The role of gesture in teaching and learning math

Mary Hynes-Berry and Jennifer McCray, with Susan Goldin-Meadow

Introduction

Whether we are chatting with friends, giving directions about how to get somewhere, or explaining how we solved a problem, our hands are usually moving. Interestingly, while we may be conscious of the words we are using, we are often not even aware that we are gesturing, much less that we are sending important additional information with our gestures. Although gestures are spontaneous and vary from individual to individual, they often reinforce or clarify the information found in speech, adding new information as well as nuance. For this chapter, we interview Susan Goldin-Meadow, a professor of psychology at the University of Chicago, who studies non-verbal communication with specific emphasis on gestures.

Goldin-Meadow spent her college junior year in Geneva, Switzerland, where she had the amazing good fortune to take classes with Jean Piaget, the founding father of research in early cognitive development. Piaget insisted that genuine understanding results from the learner actively constructing meaning, rather than passively accepting direct instruction from a teacher. Goldin-Meadow’s interest in how children represent meaning through gesture is grounded in this theory.

Goldin-Meadow’s doctoral dissertation grew out of a deep interest in where language comes from. She looked at how deaf children whose hearing losses prevent them from acquiring spoken language and whose hearing parents have not exposed them to a sign language nevertheless construct their own manual language, called “homesign,” using gesture. She was interested in the ways that these homesign languages are related to, but also quite different from, the gestures that hearing people produce when they talk. That study set off an inquiry into the relationship between language, gesture, and cognition that she has continued to investigate ever since.

Goldin-Meadow’s research provides strong evidence that gestures play an important role not only in reflecting and communicating our thoughts, but also in changing those thoughts. Although her work on the topic is far-reaching, in this chapter, we will be looking specifically at how gesture can affect the development of young children’s understanding of mathematics.

What the Research Says

1 – “Mismatches” between speech and gesture

Goldin-Meadow’s early thinking about gesture in learning emerged when she was re-examining tasks made famous by Piaget—specifically tasks that assess children’s understanding of conservation. Piaget argued that sometime between 4 and 8 years of age, children develop the ability to conserve quantity over various perceptual transformations. As Piaget defined it, being able to conserve means being able to recognize that the amount of a material stays the same even when the appearance of the material is transformed in some way. Specifically, when children are
conservers, they are able to recognize that changing the container holding a liquid, or the arrangement of a clay substance, does not change the amount of the liquid or the clay, even though the change radically alters its appearance. Goldin-Meadow looked at whether the type of gestures children used when they performed conservation tasks aligned with their explanations of their thinking about the tasks.

**Box 1: Piaget’s Conservation Tasks**

To investigate children’s understanding of conservation, Piaget developed several tasks in which a substance—such as water in a glass, a ball of clay, or a line of coins—is transformed in some superficial way, without changing the amount. In the conservation of liquid task, the change is to the container that holds the liquid. This change causes the level of the liquid to drop or rise even though the amount does not vary.

Piaget showed that 3- to 5-year-olds (in what he called the early “preoperational period”) typically will say that when the substance is transformed so that it appears to increase, there is “more” of the substance. For example, in the conservation of number task, children are shown two lines that have the same number of coins, and then watch as an interviewer spreads out the coins in one of the lines, which makes the line longer. Many preschoolers will say the line of spaced coins has a different number and “has more” since it is longer than it was when the coins were touching each other. Examples of children completing Piaget’s conservation tasks can easily be found online.

To better understand Goldin-Meadow’s research, it is important to review Piaget’s classic conservation of liquid task (for a description of this and other conservation tasks, see Box 1). In this task, an interviewer first pours the same amount of liquid into two identical glasses and has the children verbally confirm that the amounts in both glasses are equal. The children then watch as the interviewer pours the liquid from one of the glasses into a taller, narrower glass. Now looking at two glasses, one short and wide, and the other tall and narrow, the children are asked: Is there the same or different amount of liquid in both glasses? After the children give their judgment, they are asked to explain their thinking, providing an opportunity to use gesture.

