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REVIEW ARTICLE

Learning from Gesture: How Our Hands Change Our Minds

Miriam Novack[1] **· Susan Goldin-Meadow**[1]

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Abstract When people talk, they gesture, and those gestures often reveal information that cannot be found in speech. Learners are no exception. A learner's gestures can index moments of conceptual instability, and teachers can make use of those gestures to gain access into a student's thinking. Learners can also discover novel ideas from the gestures they produce during a lesson or from the gestures they see their teachers produce. Gesture thus has the power not only to reflect a learner's understanding of a problem but also to change that understanding. This review explores how gesture supports learning across development and ends by offering suggestions for ways in which gesture can be recruited in educational settings.

Keywords Gesture · Learning · Mathematics · Communication · Teaching · Development

Introduction

When people talk, they gesture—in fact, they cannot help it. Gesture is so pervasive that people routinely do it on the phone when no one can see them. Even congenitally blind individuals, who have never seen anyone gesture, move their hands when they speak (Iverson and Goldin-Meadow 1998). Gestures add a spatial or imagistic component to spoken language, and since gestures are not confined to the linear, ruled-based system of spoken language, they have the potential to express ideas that may be difficult to convey in words.

Since gestures occur most often in communicative contexts, we might guess that gesture's main purpose is to aid communication. While true to a certain extent, gesture also has important consequences for thinking and learning beyond comprehension of language. More than just clarifying or enhancing the message of a lesson, gesture can lead learners to insight and promote conceptual development. The act of gesturing can also feedback and have effects

✉ Miriam Novack
mnovack1@uchicago.edu

[1] Department of Psychology, University of Chicago, 5848 S. University Ave., Chicago, IL 60637, USA

on gesturers themselves. This paper explores how these functions of gesture can be harnessed to support learning and teaching across development.

What Gesture Reveals About What a Learner Knows

The gestures that learners produce while explaining their reasoning can provide unique insight into their thought processes. Imagine, for example, a child who does not yet understand the concept of conservation of liquid quantity and believes that the amount of water changes when it is poured from a tall, thin container into a short, fat container. When asked to justify this belief, the child might say, "this one is taller than this one," while at the same time, producing a C-shaped gesture indicating the narrow width of the tall container, followed by a wider C-shaped gesture indicating the larger width of the short container. The child is highlighting one dimension of the containers in speech (height), but his hands make it clear that he is beginning to think about a second dimension (width). His gesture is conveying different information than his words.

Learners who produce different information in gesture than in speech are revealing, for all the world to see, that they know more than they say. The information a learner conveys uniquely in gesture is often encapsulated or implicit knowledge, not yet accessible to explicit understanding (Alibali and Goldin-Meadow 1993). Yet, since gesture is not bound by the conventions of spoken language, it can provide an alternative avenue through which the learner can explore new and alternative hypotheses. Producing these new ideas in gesture is an excellent signal that the learner is in a transitional state and ready to make use of relevant input (Goldin-Meadow 2003). More specifically, children whose gestures convey different ideas from their speech when they explain a task are more likely to profit from instruction in that task than children whose gestures are redundant with their speech (Church and Goldin-Meadow 1986; Perry et al. 1988). Thus, gesture is a red flag—a marker that a learner is in a prime state for learning.

But are these subtle cues only accessible to trained researchers, painstakingly coding and re-coding learner's gestures? The answer is, thankfully, no. Teachers, as well as college undergraduates, are sensitive to the content conveyed uniquely in students' gestures. Untrained adults are able to see beyond children's speech in assessing their knowledge (Alibali et al. 1997). If asked to instruct children who do, and do not, convey information uniquely in gesture, adults are more likely to provide rich instruction to children whose gestures differ from their speech than to children whose gestures match their speech (Goldin-Meadow and Singer 2003), suggesting that adults are aware (although not necessarily consciously) that gesture is a tool they can use to predict who will profit from instruction.

