How Gesture Promotes Learning Throughout Childhood

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ABSTRACT—***The gestures children use when they talk often reveal knowledge that they do not express in speech. Gesture is particularly likely to reveal these unspoken thoughts when children are on the verge of learning a new task. It thus reflects knowledge in child learners. But gesture can also play a role in changing the child's knowledge, indirectly through its effects on the child's communicative environment and directly through its effects on the child's cognitive state. Because gesture reflects thought and is an early marker of change, it may be possible to use it diagnostically. Gesture (or its lack) may be the first sign of future developmental difficulty. And because gesture can change thought, it may prove to be useful in the home, the classroom, and the clinic as a way to alter the pace, and perhaps the course, of learning and development.***

KEYWORDS—*cognitive load; gesture; learning; problem solving; communication; math*

When people talk, they gesture. Even children move their hands when they speak. Evidence from school-aged children and from children at the early stages of language learning suggests that children's gestures often reflect knowledge that they have, but cannot yet express, thus providing insight into their unspoken thoughts. But there is now new evidence suggesting that gesture can do more than *reflect* thought—it can play a role in *changing* thought.

First, gesture can contribute to knowledge change through its communicative effects. If a child's gestures reflect the state of the child's knowledge, those gestures could serve as a signal that the child is ready for certain kinds of input. If, in turn, listeners are sensitive to this signal, they can adjust how they interact with the child, providing input targeted to the child's knowledge state. Gesturing can thus bring about knowledge change indirectly by giving children a way to shape the input they receive.

Second, gesture can contribute to knowledge change through its cognitive effects. Using objects to externalize thought saves cognitive effort that can then be put to other uses (Clark, 1999). Gesturing can be seen as externalizing a speaker's thoughts onto the body. Moreover, gesturing has been shown to lighten a speaker's cognitive load (Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001; Wagner, Nusbaum, & Goldin-Meadow, 2004). Gesturing thus has the potential to bring about knowledge change directly by affecting the learner's cognitive state.

Because gesture is such a sensitive marker of change, it has the potential to be used diagnostically. Gesture (or its lack) may be the first sign of future developmental difficulty.

GESTURE REFLECTS KNOWLEDGE NOT FOUND IN SPEECH

The gestures that accompany speech encode meaning differently from speech (Goldin-Meadow, 2003; Kendon, 1980; McNeill, 1992). Gesture relies on visual and mimetic imagery to convey an idea, whereas speech conveys meaning discretely, relying on codified words and grammatical devices. Nonetheless, the information conveyed in gesture and in speech can overlap a great deal. Consider, for example, a child asked to explain why he put 12, an incorrect response, in the blank in the following math problem: 3 + 5 + 4 = __ + 4. The child says, "I added the 3, the 5, and the 4," while pointing at the three numbers on the left side of the equal sign. The child is conveying overlapping information in gesture and speech and thus produces a gesture–speech match.

There are, however, times when gesture and speech convey different information. Consider another child who also puts 12 in the blank and gives the same incorrect "add to equal sign" explanation as the first child in speech, but a different incorrect

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explanation in gesture—she points at the 3, the 5, the 4 to the left of the equal sign, and the 4 to the right of the equal sign. This child has produced two distinct explanations—one that focuses on adding numbers up to the equal sign in speech, and another that focuses on adding all of the numbers in the problem in gesture. Her gesture thus constitutes a gesture–speech mismatch (Perry, Church, & Goldin-Meadow, 1988).

The child who produces a mismatch is conveying the "add all numbers" strategy uniquely in gesture on this particular problem. But this child could, on the very next problem, produce the "add all numbers" strategy in speech; if she does, it would be clear that this particular strategy is accessible to both gesture and speech, albeit not simultaneously. Alternatively, the information found in gesture in the mismatch might be accessible *only* to gesture; if so, the child would not be able to produce the "add all numbers" strategy in speech on any problem.

