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## Gesture's role in speaking, learning, and creating language

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### Abstract

When speakers talk, they gesture. The goal of this chapter is to understand the contribution that these gestures make to how we communicate and think. Gesture can play a role in communication and thought at many timespans. We explore, in turn, gesture's contribution to how language is produced and understood in the moment; its contribution to how we learn language and other cognitive skills; and its contribution to how language is created over generations, over childhood, and on-the-spot. We find that the gestures speakers produce when they talk are integral to communication and can be harnessed in a number of ways. (1) Gesture reflects speakers' thoughts, often their unspoken thoughts, and thus can serve as a window onto cognition. Encouraging speakers to gesture can thus provide another route for teachers, clinicians, interviewers, etc., to better understand their communication partners. (2) Gesture can change speakers' thoughts. Encouraging gesture thus has the potential to change how students, patients, witnesses, etc., think about a problem and, as a result, alter the course of learning, therapy, or an interchange. (3) Gesture provides building blocks that can be used to construct a language. By watching how children and adults who do not already have a language put those blocks together, we can observe the process of language creation first hand. Our hands are with us at all times and thus provide researchers and learners with an ever-present tool for understanding how we talk and think.

### 1. Why study gesture?

The goal of this chapter is to explore the role that our hands play in communication and cognition. We focus on the hands for a number of reasons. First, hand movements during talk—better known as *gestures*—are ubiquitous. Speakers in all cultures gesture when they talk, and the topics that elicit gesture can be as simple as a child's board game (Evans & Rubin 1979) or as complex as kinship relations (Enfield 2005). Even congenitally blind individuals, who have never seen anyone gesture, move their hands when they talk (Iverson & Goldin-Meadow 1998), highlighting the robustness of gesture in communication.

Equally important, the gestures speakers produce when they talk do not go unnoticed by their listeners. For example, an interviewee is just as likely to be led astray by the interviewer's misleading gestures as by his misleading words. Asking the listener an open-ended question, "what else was the man wearing?" accompanied by a *hat* gesture (moving the hand as though donning a hat), elicits just as many hat responses as the pointed question, "what color was the hat that the man was wearing?"—in both cases, the man was *not* wearing a hat (Broaders & Goldin-Meadow 2010). Gesture is part of our conversations and, as such, requires our research attention.

Gesture plays a role in communication at a variety of timespans—in speaking at the moment, in learning language over developmental time, and in creating language over shorter and longer periods of time. We use this structure in organizing our chapter. We begin

by exploring gesture's role in how language is processed in the moment—how it is produced and how it is understood. We then explore the role that gesture plays over development, initially in learning language and later, once language has been mastered, in learning other concepts and skills. Finally, we explore the role that gesture plays in creating language over generations (in deaf individuals who share a communication system and transmit that system to the next generation), over developmental time (in deaf children who do not have access to a usable model for language, spoken or signed), and on-the-spot (in adults who are asked to communicate without using speech).

Having shown that gesture is an integral part of communication, we end with a discussion of how gesture can be put to good use—how it can be harnessed for diagnosis and intervention in the clinic and for assessment and instruction in the classroom.

## 2. Gesture's role in language processing

### 2.1. Gesture production and its role in producing language

The gestures that speakers produce along with their speech may actually help them to produce that speech. In this section, we consider a number of accounts of this process.

Speakers' gestures convey meaning but, importantly, they do so using a different representational format from speech. Gesture conveys meaning globally, relying on visual and mimetic imagery, whereas speech conveys meaning discretely, relying on codified words and grammatical devices (McNeill 1992). According to McNeill's (1992, 2005, McNeill & Duncan 2000) *Growth Point* theory, the internal "core" or growth point of an utterance contains both the global-synthetic image carried by gesture and the linear-segmented hierarchical linguistic structure carried by speech. Moreover, the visuo-spatial and linguistic aspects of an utterance cannot be separated—gesture and speech form a single integrated system.

Building on these ideas, the *Information Packaging Hypothesis* (Kita 2000) holds that producing gestures helps speakers organize and package visuo-spatial information into units that are compatible with the linear, sequential format of speech. The visuo-spatial representations that underlie gestures offer possibilities for organizing information that differ from the more analytic representations that underlie speech. When describing complex spatial information (such as a set of actions or an array of objects), there are many possible ways in which the information can be broken down into units and sequenced. According to the Information Packaging Hypothesis, gestures, which are individual actions in space, help speakers to select and organize the visuo-spatial information into units that are appropriate for verbalization. For example, in describing the layout of furniture in a room, a speaker might produce a gesture in which her two hands represent a couch and a chair as they are positioned in the room, and this might help in formulating the utterance, "The couch and the chair are facing one another".

The most straightforward way to test the Information Packaging Hypothesis would be to manipulate gesture and observe the impact of that manipulation on how speech is packaged. At the moment, the evidence for the theory is more indirect—studies have manipulated the demands of packaging visuo-spatial information and shown that this manipulation has an effect on gesture production. In tasks where it is more challenging to package information into linguistic form, speakers produce more gestures, even when other factors are controlled. For example, Hostetter, Alibali and Kita (2007) asked participants to describe arrays of dots in terms of the geometric shapes that connected those dots (e.g., "The top 3 dots form a triangle, and the base of that triangle is the top of a square with dots at each corner"). For some participants, the shapes were drawn in the dot arrays, so that packaging the

information into units was easy; for other participants, the shapes were not provided, so participants had to decide on their own how to group the dots into shapes. In the second case, packaging the information into units for speaking was more challenging. As predicted by the Information Packaging hypothesis, participants in this latter group produced more gestures when describing the arrays.

Whether or not we gesture is also influenced by the ease with which we can access words, as proposed in Krauss' (1998, Krauss et al 2000) *Lexical Gesture Process Model*. According to this theory, gestures cross-modally prime lexical items, increasing their activation and making them easier to access. For example, if a speaker produces a circular gesture as he starts to say, "The ball rolled down the hill", the gesture will increase activation of the lexical item "roll", making it easier for the speaker to access that word. As evidence, when lexical access is made more difficult, speakers gesture at higher rates (Chawla & Krauss 1994, Morsella & Krauss 2004). Conversely, when gesture is prohibited, speakers become more dysfluent (Rauscher et al 1996).

The *Interface Model* proposed by Kita and Özyürek (2003) extends these theories, arguing that gestures are planned by an action generator, verbal utterances by a message generator. According to this view, although speech and gesture are generated by separate systems, those systems communicate bi-directionally and interact as utterances are conceptualized and formulated. Gestures are thus shaped by the linguistic possibilities and constraints provided by the language they accompany. Evidence for this view comes from cross-linguistic findings showing that the gestures speakers produce are shaped by the syntactic structures that underlie their language. For example, in English, the manner and path of a motion event are expressed in the same clause (*run down*), with manner in the verb and path in a satellite to the verb, as in "The child runs (*manner*) down (*path*) the street." In contrast, in Turkish, manner and path are expressed in separate clauses (*run* and *descend*), with path in one verb and manner in another, as in "Cocuk kosarak tepeden asagi indi" = child as running (*manner*) descended (*path*) the hill. When English speakers produce gestures for manner and path, they conflate the two into a single gesture (a inverted-V with wiggling fingers produced while moving the hand in a downward trajectory = run+down), paralleling the single-clause structure of their speech. Turkish speakers, in contrast, produce separate gestures for manner and path (a palm moved downward = down, followed by an inverted-V with wiggling fingers in place = run), paralleling the two-clause structure of their speech (Özyürek et al 2008). The particular gestures we produce are shaped by the words we speak.