How Producing Gesture Can Support Learning

Since gesture provides an avenue through which learners can consider new ideas, what happens to children who do not gesture? Might they be missing out on important learning opportunities? It turns out that simply encouraging learners to gesture can allow these implicit ideas to surface. Broaders et al. (2007) asked children to explain their solutions to incorrectly solved mathematical problems; they then asked them to solve a new set of comparable problems and encouraged half the children to gesture as they explained their solutions.

Broaders et al. found that children told to gesture added novel strategies to their repertoires, but those strategies were found only in gesture; children who were not encouraged to gesture did not add strategies to their repertoires in either gesture or speech. Importantly, children who added novel strategies uniquely in gesture were also more likely to profit from instruction in math—after the lesson (when they were no longer gesturing), the children were able to solve math problems on a paper-and-pencil test that they could not solve before the lesson. Encouraging children to move their hands can activate implicit, and correct, ideas that then prime children for learning.

The same phenomenon has recently been replicated in the domain of moral reasoning. Children who were encouraged to gesture while explaining their reasoning about a moral dilemma (debating contractual obligations against obedience to a higher authority) were more likely to express multiple perspectives in gesture (reflecting a greater understanding of the multiple elements involved in the dilemma) than children who were not encouraged to gesture. Moreover, after a lesson in moral understanding (when children were no longer gesturing at high rates), the children who had gestured during the lesson increased the number of perspectives they mentioned in speech; in fact, the more multiple-perspectives they produced in gesture prior to the lesson, the more multiple-perspectives they produced *in speech* after the lesson (Beaudoin-Ryan and Goldin-Meadow 2014). Encouraging children to move their hands activates implicit ideas that prime children for learning not only in spatial domains, like math, but also in inherently nonspatial domains, like morality.

If spontaneously producing correct strategies uniquely in gesture leads to learning, what happens if children are explicitly *taught* to produce correct strategies in gesture? Goldin-Meadow et al. (2009) gave third-graders instruction in how to solve a missing addend mathematical problem, such as $3+4+9=\_\_+9$, by teaching them to produce gestures that represented a correct strategy for solving the problem. All of the children were taught to say the words, "I want to make one side equal to the other side" (*equivalence*, a correct strategy for solving the problem). Children in one group (the *fully correct gesture* condition) were taught to produce another correct strategy (*grouping*) in gesture—they produced a *V-point* gesture with their index and middle fingers to the first two numbers in a math problem (i.e., the 3 and 4 in the $3+4+9=\_\_+9$ problem) and then pointed at the blank on the other side of the equation; the *V-point* gesture, which represents the idea that the problem can be solved by *grouping* and then adding the two addends, is one that children spontaneously produce when explaining their correct solutions to these problems (Perry et al. 1988). Children in another group (the *partially correct gesture* condition) were taught to produce a partially correct *grouping* strategy in gesture—they produced their *V-point* to the second two numbers in the problem (i.e., the *4* and *9* in the example) and then pointed at the blank; this gesture highlighted grouping but focused children's attention on the wrong numbers. A final group of children was taught no gestures at all and just learned the equivalence strategy in speech (the *speech alone* condition). Encouraging children to produce the *grouping* gesture during the lesson led them to produce the strategy explicitly in speech after the lesson and to solve more problems correctly on a written posttest (when they were no longer gesturing) than they had solved prior to the lesson. Interestingly, even children in the *partially correct gesture* condition, whose attention was directed to the wrong numbers, improved relative to children in the *speech alone* condition (although not as often as children in the *fully correct gesture* condition), suggesting that gesture was doing more than just directing the child's attention. If all gesture did was direct attention, then children in the *partially correct gesture* condition should have performed worse than children in the *speech alone* condition. Teaching children to produce correct strategies uniquely in gesture can lead to learning.