The second alternative turns out to be the case, at least in children learning mathematical equivalence—children who convey a particular strategy in gesture in a mismatch on one math problem generally do not convey that strategy in speech on *any* problems (Goldin-Meadow, Alibali, & Church, 1993). This means that children who produce mismatches have information in their repertoires that they know but cannot articulate. It also means that if listeners want to know that children have this information in their repertoires, they need to pay attention to their gestures as well as their words.

Children who produce mismatches on a task have information relevant to solving the task at their fingertips. The child in the second example has noticed (albeit not necessarily consciously) the 4 on the right side of the equation, an insight essential to solving the problem, and might therefore be particularly receptive to instruction in mathematical equivalence. Indeed, children who produce gesture–speech mismatches prior to instruction in mathematical equivalence are more likely to profit from the instruction than children who primarily produce matches (Alibali & Goldin-Meadow, 1993; Perry et al., 1988). Note that in the mismatch example presented earlier, the two strategies that the child produced, one in speech and the other in gesture, both led to incorrect solutions and were thus incorrect strategies; nevertheless, when given instruction, this child quickly learned how to solve the problem, presumably because each of the two incorrect strategies in her mismatch contained information necessary for solving the problem—the fact that the equation is composed of two parts divided by the equal sign, conveyed in the "add to equal sign" strategy, and the fact that there are four numbers in the problem, conveyed in the "add all numbers" strategy. The phenomenon of mismatch signals readiness to learn. This phenomenon is a general one, found in both school-aged children (Church & Goldin-Meadow, 1986; Pine, Lufkin, & Lewis, 2004) and adults (Perry & Elder, 1997).

We see the same phenomenon in toddlers learning their first words and sentences. Children often use gesture to communicate before they are able to use words (Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979). These gestures do not merely precede language development; they are fundamentally tied to it. For example, the gestures that children produce when in transition from single words to two-word combinations have a tight relationship to the children's development of vocabulary and syntax. A great many of the particular lexical items that a child produces initially in gesture shortly after appearing in gesture move to the child's verbal lexicon, and children who are first to produce gesture + word combinations conveying two elements in a proposition (point at bird + "nap") are also first to produce two-word combinations ("bird nap"; Iverson & Goldin-Meadow, 2005; see also Goldin-Meadow & Butcher, 2003; Ozcaliskan & Goldin-Meadow, 2005). Gesture is thus a harbinger of the child's next linguistic step.

In sum, gesture offers us an additional window onto what children know, and this window is particularly informative for two reasons. First, gesture often reveals aspects of what children know that are not accessible to us through their speech, and second, changes in gesture are often the first sign of imminent change in language learning and other cognitive tasks. But gesture may do more than just reveal children's readiness for change—it may pave the way for that change.

GESTURE CAN PLAY A ROLE IN LEARNING THROUGH ITS IMPACT ON COMMUNICATION

Children reveal information about their cognitive state through their gestures. Do listeners glean information from those gestures and alter their input to the children and, if so, do children profit from this altered input? To address these questions, without mentioning gesture, we asked teachers to watch children explaining how they solved a series of math problems. The teachers then instructed each child individually. All of the teachers, at times, picked up on information that their students produced in gesture and not in speech, often translating that information into their own speech (Goldin-Meadow, Kim, & Singer, 1999). Moreover, the teachers changed their instruction as a result: They gave different types of instruction to children who produced mismatches than to children who produced only matches. In particular, the teachers used many different types of spoken strategies and many of their own gesture–speech mismatches when teaching children who produced mismatches—and children who produced mismatches were more likely to learn how to solve the problem than children who produced only matches (Goldin-Meadow & Singer, 2003). These mismatchers may have learned simply because they were cognitively ready to learn. However, the teachers' adjustments may also have contributed to their success. To find out, we constructed math lessons that were based on the instruction teachers spontaneously gave to mismatchers and taught the lessons to children who did not know how to solve the problem. We found teacher gesture–speech mismatch was particularly effective in helping children (both matchers and mismatchers) learn how to solve the math problems (Singer & Goldin-Meadow, 2005).