An alternative view of the mechanism underlying gesture production is the *Gesture as Simulated Action* framework (Hostetter & Alibali 2008, 2010), which holds that speakers naturally activate simulations of actions and perceptual states when they produce speech. These simulations activate areas of motor and premotor cortex responsible for producing movements. If the level of motor activation exceeds a pre-set threshold (which is influenced by individual, social, and contextual factors), then the speaker produces overt motor movements, which we recognize as gestures. For example, according to this view, in speaking about a child running down a hill, a speaker forms a mental simulation of the scene that includes action and perceptual components. This simulation will activate corresponding motor and premotor areas, and if activation in those areas exceeds the speaker's gesture threshold, the speaker will produce a gesture. In support of this view, a number of studies have found that gesture rates increase when action and perceptual simulations are activated (Hostetter & Alibali 2010, Sassenberg & Van Der Meer 2010). Within this framework, linguistic factors may also influence the form of the gestures, as long as they influence the nature of speakers' simulations. For example, if linguistic factors affect the way the speaker simulates a child running down a hill, they will also shape the form of the gestures that the speaker uses to describe that event because gesture and speech are expressions of the same

simulation. Thus, according to the *Gesture as Simulated Action* framework, speaking involves simulations of perception and action, and gestures arise as a natural consequence of these simulations.

## 2.2. Gesture comprehension and its role in understanding language

Although some argue that gesture plays little role in language comprehension (Krauss et al 1996, Krauss et al 1995), there is a great deal of evidence that gesture can have an impact on language comprehension. Consider a speaker who says, “The man was wearing a hat,” while moving her hand as though grasping the bill of a baseball cap. This gesture could help listeners understand that the man was wearing a hat, and it might even encourage them infer that the hat was a baseball cap. Both observational and experimental studies support these claims.

A recent quantitative meta-analysis that included 63 separate samples found that gestures foster comprehension in listeners (Hostetter 2011). The overall effect size was moderate, and the size of the beneficial effect depended on several factors, including the topic of the gestures, their semantic overlap with speech, and the age of the listeners. Across studies, gestures about topics involving movement (e.g., how to make pottery, Sueyoshi & Hardison 2005) yielded greater benefits for listeners’ comprehension than gestures about abstract topics (e.g., the taste of tea, Krauss et al 1995). In addition, gestures that conveyed task-relevant information not expressed in speech (e.g., a gesture depicting *width* while saying “this cup is *bigger*”) played a greater role in comprehension than gestures that conveyed information that was also expressed in speech (e.g., a gesture depicting *width* while saying “this cup is *wider*”). Finally, children showed greater benefits from gesture than older listeners.

In this section, we review two types of evidence arguing that gesture has an effect on language comprehension: (1) evidence that speakers’ gestures affect listeners’ comprehension of speech, and (2) evidence that speakers’ gestures communicate information that is not expressed in speech. We conclude by considering whether there is evidence that speakers intend their gestures to be communicative.

### 2.2.1. Do speakers’ gestures affect listeners’ comprehension of speech?—

Under ordinary circumstances, listeners comprehend speech with ease. However, if speech is difficult to comprehend, either because it is unclear, ambiguous, or difficult relative to the listeners’ skills, gesture can provide a second channel that makes successful comprehension more likely.

Many studies have investigated whether gestures influence listeners’ comprehension of speech. These include studies using video clips as stimuli (e.g., Kelly & Church 1997) and studies in which listeners view or participate in “live” interactions (e.g., Goldin-Meadow et al 1999, Goldin-Meadow & Sandhofer 1999, Holler et al 2009). Across studies, researchers have used a variety of outcome measures to evaluate comprehension. In some studies, participants are asked to answer questions about the speech they heard (e.g., Kelly & Church 1998); in others, they are asked to restate or reiterate that speech (e.g., Alibali et al 1997). In still other studies, participants’ spontaneous “uptake” of information from others’ speech was assessed, either in their next speaking turn (Goldin-Meadow et al 1999) or in their behavioral responses (McNeil et al 2000).

Across studies, there is strong evidence that gestures affect listeners’ comprehension of speech. When gestures express information that is redundant with speech, they contribute to successful comprehension (Goldin-Meadow et al 1999, McNeil et al 2000). When gestures express information that is not expressed in speech, they can detract from listeners’ direct

uptake of the information in speech (e.g., Goldin-Meadow & Sandhofer 1999), but they often communicate important information in their own right, an issue we address in the next section.

**2.2.2 Does gesture communicate information on its own?**—When gesture conveys the same information as speech, it appears to help listeners pick up that information. But what happens when gesture conveys different information from speech? In the earlier hypothetical example in which the speaker said, “The man was wearing a hat,” while moving her hand as if grasping the bill of a baseball cap, the speaker expressed information about the type of hat (a baseball cap—not a cowboy hat, a stocking cap, or a sombrero) uniquely in gesture. Do listeners detect information that speakers express uniquely in gesture? They do. For example, Kelly and Church (1998) presented video clips of children explaining their judgments of Piagetian conservation tasks, and asked participants to respond to yes/no questions about the reasoning that the children expressed. A child in one video clip mentioned the height of a container in speech, but indicated the width of the container in gesture. When probed, observers often credited this child with reasoning about both the height and the width of the container. Other studies have also shown that listeners often incorporate the information conveyed uniquely in gesture into their own speech (Goldin-Meadow et al 1992, McNeill et al 1994). Thus, observers “credit” speakers with saying things that they express uniquely in gesture.

**2.2.3 Are gestures intended to be communicative?**—It is clear that gestures contribute to listeners’ comprehension. But do speakers intend for their gestures to communicate, or are gestures’ communicative effects merely an epiphenomenon of the gestures that speakers produce in the effort of speech production?

Several lines of evidence suggest that speakers do intend at least some of their gestures to be communicative. First, speakers gesture more when their listeners can see those gestures than when visibility between speaker and listener is blocked (Alibali et al 2001, Mol et al 2011). Second, when speakers repeat a message to different listeners, their gestures rates do not decline as they might if gestures were produced solely to aid with speech production (Jacobs & Garnham 2007). Third, when speakers are explicitly asked to communicate specific information to their listeners, they sometimes express some of that information uniquely in gesture, and not in speech. For example, Melinger and Levelt (2004) explicitly directed speakers to communicate specific spatial information about a task to their addressees. Speakers frequently expressed this requested information in gesture and not in speech, suggesting that at least these gestures were intended to be communicative.