How does gesture promote learning? There are likely many mechanisms through which gesture has its effects. For example, gesture can link abstract concepts in the immediate environment (Alibali et al. 2014), gesture can reduce cognitive load (Goldin-Meadow et al. 2001; Hu et al. 2015; Ping and Goldin-Meadow 2010), and gesture can enhance spoken communication (Hostetter 2011). In addition, since gesture is an act of the body, its effects on learning may stem, at least in part, from its capacity to engage the motor system (see Ping et al. 2014). Motor experience has been shown to shape learning in a variety of domains (e.g., Glenberg et al. 2007; Smith 2005; Sommerville et al. 2005; Wiedenbauer and Jansen-Osmann 2008), and gesture, which is a motoric act, may rely on similar mechanisms. New fMRI evidence finds that children who produce speech and gesture when learning about mathematics problems are more likely to later activate motor regions when just passively solving the math problems in a scanner than children who produce only speech when learning about the same problems (Wakefield et al. 2015). This pattern of activation largely overlaps with neural networks involved in learning through action on objects (cf. James and Swain 2011; Johnson-Frey 2004). Gesture may thus support learning *because* it is a type of action.

However, gesture is *representational* action, making it different from action on objects, which is meant to carry out functions, not represent ideas. This difference may be precisely the feature that is responsible for gesture's unique effects on learning. To explore this idea, Novack et al. (2014) taught children how to solve math problems while either producing actions on objects or producing gestures over objects. All children learned how to solve the types of problems on which they were trained, but only children who gestured were able to transfer their understanding to novel problem types, that is, to generalize their knowledge, an essential component of learning. Action, which involves manipulating objects, might lead children to think that their learned actions are relevant *only* to those objects themselves, resulting in shallow learning (see McNeil and Uttal 2009). In contrast, gesture, which occurs *off* objects, provides a physical distance, which may be critical for abstracting away from a particular context and generalizing to new contexts. In other words, action may hinder generalization by focusing learners on details that get in the way of transfer, whereas gesture may facilitate generalization by focusing learners on dimensions that lead to transfer. Thus, although gesture may work the way it does in part because it is itself an action, the fact that it is *representational* action may be key to the role it can play in promoting deep learning.

How Seeing Gesture Can Support Learning

Gesture can also support learning when children *see* a teacher gesture during instruction and do not produce gestures of their own (Cook et al. 2013; Church et al. 2004; Perry et al. 1995; Valenzeno et al. 2003). For example, the pointing and tracing gestures that teachers use to indicate the symmetry of shapes helps preschoolers learn the concept of bilateral symmetry (Valenzeno et al. 2003). This effect might grow out of gesture's ability to ground the abstract language of the lesson to the concrete physical environment (Valenzeno et al. 2003). But, seeing gesture can also support learning in the absence of physical objects. Ping and Goldin-Meadow (2008) gave 5- to 7-year-olds instruction in Piagetian conservation, either with gestures or without gestures; in addition, the teacher's gestures, which represented the relative widths and heights of the two glasses, were produced either in the presence of the objects to which they referred or in the absence of those objects. Children who received instruction with gesture improved more than children who received instruction without gesture, whether or not objects were present. This finding suggests that gesture instruction supports learning, not only by focusing learners' attention to objects but also by conveying ideas through its representational form.

Finally, including gesture in instruction allows teachers to provide students with multiple strategies *at the same time*. Singer and Goldin-Meadow (2005) found that children learned more from a math lesson in which a teacher simultaneously presented two correct strategies, one in speech and another in gesture (speech + gesture), compared to a lesson in which the teacher presented the same two strategies entirely in speech, which, of course, had to be produced sequentially (speech → speech). Gesture's power may come, at least in part, from its ability to co-occur with speech. If so, presenting the gesture strategy *after* the spoken strategy (speech → gesture) should be less effective than presenting the gesture strategy along with the spoken strategy (speech + gesture). Congdon et al. (2015) indeed found that speech → gesture instruction was significantly less effective for both generalization and retention than speech + gesture instruction and was, in fact, no better than speech → speech instruction.

Learning from Gesture in the Early Years

Gesture not only is a useful tool for school-aged children learning about abstract concepts like mathematics but can also support learning in infancy and young childhood. Babies as young as 4.5 months direct their attention to dynamic points (Rohlfing et al. 2012) and at 1 year benefit from synchronous speech-pointing combinations in word-learning contexts (de Villiers Rader and Zukow-Goldring 2012). Infants begin producing gestures themselves around 9 months, even before they begin speaking (Bates 1976) and at 1 year use points to inform others, as well as to retrieve information from adults (Tomasello et al. 2007; Kovács et al. 2014).

