CHAPTER 9

Gesture and Cognitive Development

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A student waves her arm wildly when the teacher asks a question. Another shrinks into her seat while trying hard not to make eye contact. Both are letting the teacher know whether they want to answer the question. Such acts are part of what is called nonverbal communication. A wide-ranging array of behaviors count as nonverbal communication—the home and work environments we create, the distance we establish between ourselves and our listeners, whether we move our bodies, make eye contact, or raise our voices, all collaborate to send messages about us (Knapp, 1978). But these messages, while clearly important in framing a conversation, are not the conversation itself. The student's extended arm or averted gaze does not constitute the answer to the teacher's question—each reflects the student's attitude toward answering the question.

According to Argyle (1975), nonverbal behavior expresses emotion, conveys interpersonal attitudes, presents one's personality, and helps manage turn-taking, feedback, and attention (see also Wundt, 1900/1973). Argyle's characterization fits with most people's intuitions about the role nonverbal behavior plays in communication. But people do not instinctively realize that nonverbal behavior can also reveal thoughts as well as feelings. Indeed, the striking omission from Argyle's list is that nonverbal behavior is given absolutely no role in conveying the message itself—only a role in conveying the speaker's

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attitude toward the message or in regulating the interaction between speaker and listener.

This is the traditional view. Communication is divided into content-filled verbal and affect-filled nonverbal components. Kendon (1980) was among the first to challenge this view, arguing that at least one form of nonverbal behavior—gesture—cannot be separated from the content of the conversation. As McNeill (1992) has shown in his ground-breaking studies of gesture and speech, the hand movements we produce as we talk are tightly intertwined with that talk in timing, meaning, and function. To ignore the information conveyed in these hand movements, these gestures, is to ignore part of the conversation.

This chapter is about children's use of gesture—how they produce gestures of their own and understand the gestures that others produce. I focus on gesture as opposed to other forms of nonverbal behavior precisely because gesture has the potential to reveal information about how speakers think, information that is not always evident in their words. I will show that gesture not only provides insight into the steps children take as they learn new tasks (beginning with early language learning), but through the impact it has on communication and cognition also plays a causal role in the learning process itself. Gesture can thus contribute to our understanding of language, communication, representation, reasoning, and many other phenomena central to talking, thinking, and learning. In addition, because gesture is a representational act performed by the body, a close look at gesture has the potential to enrich—and focus—an area of study that has come to be known as "embodied cognition" (e.g., Barsalou, 1999; Glenberg, & Kaschak, 2002).

I begin by situating gesture within behaviors traditionally identified as nonverbal (the first section, "Situating Gesture Within the Realm of Nonverbal Behavior"). Because gesture is intimately tied to speech, I discuss its development in children whose acquisition of a spoken language follows the typical course (the second section, "The Development of Gesture in Language-Learning Children") and in children who are having difficulty learning spoken language (the third section, "Gesture When Spoken Language-Learning Goes Awry"). We will see that gesture provides an important window onto early language-learning, not only preceding and predicting the onset of linguistic milestones, but also playing an active role in helping children achieve those milestones. We will also see that gesture is remarkably versatile in form and function—it assumes an imagistic and continuous form when it shares the communicative burden with speech, and assumes a segmented and discrete form, the signature of natural language, when it substitutes for speech and takes on the full communicative burden of language. Gesture is shaped by the functions it serves, rather than by the manual modality in which it is produced.

Once language has been learned, gesture continues to play a role in learning other skills. Gesture provides insight into a learner's thoughts, at times, offering a view of those thoughts that is not evident in speech (the fourth section, "Gesture Is a Window Onto the Mind"). Gesture can thus reflect thought. As such, it behooves us to understand the *mechanisms* that underlie gesturing—what makes us gesture (the fifth section, "What Makes Us Gesture? The Mechanisms That Lead to Gesturing"). Finally, we turn to the *functions* of gesturing—what purposes does gesture serve (the sixth section, "Does Gesture Have a Purpose? The Functions That Gesturing Serves")? We will see that gesture plays a role in communication and thinking and, as a result, has an impact on cognitive change; in other words, gesture goes beyond reflecting a learner's thoughts to having a hand in shaping those thoughts.

SITUATING GESTURE WITHIN THE REALM OF NONVERBAL BEHAVIOR

In 1969, Ekman and Friesen proposed a scheme for classifying nonverbal behavior and identified five types: (1) *Affect displays,* whose primary site is the face, convey the speaker's emotions, or at least those emotions that the speaker does not wish to mask (Ekman, Friesen, & Ellsworth, 1972); (2) *Regulators,* which typically involve head movements or slight changes in body position, maintain the give-and-take between speaker and listener and help pace the exchange; (3) *Adaptors* are fragments or reductions of previously learned adaptive hand movements that are maintained by habit—for example, smoothing the hair, pushing glasses up the nose even when they are perfectly positioned, holding or rubbing the chin. Adaptors are performed with little awareness and no intent to communicate; (4) *Illustrators* are hand movements that are part of an intentional speech act. They typically are produced along with speech and often illustrate that speech—for example, a child says that the way to get to her classroom is to go upstairs and, at the same time, bounces her hand upward; (5) *Emblems* are hand movements that have conventional forms and meanings—for example, the "thumbs up," the "okay," the "shush." Speakers are typically aware of having produced an emblem and produce them, with speech or without it, to communicate with others, often to control their behavior.

This chapter focuses on illustrators—called *gesticulation* by Kendon (1980) and plain old *gesture* by McNeill (1992), the term I will use here. The other four categories of nonverbal behavior (affect displays, regulators, adaptors, emblems) as catalogued by Ekman and Friesen (1969), as well as nonverbal acts such as mime and sign languages of deaf communities that are learned, are not addressed in this chapter. Also not included are the gestures, called "baby signs" (Acredolo & Goodwyn, 1996), that some hearing parents teach their young children to promote communication during the prelinguistic period (but see Kirk, Howlett, Pine, & Fletcher, 2013, for evidence that baby signs may not actually serve this purpose).

Gestures can mark the tempo of speech (beat gestures), point out referents of speech (deictic gestures), or exploit imagery to elaborate the contents of speech (iconic or metaphoric gestures). Note that gestures sit somewhere between adaptors and regulators at one end and emblems at the other end of the awareness spectrum. People are almost never aware of having produced an adaptor or regulator and are almost always aware of having produced an emblem. Because gestures are produced along with speech, they take on the intentionality of speech. Gestures are produced in the service of communication and, in this sense, are deliberate, but they rarely come under conscious control.

Gestures differ from emblems in a number of other ways (McNeill, 1992). Gestures depend on speech. Emblems do not. Indeed, emblems convey their meanings perfectly well when produced without any speech at all. In contrast, the meaning of a gesture is constructed in an ad hoc fashion in the context of the speech it accompanies. In the example given above, the bouncing-upward gesture referred to taking the stairs. If that same movement were produced in the context of the sentence "production increases every year," it would refer instead to yearly incremental increases. In contrast, emblems have a constant form-meaning relation that does not depend on the vagaries of the conversation. The "thumbs-up" emblem means "things are good" independent of the particular sentence it accompanies and even if not accompanied by any sentence whatsoever. Emblems are also held to standards of form. Imagine making the "thumbs-up" sign with the pinky, rather than the thumb—it just doesn't work. But producing the bouncing-upward gesture with either a pointing hand, an open palm, or even an O-shaped hand seems perfectly acceptable. In this sense, emblems (but not gestures) are like words, with established forms that can be understood and critiqued by members of the community in the absence of context or explanation.

It is precisely because gestures are produced as part of an intentional communicative act (unlike adaptors), and are constructed at the moment of speaking (unlike emblems) that they are of interest to us. They participate in communication yet they are not part of a codified system. As such, they are free to take on forms that speech cannot assume or, for a child who has not yet mastered a task, forms that the child cannot yet articulate in speech. As we will see in the next section, many children use gesture even before they are able to speak.

THE DEVELOPMENT OF GESTURE IN LANGUAGE-LEARNING CHILDREN

We begin by examining how children who are progressing along a typical developmental pathway use gesture.

Becoming a Gesture Producer

Children are both receivers and producers of gesture. We focus first on the trajectory children follow as they become gesture producers.

Gesture Is an Early Form of Communication

At a time in their development when children are limited in what they can say, gesture offers an additional avenue of expression, one that can extend the range of ideas a child is able to express. And young children take advantage of this offer (Bates, 1976; Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979; Petitto, 1988). For example, in a group of 23 children learning Italian, all 23 used gestures at 12 months (only 21 used words; Camaioni, Caselli, Longobardi, & Volterra, 1991). Moreover, the children's gestural vocabularies, on average, were twice the size of their speech vocabularies (11 gestures versus 5.5 words). Strikingly, even deaf children acquiring sign language produce gestures (e.g., Goldin-Meadow, Shield, Lenzen, Herzig & Padden, 2012b) and, at the earliest stages of language-learning, they produce more gestures than signs (Capirci, Montanari, & Volterra, 1998).

Children typically begin to gesture between 8 and 12 months (Bates, 1976; Bates et al., 1979). They first use deictics, pointing or hold-up gestures, whose meaning is given entirely by the context and not by their form. For example, a child of 8 months may hold up objects to draw an adult's attention to them and, several months later, point at objects to draw attention to them. In addition to deictic gestures, children produce the conventional gestures common in their cultures, for example, nods and side-to-side headshakes. Finally, at about a year, children begin to produce iconic gestures, although the number tends to be quite small and variable across children (Acredolo & Goodwyn, 1988). For example, a child might open and close her mouth to represent a fish, or flap her hands to represent a bird (Iverson, Capirci, & Caselli, 1994). But it is not until 2 years that the majority of children produce iconic gestures. In a study of 40 English-learning children, Özçalişkan and Goldin-Meadow (2011) found an abrupt increase in the iconic gestures children produced at 26 months, but an increase in deictic gestures almost a full year earlier, at 18 months. Children do not begin to produce beat or metaphoric gestures until much later in development (McNeill, 1992).

Deictic gestures offer children a relatively accessible route into language. Indeed, pointing gestures precede spoken words by several months for some children, and often predict the onset of particular words (e.g., a child's early point at a dog predicts the entry of the word "dog" into that child's spoken vocabulary 3 months later, Iverson & Goldin-Meadow, 2005). These early pointing gestures are unlike nouns in that an adult has to follow the gesture's trajectory to its target in order to figure out which object the child means to indicate. In this sense, they more closely resemble the context-sensitive pronouns "this" or "that." Despite their reliance on the here-and-now, pointing gestures constitute an important early step in symbolic development and pave the way for learning spoken language. Iverson, Tencer, Lany, and Goldin-Meadow (2000) observed five children at the earliest stages of language-learning, and calculated how many objects a child referred to using speech only ("ball"), gesture only (point at ball), or both ("ball" and point at ball, produced either at the same time or at separate moments). The children referred to a surprisingly small percentage of objects in speech only, and an even smaller percentage in both speech and gesture. Over half of the objects the children mentioned were referred to *only* in gesture. This pattern is consistent with the view that gesture serves a "bootstrapping" function in lexical development—it provides a way for the child to refer to objects in the environment without actually having to produce the appropriate verbal label.

Unlike a pointing gesture, 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. Children use their iconic gestures to label a wide range of objects (tractors, trees, rabbits, rain). They use them to describe how an object looks (big), how it feels (hot), and even whether it is there (all gone). They use them to request objects (bottle) and actions (out). However, there are differences across children, not only in how often they use iconic gestures, but also in whether they use these gestures when they cannot yet use words. Goodwyn and Acredolo (1993) compared the ages at which children first used words and iconic gestures symbolically. They found that the onset of words occurred at the same time as the onset of iconic gestures for only 13 of their 22 children. The other 9 began producing gestural symbols at least 1 month before they began producing verbal symbols—some began as much as 3 months before. Importantly, none of the children produced verbal symbols before they produced gestural symbols. In other words, none of the children found words easier than iconic gestures, but some did find iconic gestures easier than words. Interestingly, however, unlike deictic gestures, which appear to pave the way for children's early nouns (Iverson & Goldin-Meadow, 2005), iconic gestures that depict actions do not precede and predict verbs and, in fact, onset 6 months *later* than children's first verbs (Özçalişkan, Gentner & Goldin-Meadow, 2013).