To summarize thus far, gesture plays a role in both language production and comprehension. One area that has received very little attention is individual differences (Bergmann & Kopp 2010, Hostetter & Alibali 2007)—are there differences in the rate at which people gesture when they speak, or in the reliance people put on gesture when they listen to the speech of others? We know little about what accounts for individual differences in gesture, or even how consistent those differences are across tasks and conversational partners. This is an area of research in gesture studies that is ripe for future research.

### 3. Gesture’s role in language learning and beyond

Mature speakers of a language routinely use gesture when they talk, but so do young children just learning to talk. In fact, most children use gesture prior to speaking, and these gestures not only precede linguistic progress, but they also play a role in bringing that progress about.

### 3. 1. Gesture's role in the early stages of language learning

**3.1.1. Gesture precedes and predicts changes in language**—Children typically begin to gesture between 8 and 12 months (Bates 1976, Bates et al 1979). They first use deictic gestures, whose meaning is given entirely by context and not by their form. For example, a child can hold up or point at an object to draw an adult's attention to it months before the child produces her first word (Iverson & Goldin-Meadow 2005). Pointing gestures function like context-sensitive pronouns ("this" or "that") in that an adult has to follow the gesture's trajectory to its target in order to figure out which object the child is indicating. In addition to deictic gestures, children produce conventional gestures common to their cultures (Guidetti 2002). For example, in the United States, children may produce a side-to-side headshake to mean "no" or a finger held over the lips to mean "shush". Children also produce iconic gestures, although initially the number tends to be quite small and varies across children (Acredolo & Goodwyn 1988). For example, a child might open and close her mouth to represent a fish, or flap her hands at her sides to represent a bird (Iverson et al 1994). Unlike pointing gestures, the form of an iconic gesture captures aspects of its intended referent—its meaning is consequently less dependent on context. These gestures therefore have the potential to function like words and, according to Goodwyn and Acredolo (1998, p. 70), they do just that and can be used to express an idea that the child cannot yet express in speech.<sup>1</sup>

Even though they treat their early gestures like words in some respects, children rarely combine gestures with other gestures and, if they do, the phase is short-lived (Goldin-Meadow & Morford 1985). But children do frequently combine their gestures with words, and they produce these combinations well before they combine words with words. Because gesture and speech convey meaning differently, it is rare for the two modalities to contribute identical information to a message. Even simple pointing gestures are not completely redundant with speech. For example, when a child says "bottle" while pointing at the bottle, the word labels and thus classifies, but does not locate, the object. The point, in contrast, indicates where the object is, but not what it is. When produced together, point and word work together to more richly specify the same object. Children's earliest gesture-speech combinations are of this type—gesture conveys information that further specifies the information conveyed in speech; for example, pointing at a box while saying "box" (Capirci et al 1996, de Laguna 1927, Greenfield & Smith 1976, Guillaume 1927, Leopold 1949).

But gesture can also convey information that overlaps very little, if at all, with the information conveyed in the word it accompanies. A point, for example, can indicate an object that is not referred to in speech—the child says "bottle" while pointing at the baby. In this case, word and gesture together convey a simple proposition—"the bottle is the baby's"—that neither modality conveys on its own (Goldin-Meadow & Morford 1985, Greenfield & Smith 1976, Masur 1982, Masur 1983, Morford & Goldin-Meadow 1992, Zinober & Martlew 1985). The types of semantic relations conveyed in these gesture-speech combinations change over time and presage changes in children's speech (Özçaliskan & Goldin-Meadow 2005). For example, children produce constructions containing an argument and a predicate in gesture+speech ("you"+ HIT gesture) at 18 months, but do not produce these constructions in speech alone ("me touch") until 22 months.

Children thus use gesture to communicate before they use words. But do these gestures merely precede language development, or are they fundamentally tied to it? If gesture is

<sup>1</sup>Two other types of gestures found in adult repertoires—the simple rhythmic beat gesture that patterns with discourse and does not convey semantic content, and the metaphoric gesture that represents abstract ideas rather than concrete ones—are not produced by children until much later in development McNeill D. 1992. *Hand and mind: What gestures reveal about thought*. Chicago: University of Chicago Press.

integral to language learning, changes in gesture should not only predate, but also predict, changes in language. And they do. With respect to words, we can predict which lexical items will enter a child's verbal vocabulary by looking at the objects that child indicated in gesture several months earlier (Iverson & Goldin-Meadow 2005). With respect to sentences, we can predict when a child will produce her first two-word utterance by looking at the age at which she first produced combinations in which gesture conveys one idea and speech another (e.g., point at bird+"nap", Goldin-Meadow & Butcher 2003, Iverson et al 2008, Iverson & Goldin-Meadow 2005).

**3.1.2. Gesture can cause linguistic change**—There are (at least) two ways in which *children's own gestures* can change what they know about language. First, as we have just seen, gesture gives young children the opportunity to express ideas that they are not yet able to express in speech. Parents and other listeners may attend to those gestures and "translate" them into speech, thus providing children with timely input about how to express particular ideas in their language. Under this scenario, gesture plays a role in the process of change by shaping children's learning environments. Mothers do, in fact, respond to the gestures their children produce (Golinkoff 1986, Masur 1982), often translating gestures that children produce without speech into words (Goldin-Meadow et al 2007a). These mother translations have been found to have an effect on language learning. With respect to word learning, when mothers translate the gestures that their children produce into words, those words are more likely to quickly become part of the child's vocabulary than words for gestures that mothers do not translate. With respect to sentence learning, children whose mothers frequently translate their child's gestures into speech tend to be first to produce two-word utterances (Goldin-Meadow et al 2007a).

Second, gesture could play a causal role in language learning by providing children with the opportunity to practice ideas and communicative devices that underlie the words and constructions that they are not yet able to express in speech. Repeated practice could then pave the way for later acquisition. Under this scenario, gesture plays a role in the process of change by affecting the learners themselves. Evidence for this hypothesis comes from the fact that child gesture at 14 months is an excellent predictor of child vocabulary at 42 months, often better than other predictors (e.g., family income, parent speech, and even child speech at 14 months, Rowe et al 2008). However, to convincingly demonstrate that child gesture plays a causal role in word learning, we would need to randomly select children and manipulate their gestures, encouraging some to gesture and discouraging others. If the act of gesturing itself contributes to progress in language development (as it does in other domains, see section 3.2.3), children who are encouraged to gesture should have larger vocabularies than children who are discouraged from gesturing.

The *gestures that others produce* may also play a causal role in language learning. By 12 months, children can understand the gestures that other people produce. For example, they can follow an adult's pointing gesture to a target object (Butterworth & Grover 1988, Carpenter et al 1998, Murphy & Messer 1977). Moreover, parents gesture frequently when they interact with their children, and the majority of these gestures co-occur with speech (Acredolo & Goodwyn 1988, Greenfield & Smith 1976, Shatz 1982). Parent gesture could facilitate the child's comprehension, and eventual acquisition, of new words simply by providing nonverbal support for understanding speech {see {Zukow-Goldring, 1996 #782}.