The same type of give-and-take may be taking place in the earliest stages of language learning. Consider a child who does not yet know the word "dog" and refers to the animal by pointing at it. His obliging mother responds, "yes, that's a dog," thus supplying him with just the word he is looking for. Or consider a child who points at her mother while saying the word "hat." Her mother replies, "that's mommy's hat," thus translating the child's gesture + word combination into a simple sentence. In fact, mothers have been found to "translate" the gestures that one-word speakers produce into words (Goldin-Meadow, Goodrich, Sauer, & Iverson, 2007), thus providing timely models for how one- and two-word ideas can be expressed in English. Because they are finely tuned to a child's current state, maternal responses of this sort could be particularly effective in teaching children how an idea is expressed in the language they are learning.

More generally, gesture can serve as a catalyst for conversation, providing cues to children's thoughts that they cannot yet express in speech. Gesture can thus make it easier for listeners to guess children's intentions, creating better opportunities for joint attention and error-free communication (Golinkoff, 1986; Tomasello & Farrar, 1986). In sum, gesture offers a mechanism by which children can point out their thoughts to listeners, who then calibrate their speech to those thoughts and thus facilitate learning.

GESTURE CAN PLAY A ROLE IN LEARNING THROUGH ITS COGNITIVE EFFECTS ON THE LEARNER

In addition to this indirect role in learning, gesture may also play a role in learning by directly affecting the learners themselves. Indeed, including gesture in instruction might promote learning because it encourages learners to produce gestures of their own. Adults mimic nonverbal behaviors that their conversational partners produce (Chartrand & Bargh, 1999), and even infants imitate nonverbal behaviors modeled by an experimenter (Meltzoff & Moore, 1977). It would therefore not be surprising if school-aged children were to imitate the gestures that their teachers produce.

Indeed, we have found that children who cannot solve mathematical equivalence problems will imitate an instructor's gestures that represent a correct problem-solving strategy. Moreover, the children who pick up these gestures are more likely to learn from the instructor's lesson than the children who do not (Cook & Goldin-Meadow, 2006). Note that although these particular learners might have been more advanced in their understanding of mathematical equivalence to begin with. In this event, their gesturing would reflect their readiness to learn but play no role in causing it.

To convince ourselves that the act of gesturing plays a causal role in learning, we need to manipulate experimentally children's gesture. To explore this possibility, we told children to gesture while explaining their solutions to novel math problems and examined the effect of this manipulation on learning. When told to gesture, children who were unable to solve the math problems began producing new and correct problem-solving strategies in their gestures but not in their speech. Moreover, when these children were later given a math lesson, they were more likely to profit from the lesson and solve the problems correctly than children told not to gesture (Broaders, Cook, Mitchell, & Goldin-Meadow, 2007). Telling children to gesture thus encourages them to convey previously unexpressed (and correct) ideas, which, in turn, makes them receptive to instruction that leads to learning.

In an attempt to extend these findings, we explicitly told children how to move their hands when they gestured. Requiring children to produce a particular set of gestures while learning the new concept helped them retain the knowledge they had gained during the math lesson. In contrast, requiring children to produce a set of words (and no gestures) conveying the same information had no effect on solidifying learning (Cook, Mitchell, & Goldin-Meadow, 2008).

To determine whether it mattered which particular gestures the child was taught, we divided children into three groups before giving them a math lesson: children who were required to produce *correct* gestures for a particular problem-solving strategy, *grouping*, children who were required to produce *partially correct* gestures for the grouping strategy, and children who were required to produce *no* gestures at all. Children told to move their hands in a fully correct rendition of the grouping strategy during the math lesson solved more math problems correctly after the lesson, and also gave more grouping explanations, than children who moved their hands in a partially correct rendition of the grouping strategy, who, in turn, solved more problems correctly and gave more grouping explanations than children who did not move their hands at all. The more accurately a child's hand movements during the lesson simulated the grouping strategy, the more the child was able to profit from the lesson (Goldin-Meadow, Cook, & Mitchell, 2009), which suggests that the body can play a role not only in solidifying old ideas but also in creating new ones. This finding highlights the importance of motor learning even in nonmotor tasks and suggests that we may be able to lay the foundation for new knowledge just by telling learners how to move their hands.