Not surprisingly, children stop using symbolic gestures as words as they develop. They use fewer gestural symbols once they begin to combine words with other words, whether the language they are learning is English (Acredolo & Goodwyn, 1985, 1988) or Italian (Iverson et al., 1994). There thus appears to be a shift over developmental time—at the beginning children seem to be willing to accept either gestural or verbal symbols, but as they develop, children begin to rely more heavily on verbal symbols. Indeed, Namy and Waxman (1998) have found experimental support for this developmental shift. They tried to teach 18- and 26-month-old English-learning children novel words and novel gestures. Children at both ages learned the words, but only the *younger* children learned the gestures. The older children had already figured out that words, not gestures, carry the communicative burden in their worlds. Moreover, even at the earliest stages, children seem to treat gestures not as labels for objects, but as descriptors providing information about the functions or features of objects (Marentette & Nicoladis, 2011). If children treat gestures as labels, the iconity of the gesture (i.e., whether a link can be made between the gesture and the object it represents) should have no impact on the child's ability to make the mapping between gesture and object. If, on the other hand, children treat gestures as action associates that provide information about what one can do with the object, then iconicity might be expected to have an impact on the child's ability to map gesture on object—iconic gestures should be relatively easy to map onto objects, arbitrary gestures should be harder. Marentette and Nicoladis (2011) found that children ages 40 to 60 months had more difficulty mapping arbitrary gestures than iconic gestures onto their referents, providing support for the idea that gestures are not labels for objects for young children.

Children thus exploit the manual modality at the very earliest stages of language-learning. Perhaps they do so because the manual modality presents fewer burdens. It certainly seems easier to produce a pointing gesture to indicate a bird than to articulate the word "bird." It may even be easier to generate a wing-flap motion than to say "bird"—children may need more motor control to make their mouths produce words than to make their hands produce gestures. The fact that deaf children learning sign language have been reported to produce their first signs earlier than hearing children learning spoken languages produce their first words lends support to this hypothesis (Meier & Newport, 1990, although it is interesting to note that deaf children do not exhibit the same modality advantage when it comes to the production of first sentences). Whatever the reason, gesture does seem to provide an early route to first words, at least for some children.

Even though they treat gestures like words in some respects, children very rarely combine their spontaneous gestures with other gestures and, if they do, the phase tends to be short-lived (Goldin-Meadow & Morford, 1985). But children do frequently combine their gestures with words, and they produce these word-plus-gesture combinations well before they combine words with words. Children's earliest gesture-speech combinations contain gestures that convey information redundant with the information conveyed in speech; for example, pointing at an object while naming it (de Laguna, 1927; Greenfield & Smith, 1976; Guillaume, 1927; Leopold, 1949). The onset of these gesture-speech combinations marks the beginning of gesture-speech integration in the young child's communications, an accomplishment to which we now turn.

Gesture Becomes Integrated With Speech During the One-Word Period

The proportion of a child's communications that contains gesture seems to remain relatively constant throughout the single word period. What changes over this time period is the relationship gesture holds to speech. At the beginning of the one-word period, the following three properties characterize children's gestures:

1. Gesture is frequently produced alone; that is, without any vocalizations at all, either meaningless sounds or meaningful words.
2. On the rare occasions that gesture is produced with a vocalization, it is combined only with meaningless sounds and not with words; this omission is striking given that the child is able to produce meaningful words without gesture during this period.
3. The few gesture-plus-meaningless sound combinations that the child produces are not timed in an adult fashion; that is, the sound does not occur on the stroke or the peak of the gesture (cf. Kendon, 1980; McNeill, 1992).

Some time during the one-word period, two notable changes take place in the relationship between gesture and speech (Butcher & Goldin-Meadow, 2000). First, gesture-alone communications decrease and, in their place, the child begins to produce gesture-plus-meaningful-word combinations for the first time. Gesture and speech thus begin to have a *coherent semantic* relationship with one another. Second, gesture becomes synchronized with speech, not only with the meaningful words that comprise the novel combinations but also, importantly, with the old combinations that contain meaningless sounds (in other words, temporal synchronization applies to both meaningful and meaningless units and is therefore a separate phenomenon from semantic coherence). Thus, gesture and speech begin to have a *synchronous temporal* relationship with one another. These two properties—semantic coherence and temporal synchrony—characterize the integrated gesture-speech system found in adults (McNeill, 1992) and appear to have their origins during the one-word period.

This moment of integration is the culmination of the increasingly tight relation that has been evolving between hand and mouth (Iverson & Thelen, 1999). Infants produce rhythmic manual behaviors prior to the onset of babbling. These manual behaviors entrain vocal activity so that the child's vocalizations begin to adopt the hand's rhythmical organization, thus assuming a pattern characteristic of reduplicated babble (Ejiri & Masataka, 2001). These rhythmic vocalizations become more frequent with manual behaviors and less frequent with nonmanual behaviors. Thus, by 9 to 12 months, the time when children produce their first words and gestures, the link between hand and mouth is strong, specific, and stable, and ready to be used for communication (Iverson & Fagan, 2004).

Moreover, the onset of gesture-speech integration sets the stage for a new type of gesture-speech combination—combinations in which gesture conveys information that is different from the information conveyed in speech. For example, a child can gesture at an object while describing the action to be done on that object in speech (pointing to an apple and saying, "give"), or gesture at an object while describing the owner of that object in speech (pointing at a toy and saying, "mine") (Goldin-Meadow & Morford, 1985; Greenfield & Smith, 1976; Masur, 1982, 1983; Morford & Goldin-Meadow, 1992; Zinober & Martlew, 1985). This type of gesture-speech combination allows a child to express two elements of a proposition (one in gesture and one in speech) at a time when the child is not yet able to express those elements within a single spoken utterance. Children begin to produce combinations in which gesture conveys different information from speech (point at box + "open") at the same time as, or later than—but *not* before—combinations in which gesture and speech convey the same information (point at box + "box"; Goldin-Meadow & Butcher, 2003). Thus, combinations in which gesture and speech convey different information are not produced until *after* gesture and speech become synchronized, and thus appear to be a product of an integrated gesture-speech system (rather than a product of two systems functioning independently of one another).

In turn, combinations in which gesture and speech convey different information predict the onset of two-word combinations. Goldin-Meadow and Butcher (2003) found in six English-learning children that the correlation between the age of onset of this type of gesture-speech combination and the age of onset of two-word combinations was high ($r_s = .90$) and reliable. The children who were first to produce combinations in which gesture and speech conveyed different information were also first to produce two-word combinations. Importantly, the correlation between gesture-speech combinations and two-word speech was specific to combinations in which gesture and speech conveyed *different* information—the correlation between the age of onset of combinations in which gesture and speech conveyed the *same* information and the age of onset of two-word combinations was low and unreliable. It is the *relation* that gesture holds to speech that matters, not merely gesture's presence (see also Özçalişkan & Goldin-Meadow, 2005a).

Thus, once gesture and speech become integrated into a single system (as indexed by the onset of semantically coherent and temporally synchronized gesture-speech combinations), the stage is set for the child to use the two modalities to convey two distinct pieces of a single proposition within the same communicative act. Moreover, the ability to use gesture and speech to convey different semantic elements of a proposition is a harbinger of the child's next step—producing two elements within a single spoken utterance, that is, producing a simple sentence (see also Capirci, Montanari, & Volterra, 1998; Cartmill, Hunsicker, & Goldin-Meadow, 2014; Goodwyn & Acredolo, 1998; Iverson & Goldin-Meadow, 2005).

Interestingly, however, after a construction is established in a child's repertoire, the child no longer seems to use gesture as a stepping-stone to flesh out the construction. For example, children produce their first instance of an action + object construction in speech combined with gesture (e.g., "bite" + point at toast) and only later in speech alone (e.g., "drink your tea"), but when they later include the agent in the construction (i.e., agent + action + object), they do so at the same time in speech combined with gesture (e.g., point at father + "have food") and in speech alone (e.g., "I want the Lego") (Özçalişkan & Goldin-Meadow, 2009). In other words, once the skeleton of a construction is established in a child's communicative repertoire, the child no longer relies on gesture as a stepping-stone to flesh out that skeleton with additional arguments. Thus, as the verbal system becomes the preferred means of communication, the gestural system may undergo reorganization with respect to language learning, moving from a state in which gesture is a harbinger of linguistic skills that will soon appear in speech, to a state in which gesture enriches the speaker's communicative repertoire in response to discourse pressures (McNeill, 1992). But gesture remains a harbinger of things to come with respect to other cognitive skills (Goldin-Meadow, 2003b), as we will see in the next section.

Gesture Continues to Play a Role in Communication Over the Course of Development

The findings described thus far suggest that gesture and speech become part of a unified system sometime during the one-word period of language development. Over time, children become proficient users of their spoken language. At the same time, rather than dropping out of children's communicative repertoires, gesture itself continues to develop and play an important role in communication. Older children frequently use hand gestures as they speak (Jancovic, Devoe, & Wiener, 1975), gesturing, for example, when asked to narrate a story (e.g., McNeill, 1992), give directions (e.g., Iverson, 1999), or explain their reasoning on a series of problems (e.g., Church & Goldin-Meadow, 1986).

As in earlier stages, older children often use their hands to convey information that overlaps with the information conveyed in speech. Take, for example, a child participating in a Piagetian conservation task. The child is asked whether the amount of water changed when it was poured from a tall, skinny container into a short, wide container. The child says that the amount of water did change "'cause that's down lower than that one," while first pointing at the relatively low water level in the short, wide container and then at the higher water level in the tall, skinny container (Figure 9.1*a*). The child is focusing on the height of the water in both speech and gesture and, in this sense, has produced a *gesture-speech match*.

However, children also use their gestures to introduce information that is not found in their speech. Consider another child who gave the same response in speech, "'cause this one's lower than this one," but indicated the *widths* (not the heights) of the containers with her hands (two C-shaped hands held around the relatively wide diameter of the short, wide container, followed by a left C-hand held around the narrower diameter of the tall, skinny container; Figure 9.1*b*). In this case, the child is focusing on the height of the water in speech but on its width in gesture, and has produced a *gesture-speech mismatch* (Church & Goldin-Meadow, 1986). I use the term "gesture-speech mismatch" to refer to utterances in which the information conveyed in gesture is different from, but potentially able to be integrated with, the information conveyed in the accompanying speech. In other words, the information conveyed in gesture in a mismatch does not contradict the information conveyed in speech (e.g., pointing right while saying "left"); gesture-speech contradictions are true errors and are relatively infrequent (see the first part of the section "Gesture Can Reveal Thoughts Not Found in Speech" for additional discussion).

As in the early stages of language development (see Goldin-Meadow & Butcher, 2003), gesture and speech adhere to the principles of gesture-speech integration described by McNeill (1992), even when the two modalities convey different information. Consider the child in Figure 9.1*b*. She says the amount is different because the water in the short wide container is "lower" while indicating the width of the container in her gestures. Although this child is indeed expressing two different pieces of information in gesture and speech, she is nevertheless describing the same object in the two modalities. Moreover, the timing of the gesture-speech mismatch also reflects an integrated system. The child produces the width gesture as she says "this one's lower," thus synchronously expressing her two perspectives on the container.