However, it is often hard to tell whether parent gesture has an impact on child language learning above and beyond parent speech. For example, Iverson et al. (Iverson et al 1999) and Pan et al. (2005) both found a relation between parent gesture and later child language, but the relation disappeared when parent speech was taken into account. The best way to convincingly test this hypothesis is to manipulate parent gesture and observe the effects on

child language. Acredolo and Goodwyn (1988) instructed parents to use symbolic gestures (now called *baby signs*, Acredolo & Goodwyn 2002) in addition to words when talking to their children. They found that these children showed greater gains in vocabulary than children whose parents were encouraged to use only words or were not trained at all. But the children whose parents used gesture also used more of their own gestures. The vocabulary gains may thus have been mediated by child gesture.

Previous work has, in fact, found a link between parent gesture and child gesture—parents who gesture a great deal have children who gesture a great deal (Iverson et al 1999, Namy et al 2000, Rowe 2000). Moreover, parent gesture at 14 months predicts child gesture at 14 months, which, in turn, predicts child receptive vocabulary at 42 months. Importantly, parent gesture at 14 months does *not* directly predict child vocabulary at 42 months (Rowe et al 2008), suggesting that parent gesture affects later child vocabulary through child gesture—parents who gesture more have children who gesture more who, in turn, go on to develop relatively large receptive vocabularies in speech.

To summarize thus far, gesture appears to play a role in learning when the task to be learned is language itself. When gesture is produced at this age, it often substitutes for a word that the child has not yet acquired. As we will see in the next section, gesture continues throughout development to convey ideas that are not expressed in speech, but often those ideas cannot easily be translated into a single word (McNeill 1992). Thus, once children have become proficient language users, we should see a change in the kinds of ideas that gesture conveys. Future studies are needed to determine when this transition takes place.

### 3.2. Once language has been mastered: Gesture's role in learning other domains

Gesture thus seems to offer children a “helping hand” as they learn language. Does gesture play a comparable role in other domains? We turn next to this question.

**3.2.1. Gesture reveals understanding not found in speech**—When children explain their understanding of concepts and problem-solving procedures, they often express some aspects of their knowledge in gestures and not in speech. Consider a six-year-old child explaining a Piagetian conservation task, in which two rows of checkers contain the same number; the checkers in one row are spread out and the child is asked whether the two rows continue to have the same number of checkers. Children who do not yet understand number conservation believe that the number of checkers in the transformed row has changed. Figure 1A displays a non-conserving child who says the number is different “because you spreaded them out” and conveys the same information in her gestures (she produces a spreading-out motion over the transformed row). In contrast, Figure 1B displays another non-conserving child who also focuses on the movements of the experimenter in his gestures—he says the number is different “because you moved them.” However, in his gestures, he indicates that the checkers in one row can be paired with the checkers in the second row, that is, he has focused on the one-to-one correspondence between the rows. This child has expressed information about the task in gestures that he did not express at all in his speech. Responses of this sort have been called “gesture-speech mismatches” (Church & Goldin-Meadow 1986).

People express aspects of their knowledge in gesture on a wide range of cognitive tasks, including mathematical equations (e.g., Perry et al 1988), balance tasks (e.g., Pine et al 2004), logical puzzles (e.g., the Tower of Hanoi, Garber & Goldin-Meadow 2002), science explanations (Roth 2002), and even moral reasoning (Church et al 1995). In all of these domains, people sometimes express information in gesture that they do not express in the accompanying speech. Thus, across a wide range of cognitive domains, gesture reveals information about people's reasoning and problem solving that is not found in their speech.



From this perspective, gesture-speech mismatches occur when children explore aspects of the task stimuli in gesture, but do not ultimately express all of those aspects in speech. In the example presented in Figure 1B, the child uses gesture to explore the one-to-one-correspondence between the checkers in the two rows, but he does not ultimately express this aspect of the task in his speech.

### 3.2.2. The mismatch between gesture and speech presages knowledge

**change**—Gesture-speech mismatches are of interest because they provide insight into aspects of learners' knowledge that they do not express in speech. But even more important, mismatches are a good index of the stability of a learner's knowledge. Several studies across a variety of domains have shown that children who produce gesture-speech mismatches when explaining a concept are in state of transitional knowledge with respect to that concept. For example, in the domain of Piagetian conservation, Church and Goldin-Meadow (1986) found that, among partial conservers (i.e., children who conserved on some tasks and not on others), those who produced a majority of mismatches in their conservation explanations prior to instruction were more likely to profit from instruction about conservation than were those who produced few mismatches. Thus, frequent mismatches between speech and gesture in children's task explanations at pretest indexed their readiness to benefit from instruction. Similar findings have been documented in children learning about mathematical equations such as  $3 + 4 + 5 = 3 + \_$  (Perry et al 1988), in children solving balance problems (Pine et al 2004), and in adults learning about stereoisomers in organic chemistry (Ping et al. 2012).

Gesture-speech mismatch thus reflects readiness to learn—and does so better than other possible indices of learning that rely on the verbal channel alone. Church (1999) compared three indices that can be used to predict children's readiness to learn from a conservation lesson: number of pretest responses containing a gesture-speech mismatch (i.e., two different strategies, one in speech, one in gesture), number of pretest responses containing more than one strategy in speech (i.e., two different strategies, both in speech), and total number of different strategies conveyed in speech across the entire pretest. Each of these indices individually predicted learning from the lesson, but when all three were included in the same model, the only significant predictor was gesture-speech mismatch.

Gesture-speech mismatches also index knowledge transition in another sense: the state in which children frequently produce mismatches is both preceded and followed by a state in which they seldom produce mismatches. In a micro-longitudinal study, Alibali and Goldin-Meadow (1993) tracked the relationship between gesture and speech in children's explanations over a series of problems as the children learned to solve mathematical equations, such as  $3 + 4 + 5 = 3 + \_$ . Among children who produced gestures on the task, the large majority of children traversed all or part of the following path: (1) Children began in a state in which they predominantly produced gesture-speech match responses, expressing a single, incorrect strategy for solving the problems conveyed in both gesture and speech. (2) They then progressed to a state in which they produced gesture-speech mismatches, expressing more than one strategy, one in gesture and the other in speech. (3) Finally, they reached a state in which they produced gesture-speech match responses, now expressing a single, *correct* strategy conveyed in both gesture and speech. Thus, the state in which children frequently produce gesture-speech mismatches is also transitional in the sense that it is both preceded and followed by a more stable state.

**3.2.3. Gesture can cause knowledge change**—Gesture can provide information about the content and stability of children's knowledge. But can gesture do more? As in language learning, gesture might play a causal role in the process of knowledge change. There are (at least) two classes of mechanisms by which gestures could play a causal role in

bringing about knowledge change: *social mechanisms* by which learners' gestures convey information about their knowledge states to listeners who, in turn, alter the input they provide to the learners, and *cognitive mechanisms* by which learners' own gestures alter the state their knowledge. We consider each class of mechanisms in turn.