Typically, younger children will say that there is more liquid in the taller, narrower glass. They explain that since the liquid level is higher, there must be more. Older children, on the other hand, will say that the amount of water in both glasses is still the same. Their verbal explanations show logical reasoning such as:

- *You didn’t add or take away any water; you just poured it from one glass to the other.*
- *The second glass is taller, but the other glass is wider, so they are the same.*
- *If you pour water from the tall glass into the glass you took it from, the 2 glasses of the same size would be the same level again.*
Goldin-Meadow said that after years of showing videos of the Piagetian conservation tasks in child development courses she taught, she had an insight: “I always commented on the words that the children used [when they explained their thinking], but they also gestured like crazy, and nobody had ever mentioned it. So I started working with one of my students to code those gestures just to look at them.”

She and her student, Ruth (Breckie) Church, videotaped 6 conservation tasks that they administered to 28 children between the ages of 5 and 8. For each task, they asked the children to make judgments and explain their reasoning. The researchers then created a coding system for analyzing children’s speech separately from their gestures. When they compared the codes for each response, they found that some of the children used gestures that did not match the train of thought suggested by their speech.

As an example, on the liquid conservation task, a child might look at the short, wide glass and the tall, narrow glass and say that there is more liquid in the tall glass because the liquid level in it is higher. However, that same child might simultaneously be using a gesture that indicates the glasses are of different widths. That is, he might make a “C” shape with one hand: first with the fingers closer to the thumb to indicate the narrow glass, and then with fingers farther from the thumb to indicate the wide glass. Thus, evidence from what this child says indicates that he is focused only on the height of the liquid in the two glasses: however, his gestures clearly indicate awareness of width as a second (and key) difference between the two glasses. Goldin-Meadow and Church called this contrast between the understandings relayed in spoken word and gesture a “mismatch.”

**Box 2: Types of Gesture**

In many of these studies, Goldin-Meadow is interested in a specific type of gesture, called “iconic gesture.” Iconic gesture can be understood by others, even if it is not accompanied by speech, because it represents the action or object that is being referenced in some way. For example, when asked how to open a jar, one might simply make a twisting motion without saying anything or opening the jar.

In contrast to an iconic gesture, the meaning of a “deictic gesture” depends entirely on context, such as pointing to a glass and saying “glass,” or pointing to a glass and saying “mom” to indicate that it’s Mother’s glass. This kind of gesture is used when pointing and counting to show one-to-one correspondence.

Yet another type of gesture is one Goldin-Meadow terms “non-referential”; these gestures can stand on their own and reflect conventions. A good example would be nodding the head for “yes” and shaking the head for “no.” This type of gesture may change from one culture to another; for example, Bulgarians nod the head to mean “no” and shake the head to mean “yes.”

2. Mismatches as an indicator of readiness to learn

Church and Goldin-Meadow’s next step was to better understand why children were exhibiting these mismatches between speech and gesture when they explained their thinking. Church’s dissertation work, and subsequent publications with Goldin-Meadow, established that across all 6 of the conservation tasks, individual children typically produced a mixture of matches and mismatches; however, some children were producing many more mismatches than others.
Goldin-Meadow and Church wondered whether these children might be in a transitional stage in learning to conserve. They hypothesized that children who produced a lot of mismatches might be particularly ready to benefit from instruction about conservation.

To test this hypothesis, 52 children were given a pre-test of 6 conservation tasks and asked to explain their thinking, and researchers recorded their rate of gesture-speech mismatches versus matches. All children who could not yet conserve—regardless of their mismatching tendencies—were then given instruction in conservation and a post-test. They found that children who exhibited more mismatches than matches in the pre-test showed more improvement after instruction than those who had more matches than mismatches. This finding indicated that, indeed, children who exhibit more mismatches are more ready to learn than children who do not.