Further evidence that gesture-speech mismatches reflect an integrated system comes from the fact that, as in the transition from one- to two-word speech, the relationship between gesture and speech is a harbinger of the child's next step. Children who produce many gesture-speech mismatches when explaining their solutions to a task appear to be in a transitional state with respect to that task—they are more likely to profit from instruction and make progress in

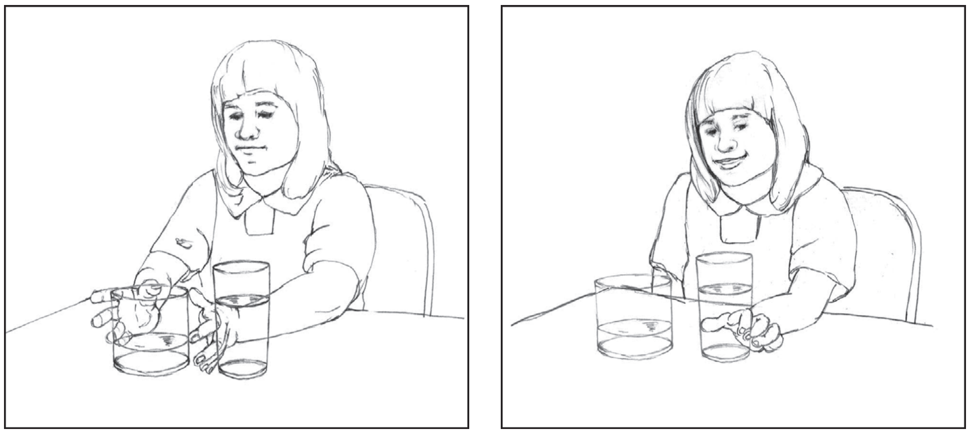

Figure 9.1 Examples of children explaining why they think the amount of water in the two containers is different. Both children say that the amount is different because the water level is lower in one container than the other. The child in the top two pictures (*a*) conveys the *same* information in gesture (he indicates the height of the water in each container)—he has produced a gesture-speech match. The child in the bottom two pictures (*b*) conveys *different* information in gesture (she indicates the width of each container)—she has produced a gesture-speech mismatch.

Source: Reprinted from Goldin-Meadow, 2003b.

the task than children who produce few mismatches. Thus, the child in Figure 1B is more likely to profit from instruction in conservation than the child in Figure 9.1*a* (Church & Goldin-Meadow, 1986). Gesture can serve as an index of readiness-to-learn not only for conservation but for other tasks as well—for example, mathematical equivalence as it applies to addition (Perry, Church, & Goldin-Meadow, 1988), balancing a beam on a fulcrum (Pine, Lufkin, & Messer, 2004) and, as we have seen, making the transition from one- to two-word speech (Goldin-Meadow & Butcher, 2003; Iverson & Goldin-Meadow, 2005). If gesture and speech were independent of one another, their mismatch would be a random event and, as a result, should have no cognitive consequence whatsoever. The fact that gesture-speech mismatch is a reliable index of a child's transitional status suggests that the two modalities are, in fact, *not* independent of one another (Goldin-Meadow, Alibali, & Church, 1993).

Importantly, gesture-speech mismatch is not limited to a particular age, nor to a particular task. Communications in which gesture conveys different information from speech have been found in a variety of tasks and over a large age range: 18-month-old infants going through their vocabulary spurt (Gershkoff-Stowe & Smith, 1997); preschoolers reasoning about a board game (Evans & Rubin, 1979), learning to count (Graham, 1999), or performing a mental transformation task (Ehrlich, Levine & Goldin-Meadow, 2006); elementary school children reasoning about conservation (Church and Goldin-Meadow, 1986) and mathematics (Perry et al., 1988) problems; middle-schoolers reasoning about seasonal change (Crowder & Newman, 1993); children and adults reasoning about moral dilemmas (Church, Schonert-Reichl, Goodman, Kelly, & Ayman-Nolley, 1995); children and adults explaining how they solved a logical puzzle (Tower of Hanoi) which requires moving three graduated disks from one peg to another, moving only one disk at a time and without placing a larger disk on a smaller one (Garber & Goldin-Meadow, 2002); adolescents predicting when rods of different materials and thicknesses will bend (Stone, Webb, & Mahootian, 1991); adults reasoning about gears (Perry & Elder, 1997), about problems involving constant change (Alibali, Bassok, Olseth, Syc, & Goldin-Meadow1999), about stereoisomers in organic chemistry (Ping et al., 2013), and about problems in geoscience (Kastens, Agrawal, & Liben, 2008); adults describing pictures of landscapes, abstract art, buildings, people, machines, and so on (Morrel-Samuels & Krauss, 1992) and narrating cartoon stories (Beattie & Shovelton, 1999a; McNeill, 1992; Rauscher, Krauss, & Chen, 1996).

Moreover, communications in which gesture and speech convey different information can be quite frequent within an individual. At certain points in their acquisition of a task, children have been found to produce gesture-speech mismatches in over half of their explanations of that task (Church & Goldin-Meadow, 1986; Perry et al., 1988; Pine et al., 2004).

Thus, gesture continues to accompany speech throughout childhood (and adulthood), forming a complementary system across the two modalities. At all ages, gesture provides another medium through which ideas can be conveyed, a medium that is analog in nature. It is, in addition, a medium that is not codified and therefore not constrained by rules and standards of form, as is speech.

Becoming a Gesture Comprehender

Children not only produce gestures—they also receive them. There is good evidence that children can understand the gestures that others produce by 12 months. For example, children look at a target to which an adult is pointing at 12 to 15 months (Butterworth & Grover, 1988; Leung & Rheingold, 1981; Murphy & Messer, 1977), and toddlers can use gesture as a source of information to support word learning (Booth, McGregor, & Rohlfing, 2008; McGregor, Rohlfing, Bean, & Marschner, 2008). But do young children integrate the information they get from the pointing gesture with the message they are getting from speech?

Allen and Shatz (1983) asked 18-month-olds a series of questions with and without gesture, for example, "what says meow?" uttered while holding up a toy cat or cow. The children were more likely to provide some sort of response when the question was accompanied by a gesture. However, they were no more likely to give the *right* response, even when the gesture provided the correct hint (i.e., holding up the cat versus the cow). From these observations, we might guess that, for children of this age, gesture serves merely as an attention-getter, not as a source of information.

Macnamara (1977) presented children of roughly the same age with two gestures—the pointing gesture or the hold-out gesture (extending an object out to a child, as though offering it)—and varied the speech that went with each gesture. In this study, the children did respond to the gesture, although nonverbally—they looked at the objects that were pointed at, and reached for the objects that were held out. Moreover, when there was a conflict between the information conveyed in gesture and speech, the children went with gesture. For example, if the pointed-at object was not the object named in the speech, the child looked at the object indicated by the gesture.

From these studies, we know that very young children notice gesture and can even respond appropriately to it. However, we do not know whether young children can integrate information across gesture and speech. To find out, we need to present them with information that has the possibility of being integrated. Morford and Goldin-Meadow (1992) did just that in a study of children in the one-word stage. The children were given "sentences" composed of a word and a gesture, for example, "push" said while pointing at a ball; or "clock" said while producing a *give* gesture (flat hand, palm facing up, held at chest level). If the children could integrate information across gesture and speech, they ought to respond to the first sentence by pushing the ball, and to the second by giving the clock. If not, they might throw the ball or push some other object in response to the first sentence, and shake the clock or give a different object in response to the second sentence. The children responded by pushing the ball and giving the clock—that is, their responses indicated that they were indeed able to integrate information across gesture and speech. Moreover, they responded more accurately to the "push" + point at ball sentence than to the same information presented entirely in speech—"push ball." For these one-word children, gesture + word combinations were *easier* to interpret than word + word combinations conveying the same information.

One more point deserves mention—the gesture + word combinations were more than the sum of their parts. Morford and Goldin-Meadow (1992) summed the number of times the children pushed the ball when presented with the word "push" alone (0.7) with the number of times the children pushed the ball when presented with the point at ball gesture on its own (1.0). That sum was significantly smaller than the number of times the children pushed the ball when presented with the "push" + point at ball combination (4.9). In other words, the children needed to experience *both* parts of the gesture + word combination in order to produce the correct response. Gesture and speech together evoked a different response from the child than either gesture alone or speech alone.

Kelly (2001) found the same effect in slightly older children responding to more sophisticated messages. The situation was as natural as possible in an experimental situation. A child was brought into a room and the door was left ajar. In the speech-only condition, the adult said, "it's going to get loud in here" and did nothing else. In the gesture only condition, the adult said nothing and pointed at the open door. In the gesture + speech condition, the adult said, "it's going to get loud in here" while pointing at the door. The adult wanted the child to get up and close the door, but he didn't indicate his wishes directly in either gesture or speech. The child had to make a pragmatic inference in order to respond to the adult's intended message.

Even 3-year-olds were able to make this inference, and were much more likely to do so when presented with gesture + speech than with either part alone. Kelly summed the proportion of times the 3-year-olds responded correctly (i.e., they closed the door) when presented with speech alone (.12) and when presented with gesture alone (.22). That sum (.34) was significantly smaller than the proportion of times the children responded correctly when presented with gesture + speech (.73). Interestingly, 4-year-olds did not show this emergent effect. Unlike younger children who needed both gesture and speech in order to infer the adult's intended meaning, 4-year-olds could make pragmatic inferences from either speech or gesture on its own. Thus, for 3-year-olds (but not 4-year-olds), gesture and speech must work together to codetermine meaning in sentences of this type. Gesture on its own is ambiguous in this context, and needs speech (or a knowing listener) to constrain its meaning. However, *speech* on its own is ambiguous in the same way, and needs gesture to constrain its meaning. It appears to be a two-way street.

Not surprisingly, older children are also able to get meaning from gesture. Moreover, they look like adults in their ability to do so (see the first part of the section "What Makes Us Gesture? The Mechanisms That Lead to Gesturing"). Kelly and Church (1997) asked 7- and 8-year-old children to watch the videotapes of other children participating in conservation tasks. In half of the examples, the children on the videotape produced gestures that conveyed the same information as their speech (i.e., gesture-speech matches, see Figure 9.1*a*); in the other half, they produced gestures that conveyed different information from their speech (i.e., gesture-speech mismatches, Figure 9.1*b*). The children in the study simply described to the experimenter how they thought the child in the videotape explained his or her answer. The child observers were able to glean substantive information from gesture, often picking up information that the child in the videotape had produced *only* in gesture. For example, if asked to assess the child in Figure 9.1*b*, children would attribute knowledge of the widths of the containers to the child despite the fact that she had expressed width only in her gestures.

Children thus get meaning from the gestures that accompany speech. Moreover, those meanings have an impact on how much information is gleaned from the speech itself. Goldin-Meadow, Kim, and Singer (1999; see also Goldin-Meadow & Singer, 2003) found that teachers' gestures can affect the way their students interpret their *speech* in a math tutorial—at times gesture helps comprehension; at other times, gesture hurts it. Children were *more* likely to repeat a problem-solving strategy the teacher produced in speech when that speech was accompanied by a matching gesture than when it was accompanied by no gesture at all. Consequently, when gesture conveys the same message as speech, perhaps not surprisingly, it helps the child arrive at that message. Conversely, children were *less* likely to repeat a strategy the teacher produced in speech when that speech was accompanied by a mismatching gesture than when it was accompanied by no gesture at all. When gesture conveys a different message from speech, it may detract from the child's ability to arrive at the message presented in speech.

The Gestural Input Children Receive

Little is known about the gestures that children receive as input during development. Bekken (1989) observed mothers interacting with their 18-month-old daughters in an everyday play situation and examined the gestures that those mothers produced when talking to their children. She found that mothers gestured less frequently overall when talking to a child compared to an adult, but produced proportionately more simple pointing gestures. Shatz (1982) similarly found that, when talking to young language-learning children, adults produce a small number of relatively simple gestures (i.e., pointing gestures rather than metaphoric and beat gestures).

More recently, Iverson, Capirci, Longobardi, and Caselli (1999) observed Italian mothers interacting with their 16- to 20-month-old children, and found that the mothers gestured less than their children did. However, when the mothers did gesture, their gestures co-occurred with speech, were conceptually simple (pointing or conventional gestures), referred to the immediate context, and were used to reinforce the message conveyed in speech. In other words, the mothers' gestures took on a simplified form reminiscent of the simplified "motherese" they used in speech. In addition, the mothers varied widely in their overall production of gesture and speech, some talking and gesturing quite a bit and others less so. And those differences were relatively stable over time despite changes in the children's use of gesture and speech (see Özçalişkan & Goldin-Meadow, 2005b).

