one set of gestures – gestures instantiating the equalizer strategy. However, in related work, we have found that, when simply told to move their hands while explaining the same math problem, children rarely produce the equalizer strategy in gesture; but they do produce other strategies in gesture and those strategies also promote learning (Broaders, Cook, Mitchell, & Goldin-Meadow, in press). Thus, the effect we observed in our study, which experimentally manipulated the gestures children produced, does not appear to be limited to the gestures we chose. A variety of gesture types seem to be able to promote learning in math.

It seems unlikely, however, that gesturing will facilitate performance in all domains. Like speech (Schooler et al., 1993), gesture has the potential to both help and hinder performance. Gesture could, for example, draw attention to unhelpful features of the problem. Schwartz and Black (1996) found that adults who were allowed to gesture while solving gear problems used a strategy in which they modeled the movement of each individual gear, often in their gestures. In contrast, adults who were prevented from gesturing generated rule-based strategies, which are a more efficient way of solving the gear task (Alibali, Spencer, & Kita, 2004, as described in Alibali, 2005). Thus, just as verbalizing hard-to-verbalize tasks can disrupt performance (Schooler, Fiore, & Brandimonte, 1997), gesturing on tasks that do not lend themselves to gesture is likely to disrupt performance. What we have shown here is that gesturing on a task that lends itself to gesture can be helpful, even when the gesturer is told how to move.

Children in all groups received the same lesson and improved approximately the same amount immediately after the lesson. But only those who gestured during learning retained the knowledge they had gained from the instruction, perhaps because gesture gave them an alternative, and embodied, way of representing the problem. It is clear that encouraging gesture offers researchers a technique for manipulating, and therefore exploring, consolidation of long-term memories. In addition, encouraging gesture offers educators a technique for improving learning in their students. One way to promote lasting change in children's minds may be to change what they do, rather than what they say.

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