**3.2.3.1 Social mechanisms by which gesture can cause change:** Gesture is implicated in social mechanisms of knowledge change. According to these mechanisms, learners' gestures convey information about their cognitive states to listeners (teachers, parents, or peers), and those listeners then use this information to guide their ongoing interactions with the learners. Learners' gestures can provide information about the leading edge of their knowledge, information that could be used to scaffold their developing understanding. Learners thus have the potential to influence the input they receive just by moving their hands. For the social construction of knowledge to occur in this way, listeners must grasp the information that learners express in their gestures, and they must also change their responses to those learners as a function of the information. Evidence supports both of these steps.

As reviewed earlier in the section on gesture's role in language comprehension, there is evidence that listeners detect and interpret the information that speakers express solely in their gestures on a variety of tasks, for example, on Piagetian conservation problems (Goldin-Meadow et al 1992, Kelly & Church 1997, 1998) and mathematical equations (Alibali et al 1997). Moreover, there is evidence that listeners can detect gestured information not only when viewing speakers on video, but also when interacting with "live" speakers in real time (Goldin-Meadow & Sandhofer 1999).

As one example, Alibali, Flevares, and Goldin-Meadow (1997) presented clips of children explaining mathematics problems to two groups of adults—teachers and college students—and asked the adults to describe each child's reasoning about the problems. Both teachers and college students detected the information that children expressed in their gestures. In some of the clips, the child expressed a strategy for solving the problems solely in gesture. For example, one boy explained his incorrect solution (he put 18 in the blank) to the problem  $5 + 6 + 7 = \_ + 7$  by saying that he added the numbers on the left side of the equation. In gesture; however, he pointed to the 5 and the 6—the two numbers that should be added to yield the correct solution of 11. In reacting to this clip, one teacher said, "What I'm picking up now is [the child's] inability to realize that these (5 and 6) are meant to represent the same number.... There isn't a connection being made by the fact that the 7 on this (left) side of the equal sign is supposed to also be the same as this 7 on this (right) side of the equal sign, which would, you know, once you made that connection it should be fairly clear that the 5 and 6 belong in the box." It seems likely that the teacher's reaction was prompted by the child's gestures. In general, the teachers were more likely to mention a strategy when the target child expressed that strategy solely in gesture than when the target child did not express the strategy in either gesture or speech.

Communication partners can thus glean information from a learner's gestures. But do they use this information to guide their interactions with the learner? If the teacher in the preceding example were asked to instruct the child she viewed in the video, she might point out the two 7's and suggest that the child cancel the like addends and then group and add the remaining numbers. In this way, the teacher would be tailoring her instruction to the child's knowledge state, and instruction that is targeted to a child's knowledge state might be particularly helpful in promoting learning in the child.

Teachers have been found to alter their input to children on the basis of the children's gestures. Goldin-Meadow and Singer (2003) asked teachers to instruct children in one-on-one tutorials on mathematical equations; they asked whether the teachers' instruction varied

as a function of their pupils' gestures. They found that the teachers offered more different types of problem-solving strategies to children who produced gesture-speech mismatches, and also produced more mismatches of their own (i.e., typically a correct strategy in speech and a different correct strategy in gesture) when instructing children who produced mismatches than when instructing children who produced matches. Importantly, including mismatches of this sort in instruction greatly increases the likelihood that children will profit from that instruction (Singer & Goldin-Meadow 2005). Children can thus have an active hand in shaping their own instruction.

**3.2.3.1 Cognitive mechanisms by which gesture can cause change:** There is growing evidence that producing gestures can alter the gesturer's cognitive state. If this is the case, then a learner's gestures will not only *reflect* the process of cognitive change, but also *cause* that change. A number of specific claims regarding how gesturing might cause cognitive change have been made.

First, gestures may manifest implicit knowledge that a learner has about a concept or problem. When learners express this implicit knowledge and express other more explicit knowledge at the same time, the simultaneous activation of these ideas may destabilize their knowledge, making them more receptive to instructional input and more likely to alter their problem-solving strategies. In support of this view, Broaders, Cook, Mitchell, and Goldin-Meadow (2007) told some children to gesture and others not to gesture as they solved a series of mathematical equations. When required to gesture, many children expressed problem-solving strategies in gesture that they had not previously expressed in either speech or gesture. When later given instruction in the problems, it was the children who had been told to gesture and expressed novel information in those gestures who were particularly likely to learn mathematical equivalence.

Second, gesturing could help learners manage how much cognitive effort they expend. Goldin-Meadow, Nusbaum, Kelly and Wagner (2001, see also Ping & Goldin-Meadow 2010, Wagner et al 2004) found that speakers who gestured when explaining how they solved a series of math problems while, at the same time, trying to remember an unrelated list of items had better recall than speakers who did not gesture. This effect holds even when speakers are told when to gesture and told when not to gesture (Cook et al 2012). If gesturing does serve to reduce a learner's effort, that saved effort could be put toward other facets of the problem and thus facilitate learning.

Third, gesturing could serve to highlight perceptual or motor information in a learner's representations of a problem, making that information more likely to be engaged when solving the problem. In line with this view, Alibali and Kita (2010) found that children asked to solve a series of Piagetian conservation tasks were more likely to express information about the perceptual state of the task objects when they were allowed to gesture than when they were not allowed to gesture. Similarly, in a study of adult learners asked to predict how a gear in an array of gears would move if the first gear were rotated in a particular direction, Alibali, Spencer, Knox and Kita (2011) found that learners who were allowed to gesture were more likely to persist in using a perceptual-motor strategy to solve the problems (i.e., modeling the movements of each individual gear), and less likely to shift to a more abstract strategy (i.e., predicting the movement of the gear based on whether the total number of gears was even or odd).

As another example, Beilock and Goldin-Meadow (2010) demonstrated that gesturing can introduce motor information into a speaker's mental representations of a problem. They used two versions of the Tower of Hanoi task, a puzzle in which 4 disks must be moved from one of three pegs to another peg; only one disk can be moved at a time and a bigger disk can

never be placed on top of a smaller disk. In one version, the heaviest disk was also the largest disk; in the other, the heaviest disk was the smallest disk. Importantly, the heaviest disk could not be lifted with one hand. Participants solved the problem twice. Some participants used the “largest=heaviest” version for both trials (the No Switch group); others used the largest=heaviest version on the first trial and the “smallest=heaviest” version on the second trial (the Switch group). In between the two trials, participants were asked to explain how they solved the problem and to gesture during their explanation. Participants who used one-handed gestures when describing the smallest disk during their explanation of the first trial performed worse on the second trial than participants who used two-handed gestures to describe the smallest disk—but only in the Switch group (recall that the smallest disk could no longer be lifted with one hand after the disks were switched). Participants in the No Switch group improved on the task no matter which gestures they produced, as did participants who were not asked to explain their reasoning and thus produced no gestures at all. The participants never mentioned weight in their talk. But weight information is an inherent part of gesturing on this task—one has to use either one hand (=light disk) or two (=heavy disk) when gesturing. When the participants’ gestures highlighted weight information that did not align with the actual movement needed to solve the problem, subsequent performance suffered. Gesturing thus introduced action information into the participants’ problem representations, and this information affected their later problem solving.