Namy, Acredolo and Goodwyn (2000) found that the number of gestures parents produced during a book-reading task with their 15-month-old children was highly correlated with the number of gestures the children themselves produced. Indeed, Acredolo and Goodwyn (1985, 1988; Goodwyn & Acredolo, 1993) found that the majority of gestures acquired by infants are derived from gestural or motor routines that parents engage in with them, either deliberately (e.g., the itsy-bitsy spider song which is routinely accompanied by a finger gesture depicting a spider crawling motion) or unwittingly (e.g., sniffing a flower). In a cross-cultural analysis, Goldin-Meadow and Saltzman (2000) found that Chinese mothers gestured significantly more when talking to their orally trained deaf children (and to their hearing children) than did American mothers. In turn, the Chinese deaf children produced more gestures than the American deaf children (Wang, Mylander, & Goldin-Meadow, 1993). As a final example of an observational study, Rowe and Goldin-Meadow (2009) videotaped 50 14-month-old American children and their parents in homes that ranged in socioeconomic status (SES), and also assessed the children's vocabulary skills at 54 months prior to school entry. They found that children from high-SES homes frequently used gesture to communicate at 14 months, and that this relation could be explained by parent gesture use (with speech controlled) at 14 months. In turn, the fact that children from high-SES homes have large vocabularies at 54 months was explained by children's (but not parents') gesture use at 14 months, suggesting that early parent gesture has an impact on early child gesture, which, in turn, has an impact on later child vocabulary.

Moreover, evidence from experimental studies suggests that the gestures adults produce are not just correlated with child gesture but can have an impact on child language-learning. Children are significantly more likely to learn a novel word if it is presented with gesture than without it (Ellis Weismer & Hesketh, 1993). When parents are asked to teach their children in the one-word stage gestures for objects and actions, it turns out that children not only learn the gestures, but their verbal vocabularies increase as well (Acredolo, Goodwyn, Horrobin, & Emmons, 1999; Goodwyn, Acredolo, & Brown, 2000), suggesting that, at least at this stage, appropriately used gesture can facilitate word learning.

The gestures that parents produce seem to have an impact on how often children gesture and may even influence the ease with which children learn new words.

However, parental gesture cannot be essential for either development. Children who are blind from birth not only are capable language-learners (Andersen, Dunlea, & Kekelis, 1984, 1993; Dunlea, 1989; Dunlea & Andersen, 1992; Landau & Gleitman, 1985; Iverson et al., 2000), but they also gesture when they talk even though they have never seen anyone gesture. Indeed, on certain tasks, congenitally blind children produce gestures at the same rate and in the same distribution as sighted children (Iverson & Goldin-Meadow, 1997; 1998). Children do not have to see gesture in order to use it.

GESTURE WHEN SPOKEN LANGUAGE-LEARNING GOES AWRY

We have seen that children who are acquiring spoken language in a timely fashion use gesture as part of their communicative acts. In this section, we first consider hearing children who cannot easily learn the spoken language that surrounds them and thus are at risk for language delay. Do these children turn to gesture? We will see that they do and that their gestures can serve as a useful diagnostic, signaling which children are likely to catch up to their typically developing peers and which children are likely to continue to be delayed.

We then turn to children who are also unable to acquire spoken language, but not because they have difficulty learning language. These children are profoundly deaf and their hearing losses prevent them from taking in the spoken language that surrounds them. But if exposed to a conventional sign language, they are able to learn that language as naturally as hearing children learn the conventional spoken language to which they are exposed (Newport & Meier, 1985). Unfortunately, many profoundly deaf children born to hearing parents are not exposed to sign language. Again, we will see that these children turn to gesture to communicate. Interestingly, however, their gestures are qualitatively different from the gestures hearing speakers produce along with their speech—the deaf children's gestures take on many of the forms (and functions) of conventional sign language.

When Hearing Children Have Difficulty Learning Spoken Language

Thal, Tobias, and Morrison (1991) observed a group of children in the one-word stage of language acquisition who were in the lowest 10% for their age group in terms of size of productive vocabulary. They characterized the children's verbal and gestural skills at the initial observation session when the children ranged in age from 18 to 29 months, and then observed each child again 1 year later. They found that some of the children were no longer delayed at the 1-year follow-up—they had caught up to their peers. The interesting point about these so-called "late bloomers" is that they had actually shown signs of promise a year earlier—and they showed this promise in gesture. The late bloomers had performed significantly better on a series of gesture tests taken during the initial observation session than did the children who, a year later, were still delayed. Indeed, the late bloomers' gesture performance was no different from normally developing peers. Thus, children whose language development was delayed but whose gestural development was not had a better prognosis than children who were delayed in both language and gesture.

Along similar lines, Sauer, Levine, and Goldin-Meadow (2010) examined 11 children with pre- or perinatal unilateral brain lesions, all of whom produced fewer word types at 18 months than 53 typically developing children. The children with brain injury were categorized into two groups based on whether their gesture production at 18 months was within or below the range for the typically developing children. Children with brain injury whose gesture was within typical range developed a productive vocabulary at 22 and 26 months, and a receptive vocabulary at 30 months, that were all within typical range. In contrast, children with brain injury whose gesture was below the typical range did not, suggesting that gesture is an early marker of children with brain injury who are likely to recover from language delay without intervention. Gesture seems to reflect skills that can help children recover from language delay.

However, gesture may not be at the forefront for all moments of language development and for all learners. Iverson, Longobardi, and Caselli (2003) observed five children with Down syndrome (mean age 48 months) and matched them on language level, essentially vocabulary size, with five typically developing children (mean age 18 months). The typically developing children showed the pattern found by Goldin-Meadow and Butcher (2003), that is, a large number of combinations in which gesture conveys information that is different from the information conveyed in speech, the gesture + speech combination that heralds the onset of two-word speech. However, the children with Down syndrome did not show this pattern. Thus, at this particular stage of development, the Down syndrome children did not display a gestural advantage, suggesting that they are not yet ready to produce two-word utterances.

What happens to children whose language continues to be delayed at later stages of development? Some children fail to acquire age appropriate language skills yet they seem to have no other identifiable problems (i.e., no emotional, neurological, visual, hearing, or intellectual impairments). Children who meet these criteria are diagnosed as having Specific Language Impairment (SLI). Evans, Alibali, and McNeil (2001) studied a group of SLI children ranging in age from 7 to $9^1/_2$ years. They asked each child to participate in a series of Piagetian conservation tasks, and compared their performance to a group of normally developing children who were matched to the SLI children on number of correct judgments on the tasks. The task-matched normally developing children turned out to be somewhat younger (7 to 8) than the children with SLI (7 to $9^1/_2$).

The question that Evans et al. asked was whether the children with SLI would turn to gesture to alleviate the difficulties they had with spoken language. They found that the SLI children did *not* use gesture more often than the task-matched children without SLI. However, the children with SLI were far more likely than the task-matched children to express information in their explanations that could be found *only* in gesture. Thus, when given a water conservation task, an SLI child might behave like the child in Figure 9.1*b*, indicating the height of the container in words but its width in gesture. Note that if we consider information encoded in *both* gesture and speech, the child in Figure 9.1*b* has expressed the essential components of a conserving explanation—the tall container is not only taller than the short container but it is also thinner (the two dimensions can compensate for each other). When Evans et al. coded gesture and speech together, the children with SLI ended up producing significantly more conserving explanations than the task-matched children without SLI. It may not be surprising that the children with SLI knew more about conservation than their task-matched peers—they were older. However, all of the "extra" knowledge that the SLI children had was in gesture. The children seemed to be using gesture as a way around their difficulties with speech.

Throughout development, speakers seem to be able to use gesture to detour around whatever roadblocks prevent them from expressing their ideas in words. These detours may not always be obvious to the ordinary listener, to the researcher, or even to the clinician. They may reside, not in how much a speaker gestures, but in the type of information the speaker conveys in those gestures. It is important to note that the gestures the SLI children produced did not form a substitute system replacing speech. Rather, the children's gestures seemed no different from the gestures that any speaker produces along with talk. The children with SLI appear to be exploiting the gesture-speech system that all speakers employ, and using it to work around their language difficulties.

When Deaf Children Cannot Learn Spoken Language and Are Not Exposed to Sign Language: Homesign

We turn next to a situation in which children are unable to acquire spoken language. It is not, however, because they cannot acquire language—it is because they cannot hear. It turns out to be extremely difficult for deaf children with profound hearing losses to acquire spoken language. If these children are exposed to sign language, they learn that language as naturally and effortlessly as hearing children learn spoken language (Lillo-Martin, 1999; Newport & Meier, 1985). However, most deaf children are not born to deaf parents who could provide them with input from a sign language from birth. Rather, 90% of deaf children are born to hearing parents (Hoffmeister & Wilbur, 1980). These parents typically do not know sign language and would prefer that their deaf children learn the spoken language that they and their relatives speak and therefore send their children to oral schools for the deaf—schools that focus on developing a deaf child's oral potential, using visual and kinesthetic cues and eschewing sign language to do so. Unfortunately, most profoundly deaf children do not achieve the kind of proficiency in spoken language that hearing children do. Even with intensive instruction, deaf children's acquisition of speech is markedly delayed when compared either to the acquisition of speech by hearing children of hearing parents, or to the acquisition of sign by deaf children of deaf parents. By age 5 or 6, and despite intensive early training programs, the average profoundly deaf child has only a very reduced oral linguistic capacity (Conrad, 1979; Mayberry, 1992; Meadow, 1968), particularly if the child has not received a cochlear implant.

The question we address is whether deaf children who are unable to learn spoken language and are not yet exposed to sign language turn to gesture to communicate. If so, do the children use gestures in the same way that the hearing speakers who surround them do (i.e., as though they were accompanying speech), or do they refashion their gestures into a linguistic system reminiscent of the sign languages of deaf communities?

It turns out that deaf children who are orally trained often communicate using their hands (Fant, 1972; Lenneberg, 1964; Mohay, 1982; Moores, 1974; Tervoort, 1961). These hand movements even have a name—"homesigns." It may not be all that surprising that deaf children exploit the manual modality for the purposes of communication—after all, it is the only modality that is accessible to them, and they are likely to see gesture used in communicative contexts when their hearing parents talk to them. What is surprising, however, is that the homesigners' gestures are structured in language-like ways (Goldin-Meadow, 2003a). Like hearing children at the earliest stages of language-learning, homesigners use both pointing gestures and iconic gestures to communicate. The difference between homesigners and hearing children is that, as they get older, homesigners' gestures blossom—they begin to take on the *functions* and the *forms* that are typically assumed by conventional language, spoken or signed.

Homesigns Resemble Language in Function and Form

Like hearing children learning spoken languages, homesigners request objects and actions from others, but they do so using gesture. For example, a homesigner might point at a nail and gesture "hammer" to ask his mother to hammer the nail. Moreover, and again like hearing children in speech, homesigners comment on the actions and attributes of objects and people in the room. For example, a homesigner might gesture "march" and then point at a wind-up toy soldier to comment on the fact that the soldier is, at that very moment, marching.

Among language's most important functions is making reference to objects and events that are not perceptible to either the speaker or the listener—displaced reference (cf. Hockett, 1960). Displacement allows us to describe a lost hat, to complain about a friend's slight, and to ask advice on college applications. Just like hearing children learning spoken languages, homesigners communicate about nonpresent objects and events (Butcher, Mylander, & Goldin-Meadow, 1991; Morford & Goldin-Meadow, 1997). For example, one homesigner produced the following string of gesture sentences to indicate that the family was going to move a chair downstairs in preparation for setting up a cardboard Christmas chimney: He pointed at the chair and then gestured "move-away." He pointed at the chair again and pointed downstairs where the chair was going to be moved. He gestured "chimney," "move-away" (produced in the direction of the chair) "move-here" (produced in the direction of the cardboard chimney). Homesigners also use their gestures to tell stories (Phillips, Goldin-Meadow, & Miller, 2001) and can even use them to serve some of language's more exotic functions—to talk to themselves (Goldin-Meadow, 1993) or to comment on their own and others' gestures (Singleton, Morford, & Goldin-Meadow, 1993).