Table 1: Three stages of learning conservation, as suggested by Church and Goldin-Meadow’s findings

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<thead>
<tr>
<th></th>
<th>Few Speech-Gesture Mismatches</th>
<th>Many Speech-Gesture Mismatches</th>
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<tbody>
<tr>
<td><strong>Pre-learning state</strong></td>
<td>Both speech and gesture tend to suggest that the child believes that transformation of container, shape or configuration will change quantity or amount.</td>
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<tr>
<td><strong>Transitional State</strong></td>
<td></td>
<td>Often, different information is conveyed in speech and gesture, suggesting that the child holds two different, yet potentially integratable, ideas simultaneously. Most often the misconception or less abstract understanding is conveyed in speech, whereas the more advanced idea is conveyed in gesture.</td>
</tr>
<tr>
<td><strong>New Understanding</strong></td>
<td>Both speech and gesture tend to indicate that the child understands that transformation of container or shape does not change the quantity. Understanding may have generalized as a principle.</td>
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The results suggest that, when learning about conservation, children move through three stages: 1) Before understanding conservation, their verbal responses are incorrect and tend to be matched by their gestures (e.g., indicating height of water level only); 2) As their readiness to understand conservation begins to develop, their verbal responses are usually still incorrect but their gestures often mismatch (e.g., showing awareness of the width of the glass); 3) When conservation understanding has consolidated, their verbal responses are now correct and are matched by their gestures (e.g., acknowledging differences in both height and width of the glasses) (See Table 1).

In other words, when moving from pre-learning to new understanding, a child’s speech and gestures may move from mostly matched to mostly mismatched, and then back to mostly matched. Thus frequent mismatches may be a key indicator that a child is in a transitional stage in thinking about conservation.

The researchers’ findings suggest that cognitive struggle is highly productive. That is, struggling to reconcile two ideas calls for more active thinking than giving a rote response that one is “sure” is correct. As Church and Goldin-Meadow examined the data from their study, as well as from
studies they completed with older children, they saw evidence that children who didn’t gesture, or whose gestures matched their verbal answers, assumed their verbal answer was correct; no questioning of this assumption was apparent in their behavior. In contrast, although the mismatches often verbally expressed a wrong answer (probably the one they would have given without questioning it at all a year ago), their gestures indicated that they had begun to see the possibility that there was another way to consider the problem.

3- Speech, gesture and number

Goldin-Meadow found the same kind of difference between speech and gesture in work she conducted with colleagues on the development of children’s early numerical understanding.

Recall from the Levine chapter, Box 1, that, before children learn the cardinal principle (that the last number counted tells how many are in the set), they learn the cardinal meanings of the number words, in order, from one to four or five. That is, they learn “how many” objects the word “one” represents, then the word “two” and so on. It can take months to learn the meaning of each number word. So one child might be able to link the correct number word to a set of one but not a set of two or above, whereas another might be able to do so for sets of one, two or three, but not four or above.

In studying children who were still learning these small number words, Goldin-Meadow and her colleagues hypothesized that children might understand something about the quantities, even if they couldn’t connect them with the correct number words (e.g., if they see a set of 4 apples, they might have some understanding of its magnitude, even if they can’t connect the word “four” to it). They wondered if such children might reveal some of this numerical knowledge through gestures.

To test this theory, they first identified children who did not yet know the cardinal principle (children who were still in the process of learning the meanings of the numbers one through four). The researchers asked these children to look at cards displaying small sets of objects. At first, the children were asked to indicate the quantity of each set using the number words. In another activity, they were asked to hold up fingers to show the quantity.

Overall, the children’s responses were more often correct when they were indicating set sizes using their fingers than when they were using number words. They could also respond correctly for higher numbers using fingers than with number words. Further, sometimes children used both a word and a number gesture at the same time, and there were often mismatches (that is, the number word and gesture were different). In these cases, the gesture tended to be accurate more often than the word. In sum, children were able to show more knowledge about the quantities with number gestures than they could with number words.