It is likely that both cognitive and social mechanisms operate when gesture is involved in bringing about change (Goldin-Meadow 2003a). For example, Streeck (2009) argues that gesturing does not just reflect thought, but it is part of the cognitive process that accomplishes a task and, in this sense, is itself thought. Moreover, because gesture is an observable and external aspect of the cognitive process, it puts thought in the public domain and thus opens the learner to social mechanisms (see also Alac & Hutchins 2004, Goodwin 2007).

#### 4. Gesture’s role in creating language

We have seen that when gesture is produced along with speech, it provides a second window onto the speaker’s thoughts, offering insight into those thoughts that cannot be found in speech and predicting (perhaps even contributing to) cognitive change. The form that gesture assumes when it accompanies speech is imagistic and continuous, complementing the segmented and combinatorial form that characterizes speech. But what happens when the manual modality is called upon to fulfill, on its own, all of the functions of language? Interestingly, when the manual modality takes over the functions of language, as in sign languages of the deaf, it also takes over its segmented and combinatorial form.

##### 4.1. Sign language: Codified manual language systems transmitted across generations

Sign languages of the deaf are autonomous languages that do not depend on the spoken language of the surrounding hearing community. For example, American Sign Language (ASL) is structured very differently from British Sign Language (BSL), despite that fact that English is the spoken language that surrounds both sign communities.

Even though sign languages are processed by the hand and eye rather than the mouth and ear, they have the defining properties of segmentation and combination that characterize all spoken language systems (Klima & Bellugi 1979, Sandler & Lillo-Martin 2006). Sign languages are structured at the sentence level (syntactic structure), at the sign level (morphological structure), and at the sub-sign level and thus have meaningless elements akin to phonemes (phonological structure). Just like words in spoken languages (but unlike the gestures that accompany speech, Goldin-Meadow et al 1996), signs combine to create larger

wholes (sentences) that are typically characterized by a basic order, for example, SVO (Subject-Verb-Object) in ASL (Chen Pichler 2008); SOV in Sign Language of the Netherlands (Coerts 2000). Moreover, the signs that comprise the sentences are themselves composed of meaningful components (morphemes Klima & Bellugi 1979).

Although many of the signs in a language like ASL are iconic (i.e., the form of the sign is transparently related to its referent), iconicity characterizes only a small portion of the signs and structures in any conventional sign language. Moreover, sign languages do not always take advantage of the iconic potential that the manual modality offers. For example, although it would be physically easy to indicate the manner by which a skateboarder moves in a circle within the sign that conveys the path, to be grammatically correct the ASL signer must produce separate, serially linked signs, one for the manner and a separate one for the path (Supalla 1990). As another example, the sign for *slow* in ASL is made by moving one hand across the back of the other hand. When the sign is modified to be *very slow*, it is made more rapidly since this is the particular modification of movement associated with an intensification meaning in ASL (Klima & Bellugi 1979). Thus, modifying the meaning of a sign can reduce its iconicity.

Moreover, the iconicity found in a sign language does not appear to play a significant role in the way the language is processed or learned. For example, young children are just as likely to learn a sign whose form does not resemble its referent as a sign whose form is an iconic depiction of the referent (Bonvillian et al 1983). Similarly, young sign learners find morphologically complex constructions difficult to learn even if they are iconic. Moving the sign *give* from the chest toward the listener would seem to be an iconically transparent way of expressing *I give to you*, and thus ought to be an early acquisition *if* children are paying attention to iconicity. However, the sign turns out to be a relatively late acquisition, presumably because the sign is marked for both the agent (*I*) and the recipient (*you*) and is thus morphologically complex (Meier 1987).

Interestingly, the segmentation and combination that characterizes established languages, signed or spoken, is also found in newly emerging sign languages, as we will see in the next section.

#### 4.2. Emerging sign systems

Deaf children born to deaf parents who are exposed to a conventional sign language learn that language as naturally, and following the same major milestones, as hearing children learning a spoken language from their hearing parents (Lillo-Martin 1999, Newport & Meier 1985). But 90% of deaf children are born to hearing parents who are not likely to know a conventional sign language (Hoffmeister & Wilbur 1980). These hearing parents very often prefer that their deaf child learn a spoken rather than a signed language. They thus choose to educate the child using an oral method of instruction, instruction that focuses on lip-reading and discourages the use of sign language and gesture. Unfortunately, it is extremely difficult for a profoundly deaf child to learn a spoken language, even when that child is given intensive oral education (Mayberry 1992). Under these circumstances, one might expect that a child would not communicate at all. But that is not what happens—deaf children who are unable to use the spoken language input that surrounds them and have not been exposed to sign language do communicate with the hearing individuals in their households and they use gesture to do so.

The gestures that deaf children in these circumstances develop are called *homesigns*. Interestingly, homesigns are characterized by segmentation and combination, as well as many other properties found in natural languages (Goldin-Meadow 2003b). For example, homesigners' gestures form a lexicon, and these lexical items are composed of morphemes

and thus form a system at the word level (Goldin-Meadow et al 2007b). Moreover, the lexical items combine to form syntactically structured strings and thus form a system at the sentence level (Feldman et al 1978, Goldin-Meadow & Mylander 1998), with negative and question sentence modulators (Franklin et al 2011), grammatical categories (Goldin-Meadow et al 1994), and hierarchical structure built around the noun (Hunsicker & Goldin-Meadow 2012). Importantly, homesigners use their gestures not only to make requests of others, but also to comment on the present and non-present (Morford & Goldin-Meadow 1997); to make generic statements about classes of objects (Goldin-Meadow et al 2005); to tell stories about real and imagined events (Morford 1995, Phillips et al 2001); to talk to themselves; and to talk about language (Goldin-Meadow 2003b)—that is, to serve typical functions that all languages serve, signed or spoken.

But homesign does not exhibit all of the properties found in natural language. We can explore the conditions under which homesign takes on more and more linguistic properties to get a handle on factors that may have shaped human language. For example, deaf children rarely remain homesigners in countries like the United States; they either learn a conventional sign language or receive cochlear implants and focus on spoken language. However, in Nicaragua, not only do some homesigners continue to use their gesture systems into adulthood, but in the late 1970s and early 1980s, rapidly expanding programs in special education brought together in great numbers deaf children and adolescents who were, at the time, homesigners (Kegl et al 1999, Senghas 1995). As these children interacted on school buses and in the schoolyard, they converged on a common vocabulary of signs and ways to combine those signs into sentences, and a new language—Nicaraguan Sign Language (NSL)—was born.

NSL has continued to develop as new waves of children enter the community and learn to sign from older peers. NSL is not unique—other sign languages have originated in communal contexts and been passed from generation to generation. The Nicaraguan case is special because the originators of the language are still alive. We thus have in this first generation, taken together with subsequent generations and current day homesigners (child and adult), a living historical record of a language as it develops through its earliest stages.