In addition to assuming the functions of language, homesigners' gestures assume its forms. One of the biggest differences between homesigners' gestures and those that hearing children use is that homesigners often combine their gestures into strings that have many of the properties of sentences. Homesigners even combine their gestures into sentences that convey more than one proposition; that is, they produce complex gesture sentences. Take, for example, a homesigner who produced the following gesture sentence to indicate that he would clap the bubble (proposition 1) after his mother twisted open the bubble jar (proposition 2) and blew it (proposition 3): He gestured "clap," pointed at himself, gestured "twist" then "blow," and pointed at his mother. Homesigners also modulate their gesture sentences, adding negative markers (side-to-side headshakes) to the beginning of the sentence and question markers (rotate palm down to palm up) to the end (Franklin, Giannakidou, & Goldin-Meadow, 2011).

Moreover, homesigners' gesture combinations are structured at underlying levels just like hearing children's early sentences (Goldin-Meadow, 1985). For example, the predicate frame underlying a gesture sentence about giving, in addition to the predicate *give,* contains three arguments—the *giver* (actor), the *given* (patient), and the *givee* (recipient). In contrast, the predicate frame underlying a sentence about eating, in addition to the predicate *eat,* contains two arguments—the *eater* (actor) and the *eaten* (patient). These underlying predicate frames influence how likely it is that a homesigner will produce a gesture for a particular argument (in fact, the likelihood with which gestures are produced provides evidence for the underlying frameworks, Goldin-Meadow, 1985).

Homesigners' gesture combinations are also structured at surface levels, containing many of the devices to mark "who does what to whom" that are found in the early sentences of hearing children (Goldin-Meadow & Mylander, 1984, 1998; Goldin-Meadow, Butcher, Mylander, & Dodge 1994). The homesigners indicate objects that play different thematic roles using three different devices: (1) by preferentially producing (as opposed to omitting) gestures for objects playing particular roles (e.g., pointing at the drum, the patient, as opposed to the drummer, the actor); (2) by placing gestures for objects playing particular roles in set positions in a gesture sentence (e.g., producing the gesture for the patient, "drum," before the gesture for the act, "beat"); or (3) by displacing verb gestures toward objects playing particular roles (e.g., producing the "beat" gesture near the patient, drum). The homesigners' gesture combinations therefore adhere to rules of syntax, albeit simple ones. On this basis, the homesigners' gesture combinations warrant the label "sentence"—homesigners' gestures thus resemble hearing children's *words,* not their gestures.

The homesigners' gestures are distinct from hearing children's gestures in having a set of elements (gestures) that combine systematically to form novel larger units (sentences). What further distinguishes the homesigners' gestures is the fact this combinatorial feature is found at yet another level—the gestures that combine to form sentences are themselves composed of parts (morphemes). For example, each gesture in a homesigner's repertoire is composed of a handshape component (e.g., an O-handshape representing the roundness of a penny) and a motion component (e.g., a short arc motion representing a putting down action). The meaning of the gesture as a whole is a combination of the meanings of its parts ("round-put-down;" Goldin-Meadow, Mylander, & Butcher, 1995; Goldin-Meadow, Goodrich, Sauer, & Iverson, 2007a). In contrast, the gestures produced by hearing speakers (including hearing children and the children's own hearing parents) are composed of sloppy handshapes that do not map neatly onto categories of meanings, combined with motions that also do not map onto categories of meanings (Goldin-Meadow et al., 1995; 2007).

One final characteristic of homesigners' gestures distinguishes them from hearing children's gestures—gestures serving noun-like functions are different in form from gestures serving verb-like functions (Goldin-Meadow, et al., 1994). For example, when a homesigner uses a "twist" gesture as a verb in a sentence meaning "twist-open the jar," he is likely to produce the gesture (a) without abbreviation (with several rotations rather than one), and (b) with inflection (the gesture is directed toward a relevant object, in this case, the jar). In contrast, when the homesigner uses the "twist" gesture as a noun in a sentence meaning "that's a twistable object, a jar," he is likely to produce it (a) with abbreviation (with one rotation rather than several), and (b) without inflection (in neutral space rather than directed at an object). Moreover, noun gestures are, at times, produced along with pointing gestures that act like demonstratives; for example, point at a bird, followed by a noun gesture for "bird" (flapping arms at sides), followed by a verb gesture for "pedal," used to describe a picture of a bird pedaling a bicycle. The pointing gesture specifies which member of the class of birds is doing the pedaling and, in this sense, forms a unit with the noun, i.e., "[[that bird] pedals]," akin to a nominal constituent containing a demonstrative ("that") and a noun ("bird"). Importantly, these point plus noun units function both semantically and syntactically like complex nominal constituents in spoken and signed languages, suggesting that the homesigner's gesture system has hierarchical structure (Hunsicker & Goldin-Meadow, 2012).

Homesigners' gestures thus resemble conventional languages, signed and spoken, in having combinatorial regularities at both the sentence and word levels, and having a noun-verb distinction. The homesigners have invented gesture systems that contain many of the basic properties found in all natural languages. It is important to note, however, that homesigners' gesture systems are not full-blown languages, and for good reason. The homesigners are inventing their gesture systems on their own without a community of communication partners. Indeed, when homesigners were brought together into a community as they were in Nicaragua after the first school for the deaf was opened in the late 1970s, their sign systems began to cohere into a recognized and shared language. That language became increasingly complex, particularly after a new generation of deaf children learned the system as a native language (Kegl, Senghas, & Coppola, 1999; Senghas, Coppola, Newport, & Supalla, 1997).

The circumstances in Nicaragua permit us to go beyond uncovering skills the child brings to language learning to gain insight into where those skills fall short; that is, to discover which properties of language are so fragile that they cannot be developed by a child lacking access to a conventional language model (Goldin-Meadow, 2010). By comparing current-day child homesigners in Nicaragua with groups whose circumstances have allowed them to go beyond child homesign, we can determine which conditions foster the development of these relatively fragile linguistic structures.

1. We can observe changes made to the system when it remains the homesigner's sole means of communication into adulthood (e.g., Coppola & Newport, 2005; Brentari, Coppola, Mazzoni, & Goldin-Meadow, 2012). Studying adult homesigners allows us to explore the impact that cognitive and social maturity have on linguistic structure.
2. We can observe changes made to the system when it becomes a community-wide language as homesigners come together for the first time (Coppola & Senghas, 2010; Senghas, Özyürek, & Goldin-Meadow, 2010). Studying the signers who originated NSL allows us to

explore the impact that a community in which signers not only produce but also receive their communication has on linguistic structure.

3. We can observe changes made to the system when it is passed through subsequent generations of learners (Senghas, 2003; Senghas & Coppola, 2001). Studying subsequent generations of NSL signers allows us to explore the impact that passing a newly birthed language through new generations of learners has on linguistic structure.
4. Finally, as a backdrop, we can study the gestures that hearing speakers produce, with speech (Senghas, Kita, & Özyürek, 2004) and without it (Brentari et al., 2012; Goldin-Meadow, So, Özyürek, & Mylander, 2008; Özyürek, Furman, Kita, & Goldin-Meadow, in press), to better understand the raw materials out of which these newly emerging linguistic systems have risen.

The manual modality can take on linguistic properties, even in the hands of a young child not yet exposed to a conventional language model. But it grows into a full-blown language only with the support of a community that can transmit the system to the next generation.

Homesigners' Gestures Do Not Look Like Their Hearing Parents' Gestures

The homesigners described in the previous section had not been exposed to a conventional sign language and thus could not have fashioned their gesture systems after such a model. They were, however, exposed to the gestures that their hearing parents used when they talked to them. These parents were committed to teaching their children English and therefore talked to them as often as they could. And when they talked, they gestured. The parents' gestures might have displayed the language-like properties found in their children's gestures. It turns out, however, that they did not (Goldin-Meadow & Mylander, 1983, 1984; Goldin-Meadow et al., 1994l Goldin-Meadow, Mylander, & Butcher, 1995; Goldin-Meadow, Mylander, & Franklin, 2007b; Hunsicker & Goldin-Meadow, 2012)—the parents' gestures looked just like any hearing speaker's gestures.

Why didn't the hearing parents display language-like properties in their gestures? In a sense, the homesigners' hearing parents did not have the option of displaying these properties in their gestures simply because the parents produced all of their gestures with talk. Their gestures formed a single system with the speech they accompanied and had to fit, both temporally and semantically, with that speech—they were not "free" to take on language-like properties. In contrast, the homesigners had no such constraints on their gestures. They had essentially no productive speech and thus always produced gesture on its own, without talk. Moreover, because gesture was the only means of communication open to these children, it had to take on the full burden of communication. The result was language-like structure. The homesigners may (or may not) have used their hearing parents' gestures as a starting point. However, it is very clear that the homesigners went well beyond that point. They transformed the speech-accompanying gestures they saw into a system that looks very much like language.

We are now in a position to appreciate just how versatile the manual modality is. It can take on linguistic properties when called upon to do so, as in homesign (and, of course in conventional sign languages). But it can also assume a nonsegmented global form when it accompanies speech, as in the cospeech gestures produced by homesigners' hearing parents (and all other hearing speakers). This versatility is important simply because it tells us that the form gesture assumes is *not* entirely determined by the manual modality. Quite the contrary, it seems to be determined by the functions gesture serves, and thus has the potential to inform us about those functions. We see in the next section that speech-accompanying gestures can provide insight into how the mind works.

GESTURE IS A WINDOW ONTO THE MIND

The gestures children produce can convey information that is not found in the speech that accompanies those gestures, and can even convey information that is not found *anywhere* in the child's spoken repertoire.

Gesture Can Reveal Thoughts Not Found in Speech

The gestures that speakers produce along with their talk are symbolic acts that convey meaning. It is easy to overlook the symbolic nature of gesture simply because its encoding is iconic. A gesture often looks like what it represents—for example, a twisting motion in the air resembles the action used to open a jar—but the gesture is no more the actual act of twisting than is the word "open." Because gesture can convey substantive information, it can provide insight into a speaker's mental representation (Kendon, 1980; McNeill, 1985, 1987, 1992).

But gesture encodes meaning differently from speech. Gesture conveys meaning globally, relying on visual and mimetic imagery. Speech conveys meaning discretely, relying on codified words and grammatical devices. Because gesture and speech employ such different forms of representation, it is difficult for the two modalities to contribute identical information to a message. Indeed, even deictic pointing gestures are not completely redundant with speech. For example, when a child utters "chair" while pointing at the chair, the word labels and thus classifies (but doesn't locate) the object. The point, in contrast, indicates where the object is but not what it is. Word and gesture do not convey identical information, but they work together to more richly specify the same object. But, as described earlier, there are times when word and gesture convey information that overlaps very little, if at all. A point, for example, can indicate an object that is not referred to in speech—the child says "daddy" while pointing at the chair. Word and gesture together convey a simple proposition—"the chair is daddy's" or "daddy sat on the chair"—that neither modality conveys on its own.

As another example, consider the children participating in the Piagetian conservation task described earlier. The child in Figure 9.1*a* said that the amount of water changed "cause that's down lower than that one," while pointing at the water levels in the two containers. Here, too, word and gesture do not convey identical information—speech tells us that the water level is low, gesture tells us how low. Yet the two modalities work together to more richly convey the child's understanding. In contrast, the child in Figure 1B used her gestures to introduce completely new information not found in her speech. She said the amount of water changed "cause this one's lower than this one," but indicated the widths of the containers with her hands. In this case, word and gesture together allow the child to convey a contrast of dimensions—this one's lower but wide, that one's higher but skinny—that neither modality conveys on its own.