Goldin-Meadow and colleagues theorized that using gestures might have been easier due to the one-to-one correspondence between the number of fingers and the number of objects shown on the card. Number names are arbitrary conventions and therefore may be harder to remember. The researchers also believe that, in this case, gesture might serve as an important bridge between a one-to-one understanding of amount and the cardinal amount concept toward which children are
building. Recently, Goldin-Meadow and colleagues have found that children who produce these gesture-speech mismatches on number tasks are more likely to profit from instruction. Mismatch appears to be a general index of readiness-to-learn.

4- Gestures aid young children’s mathematical learning

More recently, Goldin-Meadow and her associates have confirmed not only that gestures provide useful clues to children’s understanding, but also that they can be a significant aid to student learning. In one study with Raedy Ping, Goldin-Meadow provided instruction to 5- to 7-year-olds about conservation. The instructor modeled conservation tasks and verbalized explanations as to why the amounts were still equal even after the transformation. For example, in the liquid conservation task, the instructor might have said, “One of the glasses is taller, and the other one is shorter. But the shorter glass is wider, and the taller glass is skinnier.” In addition to the verbal explanation, some children also saw accompanying gestures. For example, when stating that one glass is taller and the other is shorter, the instructor made a gesture showing one hand held higher than the other; to show the difference in width, she made a C-shape with her hand, changing its width. The researchers found that children improved significantly more on the conservation task when the instruction they received included gestures.

Note that, in the experiment above, the gestures used by the teacher were designed to reinforce what the teacher was saying. To use Goldin-Meadow’s terminology, the teachers’ gestures and words matched. Thus, they were conveying the same message through two modalities. However, further research that she conducted with Melissa Singer with 3rd and 4th graders suggested that it can be more effective to use mismatches in instruction. In this case, the teacher expresses one correct idea with words and simultaneously uses gestures to convey a second, also correct idea. Providing children with one idea in speech and the other in gesture was more effective than providing both ideas in speech (for more details on the study, see Box 3). The researchers speculated that expressing both ideas verbally might be overwhelming to children, whereas when one idea is provided in speech and the second in gesture, one might enhance the child’s understanding of the other.

Box 3: Goldin-Meadow’s studies on gesture and mathematical equivalence

Goldin-Meadow and her colleagues have conducted a series of studies examining ways to help children learn how to solve equivalence problems such as $6+4+5=\square+5$. The researchers first identified different ideas that children draw upon in order to solve the problems, and how children naturally express these ideas in both language and in gesture. They then used these identified expressions (speech and gesture) in instruction, to see what types of input helped children learn how to solve the problems, such as in the study with Singer, above.

The following are examples of equivalence ideas and the gestures that suggest them:

1. Equalizer—the idea that both sides must be equal. This can be gestured with a flat palm sweeping first under the left side of the problem and then under the right.

2. Add-subtract: The strategy to add all numbers on one side and then subtract the number that is common on both sides (in the above example, the 5). This can be gestured by pointing at the 6, the 4, and the left 5, then producing a flick-away gesture near the right 5.

3. Grouping: The strategy to group the two non-common numbers (the 6 and the 4) and indicating that these should equal the number in the box. This can be gestured by making a “V” shape with two fingers under the two non-common numbers and then pointing to the box with the index finger.
In other studies, Goldin-Meadow and her colleagues found that students learn from gesturing themselves. In these studies they had children attempt to solve problems, explaining their thinking using gesture, before they were given a lesson on how to solve the problems. In one study the children were just told in general to use their hands to explain their thinking. In another study, children were told to produce a specific gesture. In both studies, the researchers found that children who were told to gesture learned more from the lesson than children who were not told to gesture. Why would gesturing help the children to learn? The researchers hypothesized that children may know some information implicitly, and that gesturing might help them access that information.

**Conclusion**

Goldin-Meadow’s extensive research on gestures touches on the full spectrum of the complex role gesture plays in the teaching and learning dynamic. She and her colleagues have found that a learner’s mismatch between words and gestures seems to signal readiness to develop new understanding; they have also found that when a teacher matches words and gestures, or when the teacher uses gestures that provide additional insight that is different from the words alone, learning is enhanced. They have also found that having children gesture themselves can help them learn.

**Suggested References**