Just like older children, the gestures that infants and young children produce provide insight into what they know, even before they can express that knowledge in words. Children will begin to reference items in gesture when they are on the verge of being able to produce those items in speech, and they produce supplemental speech + gesture combinations (i.e., pointing to a cup and saying "daddy" to mean "daddy's cup") right before they begin to create two-word utterances in spoken language (Iverson and Goldin-Meadow 2005). Finally, children who have not yet learned all of their number words are more accurate when labeling sets of items in gesture than in speech (Gunderson et al. 2015).

Young children can also benefit from explicit gesture interventions, like school-aged children. Eighteen-month-olds who are given pointing training increase the number of gesture meanings they express during spontaneous interactions with their caregivers, which, in turn, increases their spoken language vocabulary (LeBarton et al. 2015). Toddlers are more likely to learn the concept of "under" if given instruction with gesture than if given instruction with pictures or just words (McGregor et al. 2009). Finally, iconic gesture instruction (but not pointing instruction) teaches 2-year-old children how to operate a novel toy, suggesting that by 2 years of age, children can benefit from the representational structure of gesture in a learning context (Novack et al. 2015). Learning from gesture is thus a pervasive phenomenon across the lifespan.

Open Questions and Implications for Educational Settings

There remain many open questions regarding the relative effectiveness of gesture in instruction, and as such, work is still needed to delineate the situations in which gesture is, and is not, helpful in a learning context. For example, recent studies have found that the effect of producing specific gestures during instruction may interact with prior knowledge; gesture can be less useful in a domain (and, in some cases, can even be detrimental) for children with low competence in that domain (Post et al. 2013; Wakefield and James 2015). In addition, gesture's usefulness may change with age—children's ability to learn from representational gesture during instruction may be constrained by their ability to interpret symbolic forms. In fact, Novack et al. (2015) found that although 2-year-olds were able to learn the function of a novel toy from watching an iconic gesture demonstration, they learned *more* from watching an incomplete-action demonstration, suggesting that the capacity to learn from gesture, relative to other types of instruction, may change with age.

However, acknowledging that many open questions remain, we believe that the evidence currently available showing that gesture can play a formative role in learning across development should give teachers and educators the confidence to introduce gesture into their classrooms in several ways.

First, teachers can give students opportunities to gesture by asking them to explain their answers to problems (which tends to spontaneously elicit gesture) and by explicitly encouraging them to use their hands during these explanations. Teachers also need to pay attention to the information students convey in gesture. If teachers pay attention only to what students say with their mouths, they will miss the knowledge that students display uniquely in their hands. Since the information students convey in gesture is often at the cutting edge of their knowledge, if teachers attend to those gestures, they will be better able to adapt their instruction to the skills of their students.

Second, teachers can gesture themselves when teaching. Teachers' gestures can guide children's attention and scaffold verbal information. Teachers' gestures can also have a trickle down effect that might lead to increased student gesturing. Research has found that when instructors gesture during a lesson, children are more likely to gesture as well, which, in turn, leads them to profit from the lesson (Cook and Goldin-Meadow 2006). By gesturing themselves, not only do teachers improve the quality of a lesson but they also create a classroom culture that includes gesturing.

Finally, gestures can be particularly helpful in a classroom setting when other tools are not available. Gestures can be used to represent ideas that are challenging to demonstrate (e.g., using the hands to represent molecules that are otherwise too small to see, Stieff and Raje 2010). Gestures can also be used by children in place of physical objects, like manipulatives. Unlike manipulatives, which can be cumbersome and likely have to remain in the classroom, hands travel with the learner. Children can make use of their gestures wherever they are—in the classroom, at home, and even on a test.

Gestures are portable, flexible, and ideal for improving learning contexts. They can be teaching tools for teachers as well as learning tools for students. If recognized as more than mere hand-waving, gestures have the potential to support learning across development.

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