We can posit a continuum based on the overlap of information conveyed in gesture and speech (Goldin-Meadow, 2003b). At one end of the continuum, gesture elaborates on a topic that has already been introduced in speech. At the other end, gesture introduces new information that is not mentioned at all in speech. Although at times it is not clear where to draw a line to divide the continuum into two categories, the ends of the continuum are obvious and relatively easy to identify. As mentioned earlier, we have called cases in which gesture and speech convey overlapping information *gesture-speech matches* and those in which gesture and speech convey nonoverlapping information *gesture-speech mismatches*.

The term *mismatch* adequately conveys the notion that gesture and speech express different information. However, *mismatch* also brings with it an unintended notion of conflict. The pieces of information conveyed in gesture and in speech in a mismatch need not conflict and, in fact, rarely do. There is almost always some framework within which the information conveyed in gesture can be fitted with the information conveyed in speech. For example, it may seem as though there is a conflict between the height information conveyed in the child's words ("lower") and the width information conveyed in her gestures in Figure 9.1*b*. However, in the context of the water conservation problem, the two dimensions actually compensate for one another. Indeed, it is essential to understand this compensation—that the water may be lower than it was in the original container but it is also wider—in order to master conservation of liquid quantity.

As observers, we are often able to envision a framework that would resolve a potential conflict between the information encoded in children's talk and the information encoded in their gestures. However, the children themselves may not be able to envision such a framework, particularly if left to their own devices. But children can profit from a framework if one is provided by someone else. Take the training study in conservation described earlier. When given instruction that provides a framework for understanding conservation, children who produce gesture-speech mismatches in their conservation explanations profit from that instruction and improve on the task. Children who do not yet produce mismatches, and thus do not have the ingredients of a conserving explanation in their repertoires, do not profit from the instructions (Church & Goldin-Meadow, 1986; see also Perry et al., 1988; Pine et al., 2004). In sum, gesture can reflect thoughts that are quite different from the thoughts a child conveys in speech. Moreover, if such a child is offered instruction that provides a framework for those thoughts, the child is likely to learn.

Gesture Offers Unique Insight Into a Child's Knowledge

The information conveyed by gesture in a gesture-speech match is obviously accessible to speech. But what about the information conveyed by gesture in a gesture-speech mismatch? The child does not express the information in speech *in that response*—otherwise we would not call it a mismatch. But perhaps the child does not express that information *anywhere* in his or her explanations of the task.

Perhaps the information conveyed in the gestural component of a mismatch is truly unique to gesture.

Goldin-Meadow, Alibali, and Church (1993) examined the problem-solving strategies that a group of 9- to 10-year-old children produced in speech and gesture when solving and explaining six mathematical equivalence problems. They found that if a child produced a problem-solving strategy in the gestural component of a mismatch, that child very rarely produced that strategy *anywhere* in his or her speech. Interestingly, this was not true of the problem-solving strategies found in the spoken component of the children's mismatches—these spoken strategies could almost always be found in gesture on some other response. What this means is that whatever information the children were able to express in speech they were also able to express in gesture—not necessarily on the same problem, but at some point during the task. Thus, at least on this task, when children can articulate a notion in speech, they are also able to express that notion in gesture. But the converse is not true—when children express a notion in gesture, sometimes they are also able to express that notion in speech and sometimes they are not.

Even in judgments of others' explanations, there seems to be an asymmetric relation between gesture and speech—when children notice a speaker's words, they also notice that speaker's gesture, but not vice versa. Graham (1999) asked very young children to "help" a puppet learn to count. Half the time the puppet counted correctly, but the other half of the time the puppet added an extra number (e.g., the puppet would say "one, two, three" while counting two objects). In addition, when the puppet made these counting errors, he either produced the same number of pointing gestures as number of words (three in this example), a larger or smaller number of pointing gestures (four or two pointing gestures), or no pointing gestures at all. The child's job was to tell the puppet whether his counting was correct and, if incorrect, to explain why the puppet was wrong. The interesting result from the point of view of this discussion concerns whether children made reference to the puppet's number words (speech only) or points (gesture only) or both (gesture + speech) in their explanations: 2-year-olds did not refer to either gesture or speech; 3-year-olds referred to gesture but not speech (gesture only); and 4-year-olds referred to both gesture and speech (gesture + speech). Very few children across all three ages referred to the puppet's speech without also referring to the puppet's gesture. In other words, when they noticed the puppet's speech, they also noticed his gesture, but not necessarily vice versa.

We now know that children can express knowledge in gesture that they do not express in speech. But is there some other means by which children can tell us that they "have" this knowledge? Knowledge that is accessible to gesture but not to speech, by definition, cannot be articulated. But perhaps this knowledge can be accessed in some other less explicit way, for example, by a rating task (cf. Acredolo & O'Connor, 1991; Horobin & Acredolo, 1989; Siegler & Crowley, 1991). In a rating task, all the raters need do is make a judgment about information provided by the experimenter. They do not need to express the information themselves.

Garber, Alibali, and Goldin-Meadow (1998) addressed this issue with respect to mathematical equivalence. If a child produces a problem-solving strategy uniquely in gesture, will the child later accept the answer generated by that strategy on a rating task? Take, for example, the child in Figure 9.2. On the problem 7 + 6 + 5 = __ + 5, the child puts 18 in the blank and says "7 plus 6 is 13 plus 5 more is 18 and that's all I did"—in other words, she gives an "add-numbers-to-equal-sign" strategy in

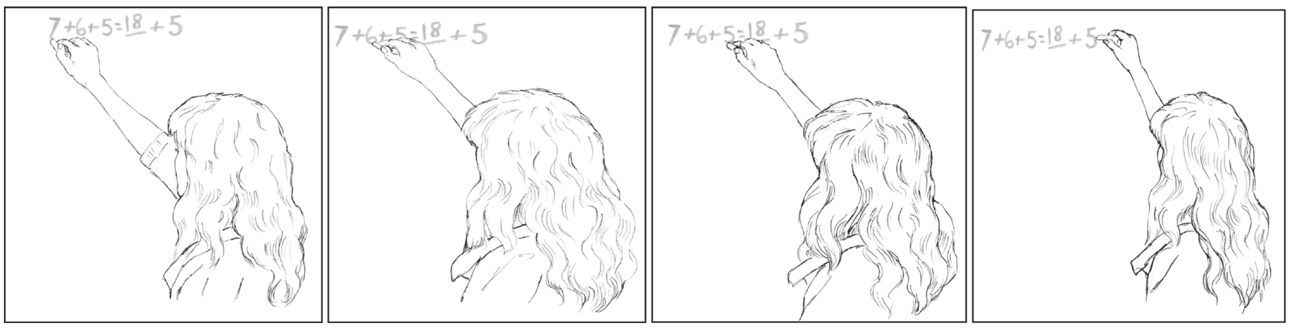

Figure 9.2 Example of a child producing a gesture-speech mismatch on a mathematical equivalence problem. The child says that she added the numbers on the left side of the equation (i.e., an add-numbers-to-equal sign strategy). In gesture, however, she points at the last number on the right side of the equation as well as the three on the left (i.e., add-all-numbers strategy)

Source: Reprinted from Goldin-Meadow, 2003b.

speech. In gesture, however, she points at all four numbers (the 7, the 6, the left 5, and the right 5), thus giving an "add-all-numbers" strategy in gesture. She does not produce the add-all-numbers strategy in speech in any of her explanations. When later asked to rate the acceptability of possible answers to this problem, the child, of course, accepts 18 (the number you get when you add up the numbers to the equal sign). However, the child is also willing to accept 23, the number you get when you add all of the numbers in the problem—that is, the answer you get when you use the problem-solving strategy that this child produced *uniquely* in gesture.

Children thus can express knowledge with their hands that they do not express *anywhere* in their speech. This knowledge is not fully explicit (it cannot be stated in words). However, it is not fully implicit either (it is evident not only in gesture but also in a rating task). Knowledge expressed uniquely in gesture thus appears to represent a middle point along a continuum of knowledge states, bounded at one end by fully implicit knowledge that is embedded in action, and at the other by fully explicit knowledge that is accessible to verbal report (cf. Dienes & Perner, 1999; Goldin-Meadow & Alibali, 1994, 1999; Karmiloff-Smith, 1986, 1992).

A growing group of researchers have come to believe that linguistic meaning is itself grounded in bodily action (Barsalou, 1999; Glenberg & Kaschak, 2002; Glenberg & Robertson, 1999; Richardson, Spivey, Barsalou, & McRae, 2003; Zwaan, Stanfield, & Yaxley, 2002)—that meaning derives from the bio-mechanical nature of bodies and perceptual systems and, in this sense, is embodied (Glenberg, 1997; see Lakoff & Johnson, 1999; Niedenthal, 2007; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996; and Wilson, 2002, for more general views of embodied cognition, and Kontra, Beilock, & Goldin-Meadow, 2012, for a developmental perspective on the notion). Under this view, it is hardly surprising that gesture reflects thought. Gesture may be an overt depiction of the action meaning embodied in speech. However, gesture has the potential to do more—it could play a role in shaping those meanings. There are (at least) two ways in which gesture could play a role in creating, rather than merely reflecting, thought.

1. Gesture could play a role in shaping thought by displaying, for all to see, the learner's newest, and perhaps undigested, thoughts. Parents, teachers, and peers would then have the opportunity to react to those unspoken thoughts and provide the learner with the input necessary for future steps. Gesture, by influencing the input learners receive from others, would then be part of the process of change itself. In other words, gesture's participation in the process of *communication* could contribute to cognitive change.
2. Gesture could play a role in shaping thought more directly by influencing the learners themselves. Gesture externalizes ideas differently from speech and therefore may draw on different resources. Conveying an idea across modalities may, in the end, require less effort than conveying the idea within speech alone. In other words, gesture may serve as a "cognitive prop," freeing up cognitive effort that can be used on other tasks. If so, using gesture may actually ease the learner's processing burden and, in this way, function as part of the mechanism of change. In other words, gesture's participation in the process of *thinking* could contribute to cognitive change.

Gesture thus has the potential to contribute to cognitive change indirectly by influencing the learning environment (through communication) or more directly by influencing the learner (through thinking). Before considering the possible *functions* that gesture might serve, we take a moment to consider the factors that lead us to gesture. In other words, we consider the *mechanisms* responsible for gesturing.

WHAT MAKES US GESTURE? THE MECHANISMS THAT LEAD TO GESTURING

We begin our exploration of the mechanism underlying gesture production by focusing on the *communicative* factors that might encourage us to gesture—do we need a communication partner to gesture and does there need to be visual access between that partner and us? We then consider *cognitive* factors that could lead to gesture—does thinking hard make us gesture and does gesturing increase when the difficulty comes either from the act of speaking itself or from the nature of the task (e.g., when the number of items in the task is increased, when the memory load is increased, when the conceptual load is increased)?

Does Having a Conversation Partner Make Us Gesture?

To explore whether communicative factors play a role in the mechanism responsible for creating gesture, we need to manipulate factors relevant to communication and determine whether those factors influence gesturing. In this section, we ask whether one factor essential to communication—having a conversation partner – has an impact on whether speakers gesture.

We Gesture More When We Know Listeners Can See Us

Our goal in this section is not to figure out whether listeners get meaning from gesture (we address this question in the section "Does Gesture Have a Purpose? The Functions That Gesturing Serves"), but to figure out whether the need to communicate information to others is the force that drives us to gesture. The easiest way to explore this question is to ask people to talk when they know that their listener can see them versus when they know their listener cannot see them. If the need to convey information to conversation partners is what motivates us to gesture, we ought to gesture more when we know that others can see those gestures.