Analyses of adult homesign in Nicaragua have, in fact, uncovered linguistic structures that may turn out to go beyond the structures found in child homesign: the grammatical category subject (Coppola & Newport 2005); pointing devices representing locations vs. nominals (Coppola & Senghas 2010); morpho-phonological finger complexity patterns (Brentari et al 2012); and morphological devices that mark number (Coppola et al 2012). By contrasting the linguistic systems constructed by child and adult homesigners, we can see the impact that growing older has on language creation.

In addition, by contrasting the linguistic systems constructed by adult homesigners in Nicaragua with the structures used by the first cohort of NSL signers, we can see the impact that a community of users has on language. Having a group with whom they could communicate meant that the first cohort of signers were both producers and receivers of their linguistic system, a circumstance that could lead to a system with greater systematicity, but perhaps less complexity, as the group may need to adjust to the lowest common denominator (i.e., to the homesigner with the least complex system).

Finally, by contrasting the linguistic systems developed by the first and second cohorts of NSL signers (e.g., Senghas 2003), we can see the impact that passing a language through a new generation of learners has on language. Once learners are exposed to a system that has linguistic structure, the processes of language change may be identical to the processes studied in historical linguistics. One interesting question is whether the changes seen in NSL

in its earliest stages are of the same type and magnitude as the changes that occur in mature languages over historical time.

#### 4.4. Gestures used by hearing adults when they are not permitted to speak

A defining feature of homesign is that it is not shared in the way that conventional communication systems are. Deaf homesigners produce gestures to communicate with the hearing individuals in their homes. But the hearing individuals, particularly hearing parents who are committed to teaching their children to talk and thus to oral education, use speech back. Although this speech is often accompanied by gesture (Flaherty & Goldin-Meadow 2010), as we have seen earlier, the gestures that co-occur with speech form an integrated system with that speech and, in this sense, are not free to take on the properties of the deaf child's gestures. As a result, although hearing parents respond to their deaf child's gestures, they do not adopt the gestures themselves (nor do they typically acknowledge that the child even uses gesture to communicate). The parents produce co-speech gestures, not homesigns.

Not surprisingly, then, the structures found in child homesign cannot be traced back to the spontaneous gestures that hearing parents produce while talking to their children (Goldin-Meadow et al 1994, Goldin-Meadow & Mylander 1983). Homesigners see the global and unsegmented gestures that their parents produce. But when gesturing themselves, they use gestures that are characterized by segmentation and combination. The gestures that hearing individuals produce when they talk therefore do not provide a model for the linguistic structures found in homesign.

Nevertheless, co-speech gestures could provide the raw materials (e.g., handshapes, motions) for the linguistic constructions that homesigners build (see, for example, Goldin-Meadow et al 2007b) and, as such, could contribute to the initial stages of an emerging sign language (see Senghas et al 2004). Moreover, the disparity between co-speech gesture and homesign has important implications for language learning. To the extent that the properties of homesign differ from the properties of co-speech gesture, the deaf children themselves are likely to be imposing these particular structural properties on their communication systems. It is an intriguing, but as yet unanswered, question as to where the tendency to impose structure on homesign comes from.

We have seen that co-speech gestures do not assume the linguistic properties found in homesign. But what would happen if we were to ask hearing speakers to abandon speech and create a manual communication system on the spot? Would that system contain the linguistic properties found in homesign? Examining the gestures that hearing speakers produce when requested to communicate without speech allows us to explore the robustness of linguistic constructions created on-line in the manual modality.

Hearing gesturers asked to gesture without speaking are able to construct some properties of language with their hands. For example, the order of the gestures they construct on the spot indicates who does what to whom (Gershkoff-Stowe & Goldin-Meadow 2002, Goldin-Meadow et al 1996). However, hearing gesturers do not display other linguistic properties found in established sign languages and even in homesign. For example, they do not use consistent form-meaning pairings akin to morphemes (Singleton et al 1993), nor do they use the same finger complexity patterns that established sign languages and homesign display (Brentari et al 2012).

Interestingly, the gestures that hearing speakers construct on the spot without speech do not appear to be derived from their spoken language. When hearing speakers of different languages (English, Spanish, Chinese, Turkish) are asked to describe animated events using their hands and no speech, they abandon the order typical of their respective spoken

languages and produce gestures that all conform to the same order—SOV (e.g., captain-pail-swings, Goldin-Meadow et al 2008). This order has been found in some emerging sign languages (e.g., Al-Sayyid Bedouin Sign Language, Sandler et al 2005). Moreover, the SOV order is also found when hearing speakers of the same four languages perform a non-communicative, non-gestural task (Goldin-Meadow et al 2008). Recent work on English-, Turkish-, and Italian-speakers has replicated the SOV order in hearing gesturers, but finds that gesturers move away from this order when given a lexicon (either spoken or manual, Hall et al 2010); when asked to describe reversible events involving two animates (girl pulled man, Meir et al 2010) and when asked to describe more complex events (man tells child that girl catches fish, Langus & Nespors 2010). Studies of hearing gesturers give us the opportunity to manipulate conditions that have the potential to affect communication, and to then observe the effect of those conditions on the structure of the emerging language.

#### 4.5. Do signers gesture?

We have seen that hearing speakers produce analog, imagistic signals in the manual modality (i.e., gesture) along with the segmented, discrete signals they produce in the oral modality (i.e., speech), and that these gestures serve a number of communicative and cognitive functions. The question we now ask is whether signers also produce gestures and, if so, whether those gestures serve the same functions as co-speech gesture.

Deaf signers have been found to gesture when they sign (Emmorey 1999). But do they produce mismatches and do those mismatches predict learning? ASL-signing deaf children were asked to explain their solutions to the same math problems studied in hearing children (Perry et al 1988), and were then given instruction in those problems in ASL. The deaf children produced gestures as often as the hearing children. Moreover, the deaf children who produced many gestures conveying different information from their signs (i.e., gesture-sign mismatches) were more likely to succeed after instruction than the deaf children who produced few (Goldin-Meadow et al in press).

These findings suggest not only that mismatch can occur within a single modality (hand alone), but that within-modality mismatch can predict learning just as well as cross-modality mismatch (hand and mouth). Juxtaposing different ideas across two modalities is thus not essential for mismatch to predict learning. Rather, it appears to be the juxtaposition of different ideas across two distinct representational formats—an analog format underlying gesture vs. a discrete segmented format underlying words or signs—that is responsible for mismatch predicting learning.

### 5. Gesture's role in the clinic and the classroom

The gestures learners spontaneously produce when they talk provide insight into their thoughts—often their cutting-edge thoughts. This fact opens up the possibility that gesture can be used to *assess* children's knowledge in the clinic and the classroom. Moreover, the fact that encouraging learners to gesture on a task can lead to better understanding of the task opens up the possibility that gesture can also be used to *change* what children know in the clinic or the classroom.