Does encouraging young language learners to gesture have an impact on the course of language learning? We do not yet know. However, we do know that children who produce gestures (typically pointing gestures) for more different objects at 14 months will have larger vocabularies at 42 months than children who do not produce gestures for a variety of objects (Rowe, Ozcaliskan, & Goldin-Meadow, 2009; see also Rowe & Goldin-Meadow, 2009b). Moreover, child gesture is not a global predictor of language learning, but rather particular child gestures *selectively* predict particular child language outcomes. The number of different meanings children convey in gesture at 18 months predicts their vocabulary size at 42 months, but the number of

gesture + speech combinations they produce at 18 months does not. In contrast, the number of gesture + speech combinations, particularly those conveying sentence-like ideas, children produce at 18 months predicts sentence complexity at 42 months, but the number of different meanings they convey in gesture at 18 months does not (Rowe & Goldin-Meadow, 2009a). We can thus anticipate particular milestones in vocabulary and sentence complexity at age 3½ by watching how children moved their hands 2 years earlier.

Why does early gesture use selectively predict later spoken vocabulary size and sentence complexity? One possibility is that gesture use reflects two separate abilities, word learning and sentence making, on which later linguistic abilities can be built. Using gesture in specific ways, such as to indicate objects in the environment or to add arguments to a verbal utterance, allows children to communicate meanings at a time when they are unable to express those meanings in speech. Expressing many different meanings in gesture early in development could be nothing more than an early sign that the child is going to be a good vocabulary learner; alternatively, the act of expressing vocabulary meanings in gesture could play an active role in helping children become better vocabulary learners. Similarly, expressing many gesture + speech combinations early in development could be nothing more than an early sign that the child is going to be a good sentence learner, or it could help children become better sentence learners. In other words, the early gestures that children produce could either simply reflect their potential for learning particular aspects of language or play a role in helping them realize that potential. To test this alternative hypothesis, we will need to manipulate early child gesture and examine the effects of this manipulation on later language learning.

GESTURE CAN PROVIDE THE FIRST SIGN OF DEVELOPMENTAL TROUBLE

Gesture and speech form an integrated system in both adults (McNeill, 1992) and children (Goldin-Meadow, 2003), even at the early stages of language learning (Butcher & Goldin-Meadow, 2000). Because gesture and speech are so tightly intertwined, changes in gesture can predict, and may even help bring about, changes in speech. But what if a child is not following a typical language-learning path? If the gesture–speech system is robust, children whose language is delayed should also display delays in gesture. There is, in fact, evidence from children who have suffered brain injury that delays in sentence construction are accompanied by delays in gesture (Ozcaliskan, Levine, & Goldin-Meadow, 2009).

Many, but not all, children with pre- or perinatal unilateral brain lesions have early language delays; these early delays are transient for some children but persistent for others. Can we use gesture to predict which children will sustain persistent delays and which will not? We calculated the number of different gestures and words children with brain injury produced during naturalistic interactions with their parents at 18 months and then assessed the children's spoken vocabulary on a standardized test at 30 months. Gesture use was highly variable in the children with brain injury at 18 months. Importantly, it was the children who produced few gesture types at 18 months who exhibited delays in vocabulary comprehension 1 year later. In other words, child gesture at 18 months predicted child vocabulary comprehension at 30 months—even when controlling for child speech at 18 months (Sauer, Levine, & Goldin-Meadow, in press).