A number of studies have manipulated whether the speaker and listener can see each other and observed the effect on gesture. In most studies, the speaker has a face-to-face conversation with a listener in one condition, and a conversation in which a barrier prevents the speaker and listener from seeing one another in the second condition. In some studies, the second condition is conducted over an intercom, and in some the first condition is conducted over a videophone. In some studies, the camera is hidden so that the speakers have no sense that they are being watched. It doesn't really seem to matter. In most studies (although not all), people gesture more when speaker and listener can see each other than when they cannot (Alibali, Heath, & Myers, 2001a; Bavelas, Chovil, Lawrie & Wade, 1992; Cohen & Harrison, 1973; Krauss, Dushay, Chen & Rauscher, 1995; the exceptions were Lickiss and Wellens, 1978; Rimé, 1982). For example, Alibali et al. (2001) asked speakers to watch an animated cartoon and narrate the story under two conditions: when the speaker and listener could see each other and when they could not see each other. Speakers produced more representational gestures (gestures that depict semantic content) when speaker and listener could see each other than when they could not, but not more beat gestures (simple, rhythmic gestures that do not convey semantic content). Thus, speakers do increase their production of at least some gestures when they know someone is watching.

But do speakers really intend to produce gestures for their listeners? There is no doubt that speakers change their *talk* in response to listeners. Perhaps the changes in gesture come about as a by-product of these changes in speech. Speakers could alter the form and content of their talk and those changes could "automatically" bring with them changes in gesture. To address this possibility, we need to examine not only changes that occur in gesture as a function of who the listener is, but also changes that occur in the accompanying speech. Alibali, Heath, and Myers (2001a) did just that but found no differences anywhere—speakers used the same number of words, made the same number of speech errors, and said essentially the same things whether or not speaker and listener could see each other. Thus, when the speakers in this study produced more gestures with listeners they knew could see them than with listeners they knew could not see them, it was not because they had changed their talk—at some level, albeit not necessarily consciously, they meant to change their gestures.

Congenitally Blind Speakers Gesture Even When Addressing Blind Listeners

Speakers gesture more when they and their listeners can see each other than when they cannot, suggesting that there is a communicative aspect to gesturing. In another sense, however, the more striking finding in each of these studies is that speakers continue to gesture even when there is no listener there at all. Although statistically less likely, gesture was produced in *all* the experimental conditions in which there was no possibility of a communicative motive (that is, when neither speaker nor listener could see each other). As an example that everyone can relate to, people gesture when talking on the telephone despite the fact that there is no one around to see those gestures. Why? If the need to communicate to the listener is the *only* force behind gesturing, why do we continue to move our hands when listeners can no longer see us?

One possibility is that we gesture out of habit. We are used to moving our hands around when we speak to others and old habits die hard. This hypothesis predicts that if someone were to spend a great deal of time talking only to unseen people, eventually that person's gestures would fade away. Another possibility is that, even when no one is around, we imagine a listener and we gesture for that listener. The only way to test these hypotheses is to observe speakers who have never spoken to a visible listener. Individuals who are blind from birth offer an excellent test case. Congenitally blind individuals have never seen their listeners and thus cannot be in the habit of gesturing for them. Moreover, congenitally blind individuals never see speakers moving their hands as they talk and thus have no model for gesturing. Do they gesture despite their lack of a visual model?

Iverson and Goldin-Meadow (1998, 2001) asked children and adolescents blind from birth to participate in a series of conservation tasks, and compared their speech and gesture on these tasks to age- and gender-matched sighted individuals. All of the blind speakers gestured as they spoke, despite the fact that they had never seen gesture or their listeners. The blind group gestured at the same rate as the sighted group, and conveyed the same information using the same range of gesture forms. Blind speakers apparently do not require experience seeing gestures before spontaneously producing gestures of their own. Indeed, congenitally blind children produce gestures at the earliest stages of language-learning just as sighted children do (Iverson et al., 2000). They even produce pointing gestures at distal objects, although those gestures are not as frequent as in sighted children and are produced with a palm hand rather than a pointing hand. Moreover, blind children produce spontaneous gestures along with their speech even when they know that their listener is blind and therefore unable to profit from whatever information gesture offers (Iverson & Goldin-Meadow, 1998; 2001).

To sum up thus far, gesture seems to be an inevitable part of speaking. We do not need to have others around in order to gesture (although having others around does increase our gesture rate). Indeed, we do not need to have ever seen anyone gesture in order to produce gestures of our own. Gesture thus appears to be integral to the speaking process itself, and the mechanism by which gesture is produced must be tied in some way to this process. Gesture frequently accompanies speech in reasoning tasks where the speaker must think through a problem. In conservation tasks, for example, participants must consider and manipulate relationships between several different spatial dimensions of the task objects simultaneously (e.g., in the liquid quantity task, the relationship between container height and width and water level). It may be easier to express aspects of these dimensions and their relationships in the imagistic medium offered by gesture than in the linear, segmented medium provided by speech (cf. McNeill, 1992). Gesture may thus provide children with a channel for expressing thoughts that are difficult to articulate in speech. As a result, children—even blind children—may produce gestures when explaining their reasoning in a conservation task because some of their thoughts about the task lend themselves more readily to gesture than to speech. Gesture, in other words, might simply reflect a child's thoughts in a medium that happens to be relatively transparent to most listeners. We explore whether cognitive factors play a role in the mechanism underlying gesturing in the next section.

Does Thinking Hard Make Us Gesture?

When do we gesture? One possibility is that we gesture when we think hard. If so, we would expect gesture to increase when either the act of speaking or the task itself becomes difficult.

Gesturing When Speaking Is Difficult

Consider first what happens when speaking is made more difficult. When we talk, we hear ourselves, and this feedback is an important part of the speaking process. If the feedback we get from our own voice is delayed, speaking becomes much more difficult. McNeill (1992) carried out a series of experiments observing what happens to gesture under delayed auditory feedback—the experience of hearing your own voice continuously echoed back. Delayed auditory feedback slowed speech down and stuttering and stammering became frequent. But it also had an effect on gesture, which increased in all speakers. (Interestingly, however, gesture did not lose its synchrony with speech, an outcome we might have expected given that gesture and speech form a unified system.) The most striking case was a speaker who produced absolutely no gestures at all under conditions of normal feedback; he began gesturing only during the second half of the narration when feedback was delayed. Speakers also gesture more when they have trouble finding the right word (Rauscher, Krauss, & Chen, 1996), when they are producing unrehearsed speech (Chawla & Krauss, 1994), and when they are about to produce less predictable words (Beattie & Shovelton, 2000) or syntactic structures (Cook, Jaeger, & Tanenhaus, 2009). When the act of speaking becomes difficult, speakers seem to respond by increasing their gestures.

A similar increase in gesturing is seen in individuals suffering from aphasia. These individuals, typically as a result of stroke, trauma, or tumor, have greatly impaired language abilities relative to individuals without brain injury—speaking is difficult for aphasic individuals. When Feyereisen (1983) asked aphasic individuals to describe how they passed an ordinary day, they produced many more gestures than nonaphasic speakers (see also Hadar, Burstein, Krauss, & Soroker, 1998). Again, increased gesturing seems to be associated with difficulty in speaking.

Finally, bilinguals who are not equally fluent in their two languages have more difficulty speaking their nondominant language than their dominant language. Marcos (1979) asked Spanish-English bilinguals, some dominant in English and others dominant in Spanish, to talk about love or friendship in their nondominant language. The less proficient a speaker was in his or her nondominant language, the more gestures that speaker produced when speaking that language (see also Gulberg, 1998). The assumption is that speaking the nondominant language is more difficult for these individuals, and they respond by increasing their rate of gesturing.

Gesturing When the Number of Items or Choices in a Task Is Increased

Gesturing also increases when the focal task is itself made more difficult. For example, Graham (1999) asked 2-, 3-, and 4-year-old children to count sets of two-, four-, and six-object arrays. Children learn to count small numbers before learning to count large numbers (Gelman & Gallistel, 1978; Wynn, 1990). If children gesture only when the counting problem is hard, we might expect them to gesture more on arrays with four and six objects than on arrays with only two objects. The 4-year-olds did just that (apparently, the 2- and 3-year-olds were challenged by all three arrays and gestured as much as possible on each one). When the counting task is hard, children rely on gesture (see also Saxe & Kaplan, 1981).

Gesturing has also been found to increase when speakers have options to choose among. Melinger and Kita (2001, 2007 asked native speakers of Dutch to describe map-like pictures, each depicting a path with several destinations (marked by colored dots). The speaker's task was to describe from memory the path that leads past all of the destinations. Importantly, some of the maps had routes that branched in two directions, which meant that the speaker had a choice of paths (more than one item to choose among). The question is whether speakers would produce more gestures when describing the branching points on the maps than when describing points where there were no choices to be made. They did. Controlling for the amount of directional talk the speakers produced, Melinger and Kita calculated the percentage of directional terms that were accompanied by gesture at branching points versus nonbranching points and found that the speakers gestured more at branching points. The presumption is that the branching points elicited more gesture because they offered the speaker more than one item to choose among and, in this sense, were conceptually challenging.

Gesturing When the Memory Load in a Task Is Increased

Describing a scene from memory ought to be more difficult than describing a scene within view. We might therefore expect speakers to produce more gestures when asked to retrieve information from memory. De Ruiter (1998) asked Dutch speakers to describe pictures on a computer screen so that the listener could draw them. Half of the pictures were described while they were visible on the computer screen, and half were described from memory. The speakers produced more gestures when describing the pictures from memory than when describing them in full view.

Wesp, Hesse, Keutmann, and Wheaton (2001) found the same effect in English-speakers. They asked speakers to describe still-life watercolor paintings so that the listener could later pick the painting out of a set of paintings. Half of the speakers were asked to look at the painting, form an image of it, and then describe it from memory. The other half were asked to describe the painting as it sat in front of them. Speakers who described the paintings from memory produced more gestures than those who described the paintings in full view. When the description task becomes difficult, speakers react by increasing their gesture rates.

Gesturing When the Conceptual Load in a Task Is Increased

Reasoning about a set of objects ought to be more difficult than merely describing those same objects, and thus ought to elicit more gestures. Alibali, Kita, and Young (2000) asked a group of kindergartners to participate in both a reasoning and a description task. In the reasoning task, the children were given six Piagetian conservation problems tapping their understanding of continuous quantity and mass. In the description task, they were presented with precisely the same objects, but this time they were asked to describe how the objects looked rather than to reason about their quantities. The children produced more iconic gestures (but not more deictic gestures) when *reasoning* about the objects than when *describing* the objects. In other words, they produced more gestures that conveyed substantive information when doing the harder task. Along similar lines, Liben, Christensen, and Kastens (2010) asked university students to read aloud a passage describing the geological concepts of strike and dip. They found that only novices, who did not know the material and thus found the task conceptually demanding, gestured during the reading (see also Hostetter, Alibali, & Kita, 2007; Melinger & Kita, 2007; Kita & Davies, 2009).

However, an increase in task difficulty does not always bring with it an increase in gesture (Cohen & Harrison, 1973; De Ruiter, 1998). For example, De Ruiter (1998) found no differences in rate of gesturing for pictures that were easy versus hard to describe. Null effects are difficult to interpret. Perhaps the task was not hard enough to inspire gesture. But then, of course, we need to specify what we mean by "hard enough?" If gesture and speech are interlinked in a specific way, then we might expect only certain types of tasks and verbal difficulties to lead to an increase in gesture. Ideally, theories of how gesture and speech relate to one another ought to be sufficiently specified to predict the kinds of difficulties that will lead to more gesture—but we haven't achieved the ideal yet. None of the current theories can explain these null results.

DOES GESTURE HAVE A PURPOSE? THE FUNCTIONS THAT GESTURING SERVES

Thus far, we have examined studies that manipulate communicative and cognitive factors and then chart the effects of those manipulations on gesture. And we have found that the manipulations have an impact on gesturing, suggesting that both communicative and cognitive factors play a causal role in gesture production. The studies thus provide rather convincing evidence with respect to the *mechanisms* that underlie gesturing, the process by which gesture comes about.