#### 5.1. Clinical situations

Gesture can provide unique information about the nature and extent of underlying deficits in children and adults with a variety of language and communication disorders (Capone & McGregor 2004, Goldin-Meadow & Iverson 2010). Studies of a range of disordered populations across the lifespan have identified subgroups on the basis of gesture use and then examined future language in relation to subgroup membership. For example, spontaneous gesture production at 18 months in children with early focal brain injury can be



used to distinguish children who are likely to recover from initial language delay from children who are not likely to recover (Sauer et al 2008).

As another example, infants subsequently diagnosed with autism produce fewer gestures overall and almost no instances of pointing at 12 months, compared to typically developing infants at the same age (Osterling & Dawson 1994, see also Bernabei et al 1998). This finding has been replicated in prospective studies of younger infant siblings of older children already diagnosed with autism. Infant siblings who later turn out to be diagnosed with autism have significantly smaller gesture repertoires at 12 and 18 months than infant siblings who do not receive such a diagnosis, and than a comparison group of infants with no family history of autism. Importantly, at early ages, gesture seems to be more informative about future diagnostic status than word comprehension or production—differences between infant siblings later diagnosed with autism and the two comparison groups do not emerge in speech until 18 months of age (Mitchell et al 2006). Future work is needed to determine whether gesture use (or its lack) is a specific marker of autism or a general marker of language and communication delay independent of etiology.

Early gesture thus appears to be a sign of resilience in children with language difficulties, and an indicator that they may not be delayed in the future. In contrast, adults with aphasia who gesture within the first months after the onset of their illness appear to do *less* well in terms of recovery than aphasic adults who do not gesture (Braddock 2007). An initial pattern of “compensation” via gesture thus appears to be a positive prognostic indicator for language recovery in children, but not in adults. These findings suggest that encouraging gesture might be more helpful to children with language disabilities than to adults.

## 5.2. Educational situations

Because children’s gestures often display information about their thinking that they do not express in speech, gesture can provide teachers with important information about their pupils’ knowledge. As reviewed earlier, there is evidence that teachers not only detect information that children express in gesture (e.g., Alibali et al 1997) but also alter their input to children as a function of those gestures (Goldin-Meadow & Singer 2003).

It is also becoming increasingly clear that the gestures teachers produce during their lessons matter for students’ learning. Many studies have shown that lessons with gestures promote deeper learning (i.e., new forms of reasoning, generalization to new problem types, retention of knowledge) better than lessons without gestures. For example, Church, Ayman-Nolley, and Mahootian (2004) examined first-grade students learning about Piagetian conservation from videotaped lessons and found that, for native English speakers, 91% showed deep learning (i.e., added new same judgments) from a speech-plus-gesture lesson, compared to 53% from a speech-only lesson. For Spanish speakers with little English proficiency, 50% learned from the speech-plus-gesture lesson, compared to 20% from the speech-only lesson. As a second example, Valenzeno, Alibali, and Klatzky (2003) studied preschoolers learning about symmetry from a videotaped lesson and found that children who viewed a speech-plus-gesture lesson succeeded on more than twice as many posttest problems as children who viewed a speech-only lesson (2.08 vs. 0.85 out of 6). Clearly, teachers’ gestures can have a substantial impact on student learning. A teacher’s inclination to support difficult material with gesture may be precisely what their students need to grasp challenging material.

Building on growing evidence that teachers’ gestures matter for student learning, recent studies have sought to characterize how teachers use gesture in naturalistic instructional settings (e.g., Alibali & Nathan 2011, Richland et al 2007). Other research has sought to instruct teachers about how to effectively use gesture (Hostetter et al 2006). Given that

teachers' gestures affect the information that students take up from a lesson, and given that teachers can alter their gestures if they wish to do so, it may be worthwhile for teachers to use gesture intentionally, in a planned and purposeful fashion, to reinforce the message they intend to convey.

In light of evidence that the act of gesturing can itself promote learning, teachers and clinicians may also wish to encourage children and patients to produce gestures themselves. Encouraging children to gesture may serve to activate their implicit knowledge, making them particularly receptive to instruction (Broaders et al 2007). Teachers may also encourage their students to gesture by producing gestures of their own. Cook and Goldin-Meadow (2006) found that children imitated their instructor's gestures in a lesson about a mathematics task and, in turn, children's gestures predicted their success on the math problems after instruction. Thus, teacher gesture promoted student gesture, which in turn fostered cognitive change.

## 6. Conclusions

We have seen that gesture is a robust part of human communication and can be harnessed in a variety of ways. First, gesture reflects what speakers know and can therefore serve as a window onto their thoughts. Importantly, this window often reveals thoughts that speakers do not even know they have. Encouraging speakers (e.g., students, patients, witnesses) to gesture thus has the potential to uncover thoughts that would be useful for individuals who interact with these speakers (teachers, clinicians, interviewers) to know. Second, gesture can change what speakers know. The act of producing gesture can bring out previously unexpressed thoughts and may even introduce new thoughts into a speaker's repertoire, altering the course of a conversation or developmental trajectory as a result. Encouraging gesture thus also has the potential to change cognition. Finally, gesture provides building blocks that can be used to construct a language. By watching how children and adults who do not already have a language put those blocks together, we can observe the process of language creation first hand. Our hands are with us at all times and we routinely use them for communication. They thus provide both researchers and learners with an ever-present tool for understanding how we talk and think.

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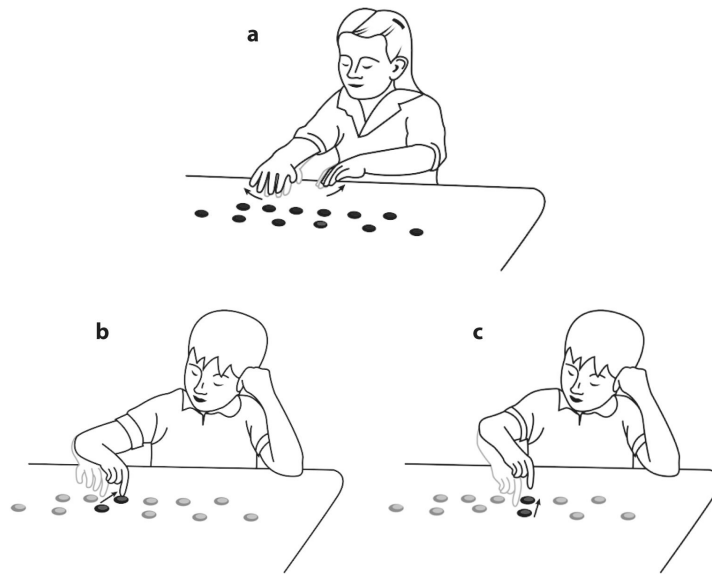
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**Figure 1.** Examples of children gesturing while giving explanations for their non-conserving judgments on a number conservation task. In the top picture (A), the child says, “you spreaded it out,” while producing a spreading motion with her hands, thus producing a gesture-speech match. In the bottom pictures (B), the child says, “you moved them,” again focusing on the experimenter’s movements in speech but, in gesture, he produces pointing gestures that align the checkers in one row with the checkers in the other row (one-to-one correspondence), thus producing a gesture-speech mismatch.