These findings are consistent with research on language development in other child clinical groups (Bates, O'Connell, & Shore, 1987; Capone & McGregor, 2004; Thal & Tobias, 1992). Thal and Tobias (1992) observed communicative gesture use in 18- to 28-month-old late talkers, none of whom had been diagnosed with brain injury. The late talkers who no longer had speech delays at a 1-year follow-up had, at the earlier ages, produced significantly more communicative gestures than the late talkers whose speech delays persisted at the 1-year follow-up. Thus, early gesture (or its lack) can be used to predict later language delay in children with and without obvious neurologic impairments.

Findings of this sort have both theoretical and practical implications. Theoretically, the findings provide further evidence that the integrated gesture–speech system is fundamental to the language-learning process. The fact that gesture and speech remain linked even when different brain structures underlie language functions suggests that early gesture may be inextricably linked to the language learning process.

In terms of practice, the findings suggest that early delays in gesture production can be used to identify children whose language learning is likely to go awry in the future. If so, clinicians can use early gesture diagnostically to identify children likely to have persistent language difficulties well before those difficulties appear in speech. We may therefore be able to offer these children interventions (perhaps in the form of more intensive gesture instruction) at a time when their language-learning trajectory is still malleable.

QUESTIONS FOR THE FUTURE

To summarize, gesture provides insight into a child's thoughts. This window into the mind is particularly useful when children are on the verge of learning a concept simply because, at these transitional moments, gesture can reveal thoughts that children do *not* express in their speech. However, gesture does more than reveal thoughts—it can play a role in changing those thoughts in two ways. Gesture can change thought indirectly by revealing children's unspoken thoughts to listeners who can then adjust their input accordingly. It can also change thought more directly by having an impact on the child learners themselves, perhaps by allowing them to express knowledge using their own bodies.

An important question for future work is to determine whether gesture's effectiveness as a learning tool stems from the fact that

it is a motor act performed by the body (Barsalou, 1999; Glenberg & Robertson, 2000). People are particularly likely to remember an action that they have used their bodies to perform (Saltz & Donnenwerth-Nolan, 1981), and the body has been implicated in routine language comprehension. For example, when comprehending an action word that is semantically related to a body part (*lick*, *pick*, and *kick*), the area in the brain that is associated with that part (the face, hand, or leg area, respectively) is activated (Pulvermuller, 2005). Doing an action thus provides an additional pathway that can be exploited during learning, one that gesturing may also activate.

A second question for future work concerns development: does gesture's role in cognition change over time? Proficient language users, like beginning language learners, convey information in gesture that is different from the information conveyed in speech and often do so when describing tasks that they are on the verge of learning (Goldin-Meadow, 2003). Note, however, that the learning task facing the young child is language itself. When gesture is used in these early stages, it is used as an assist into the linguistic system, substituting for words that the child has not yet acquired—it is during the period when gesture can substitute for words that researchers have recommended teaching "baby signs" to children (Acredolo & Goodwyn, 1996). Although it is not clear that teaching baby signs to a preverbal child has long-term effects on the child's vocabulary, it is likely to have positive short-term effects on parent–child interaction, allowing parent and child to communicate at a time when they cannot do so using words. But once the basics of language have been mastered, children are free to use gesture for other purposes—in particular, to help them grapple with new ideas in other cognitive domains, ideas that are often not easily translated into a single lexical item. As a result, although gesture conveys ideas that do not fit neatly into speech throughout development, we might expect to see a transition in the kinds of ideas that gesture conveys as children become proficient language users. Initially, children use gesture as a substitute for the words they cannot yet express. Later, once they master language and other learning tasks present themselves, they use gesture to express more global ideas that do not fit neatly into wordlike units. We are currently exploring when this transition takes place.

Because gesture reflects thought, it can be used by researchers, parents, teachers, and clinicians as a window into the child's mind, a window that provides a perspective that is often different from the perspective that speech provides. Moreover, because gesture has the potential to change thought, it can be used in the home, the classroom, and the clinic to alter the pace, and perhaps the course, of learning and development.

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