Note, however, that the studies are not conclusive with respect to the *function*s gesture serves. Just because gesturing increases in situations where a listener is present doesn't mean that the listener gleans information from gesture. In order to determine whether gesture functions to communicate information to listeners, we need to manipulate *gesture* and explore the effects of that manipulation on *listener comprehension*. Similarly, just because gesturing increases on tasks that require more thought does not mean that gesturing plays a causal role in thinking. Gesture may be reflecting the speaker's thought processes, rather than causing them. In order to explore whether gesture functions to help us think, we need to manipulate *gesture* and observe the effect of the manipulation on *thinking*. We turn to studies of this sort in the next sections, focusing on the functions gestures might serve first in communication and then in thinking.

Gesture's Role in Communication: Does Gesture Convey Information to the Listener?

A child's gestures can signal to parents and teachers that a particular notion is already in that child's repertoire but is not quite accessible. These listeners can then alter their behavior accordingly, perhaps giving explicit instruction in just these areas. For example, in response to the child utterance, "dada" + point hat, a mother might say "yes, that's dada's hat," thus "translating" the information the child conveyed across two modalities into the spoken modality, and providing just the right target for a learner who had this notion in mind (see Goldin-Meadow, Goodrich, Sauer, & Iverson, 2007a, for evidence that this process occurs in mother-child conversation). Adults routinely "expand" the utterances children produce (Cazden, 1965), thus providing the children with timely linguistic input. What gesture adds to the mix is information about which linguistic piece the child is likely to be contemplating but has not expressed. Without the point at the hat in the example just mentioned, mother might be just as likely to say "yes, dada is at work" in response to the child's utterance, which is a nice example of an English grammatical sentence but is not a sentence that speaks to the child's thoughts at the moment. Gesture can help parents and teachers tune more precisely into a child's current thoughts.

Of course, this process can only work if adults are able to glean substantive information from child gesture. Although there is little disagreement in the field about whether there is information displayed in gesture, there is great disagreement about whether ordinary listeners take advantage of that information. Does someone who has not taken a course in gesture-coding understand gesture? Do gestures communicate? Some researches are completely convinced that the answer is "yes" (e.g., Kendon, 1994). Others are equally convinced that the answer is "no" (e.g., Krauss, Morrel-Samuels, & Colasante, 1991). A number of approaches have been taken to this question, some more successful than others.

Looking at Gesture in the Context of Speech

We glean very little information from the gestures that accompany speech when they are presented on their own (Feyereisen, van de Wiele, & Dubois, 1988; Krauss, Morrel-Samuels, & Colasante, 1991). However, we may still be able to benefit from gestures when they are viewed as they were meant to be viewed—in the context of speech. There are hints that we get information from gesture when it accompanies speech in observations of how listeners behave in conversation. For example, Heath (1992, cited in Kendon, 1994) describes several interchanges in which the recipient seems to grasp the meaning of an utterance before its completion, and to do so on the basis of gesture. A doctor is explaining that a particular medicine will "damp down" a symptom and makes several downward movements of his hand as he does so. The timing, however, is important. He says "they help sort of you know to dampen down the inflammation," and has already completed three downward strokes of his gesture by the time he says "you know"—he gestures before he actually produces the word "dampen." It is at this point, after the gesture but before the word "dampen," that the listener looks at the doctor and begins to nod. The listener appears to have gotten the gist of the sentence well before its end, and to have gotten that gist from gesture.

Examples of this sort are suggestive but not at all definitive. We really have no idea what the listener is actually understanding when he nods his head. The listener may *think* he's gotten the point of the sentence, but he may be completely mistaken. He may even be pretending to understand. We need to know exactly what recipients are taking from gesture in order to be sure that they have truly grasped its meaning. To do that, we need a more experimental approach.

Graham and Argyle (1975) asked people not to gesture on half of their descriptions of drawings and then examined how accurate listeners were in recreating those drawings when they were described with and without gesture. The listeners were significantly more accurate with gesture than without it. However, when speakers are forced not to use their hands, they may change the way they speak. In other words, the speech in the two conditions (messages with gesture versus without it) may differ, and this difference could be responsible for the accuracy effect. Graham and Heywood (1975) addressed this concern by reanalyzing the data with this issue in mind. But a more convincing approach to the problem would be to hold speech constant while exploring the beneficial effects of gesture. And, of course, this manipulation can easily be accomplished with videotape.

Krauss, Dushay, Chen, and Rauscher (1995) asked speakers to describe abstract graphic designs, novel synthesized sounds, or samples of tea. Listeners then saw and heard the videotape of the speakers or heard only the soundtrack, and were asked to select the object being described from a set of similar objects. Accuracy was straightforwardly measured by the number of times the correct object was selected. In none of the experiments was accuracy enhanced by allowing the listener to see the speaker's gestures. Thus, in certain situations, gesture can add *nothing* to the information conveyed by speech.

However, other researchers have found that gesture enhances the message listeners take from a communication (e.g., Berger & Popelka, 1971; Thompson & Massaro, 1986; Riseborough, 1981). For example, Riseborough (1981) gave listeners extracts from videotapes of a speaker describing an object (e.g., a fishing rod) to another person. The extracts were presented with both video and sound or with sound alone. Listeners guessed the correct object more rapidly when they could see the iconic gestures that accompanied the description than when they could not. In a subsequent experiment, Riseborough made sure that it wasn't just the hand waving that mattered. She compared responses (this time accuracy scores) to speech accompanied by vague movements versus well-defined iconic gestures, and found that accuracy was much better with the real gestures. As additional examples, we know that listeners increase their reliance on a speaker's gestures in situations when there is noise in the speech signal (Holle, Obleser, Rueschemeyer, & Gunter, 2010; Rogers, 1978; Thompson & Massaro, 1986, 1994); that listeners are particularly influenced by gesture when the spoken message is relatively complex (McNeil, Alibali, & Evans, 2000); and that listeners are faster to identify a speaker's referent when speech is accompanied by gesture than when it is not (Silverman, Bennetto, Campana, & Tanenhaus, 2010).

It is, of course, possible that listeners are not really gleaning *specific* information from gesture. Gesture could be doing nothing more than heightening the listener's attention to speech that, in turn, results in more accurate and faster responses. Beattie and Shovelton (1999b) avoid this concern by examining in detail the types of information that listeners take from a message when they hear it with and without gesture. Each listener saw clips drawn from a narration of a cartoon in the audio + video condition (soundtrack and picture), the audio condition (just the soundtrack), and the video condition (just the picture). After each clip, the listener answered a series of planned questions about the objects and actions in the clip (e.g., "what object(s) are identified here?" "what are the object(s) doing?" "what shapes are the object(s)?").

The results were quite clear. When the listeners could see the iconic gestures as well as hear the speech, they answered the questions more accurately than when they just heard the speech. All ten listeners showed the effect. However, gesture was more beneficial with respect to certain semantic categories than others—for example, the relative position and the size of objects. Take as an instance one videoclip in which the speaker said "by squeezing his nose" while opening and closing his left hand. All of the listeners in both the audio + video and the audio condition accurately reported the squeezing action. However, listeners in the audio + video condition were much more likely than those in the audio condition to accurately report the size and shape of the nose, its position with respect to the squeezing hand, and whether it was moving. It is not surprising that the listeners in the audio condition did not report these pieces of information—they didn't hear them *anywhere* in the soundtrack they were given. But it may be surprising (depending upon your point of view) that the listeners in the audio + video condition not only noticed the extra information conveyed in gesture, but were able to integrate that information into the mental image they were developing on the basis of speech. Listeners really can glean specific information from gesture.

As another example, Cook and Tanenhaus (2009) showed that the information speakers reveal in their gestures about their prior motor experience can have a direct effect of the listener. They asked adults to explain their solutions to the Tower of Hanoi problem that was described earlier . Some adults solved the problem on a computer; some solved it with real disks. The problem-solvers' verbal explanations were identical across the two groups, but their gestures differed. Adults who had solved the problem with real disks traced the trajectory of the disk with their hands (they mimed moving the disk up and over each peg). In contrast, adults who had solved the problem on the computer moved their hands laterally, mimicking the way the disks are moved on the screen (i.e., they do not have to be taken off the pegs before they are moved). The adults thus provided reliable cues about the problem-solving experiences they had had, cues that were not evident in their speech. But the important point for our discussion here is that listeners picked up on this subtle information. Listeners who saw the arced gestures were more likely to move the disk up and over the peg when they were later asked to solve the Tower of Hanoi problem on the computer (where it is not necessary to arc the disks to move them) than listeners who saw the lateral gestures. The listeners had not only read the action information from the speakers' gestures, but that information had had an effect on their own subsequent actions.

Looking at Gesture With Mismatching Speech

When gesture conveys precisely the same information as speech, we can never really be sure that the listener has gotten specific information from gesture. Even if a listener responds more accurately to speech accompanied by gesture than to speech alone it could be because gesture is heightening the listener's attention to the speech—gesture could be serving as an energizer or focuser, rather than as a supplier of information. Note that the data from the Beattie and Shovelton (1999b) study are not plagued by this problem. We are convinced that the listeners in this study are gleaning specific information from gesture simply because that information does not appear *anywhere* in speech. It must be coming from gesture—it has no place else to come from. In general, the very best place to look for effects of gesture on listeners is in gesture-speech mismatches—instances where gesture conveys information that is not found in speech.

McNeill, Cassell, and McCullough (1994) asked listeners to watch and listen to a videotape of someone recounting a "Tweety Bird" cartoon. The listener never sees the cartoon, only the narration. Unbeknownst to the listener, the narrator is performing a carefully choreographed program of mismatching gestures along with a number of normally matching gestures. The listener's task is to retell the story to yet another person, and that narration is videotaped. The question is whether we will see traces in the listener's own narration of the information conveyed by gesture in the mismatched combinations planted in the video narrative. And we do. Consider an example. The narrator on the videotape says, "he comes out the bottom of the pipe," while bouncing his hand up and down—a verbal statement that contains no mention of how the act was done (that is, no verbal mention of the bouncing manner), accompanied by a gesture that does convey bouncing. The listener resolves the mismatch by inventing a staircase. In her retelling, the listener talks about going "downstairs," thus incorporating the bouncing information found *only* in the narrator's gestures into her own speech. The listener must have stored the bouncing manner in some form general enough to serve as the basis for her *linguistic* invention ("stairs"). The information conveyed in gesture is often noticed by listeners, but it is not necessarily tagged as having coming from gesture (see also Bavelas, 1994).

We find the same effects when adult listeners are asked to react to gesture-speech mismatches that children spontaneously produce on either a mathematical equivalence task (Alibali, Flevares, & Goldin-Meadow, 1997) or a conservation task (Goldin-Meadow, Wein, & Chang, 1992). Half of the videotapes that the adults saw were gesture-speech matches (e.g., Figure 9.1*a*) and half were gesture-speech mismatches (e.g., Figures 9.1*b* & 9.2). The adults, half of whom were teachers and half undergraduate students, were simply asked to describe the child's reasoning. Recall that a mismatch contains two messages, one in speech and one in gesture. A match contains only one. If adults are gleaning information from child gesture, we might therefore expect them to say more when they assess a child who produces a mismatch than when they assess a child who produces a match. And they did. In both studies, the adults produced many more "additions"—that is, they mentioned information that could not be found anywhere in the speech of the child they were assessing—when evaluating children who produced mismatches than when evaluating children who produced matches. Moreover, over half of these "additions" could be traced back to the gestures that the children produced in their mismatches. Consider this example. In the conservation task, one child said that the rows contained different numbers of checkers after the top row had been spread out "because you moved 'em." However, in his accompanying gesture, the child indicated that the checkers in one row could be matched in a one-to-one fashion with the checkers in the other row (he pointed to a checker in one row and then to the corresponding checker in the other row, and repeated this gesture with another pair of checkers). An adult described this child as saying "you moved 'em but then he pointed … he was matching them even though he wasn't verbalizing it," while producing a one-to-one correspondence gesture of her own. Thus, the adult had attributed to the child reasoning that was explicitly mentioned in the child's speech (i.e., reasoning based on the fact that the checkers had been moved), along with reasoning that appeared only in the child's gesture (i.e., reasoning based on one-to-one correspondence).

In this example, the adult explicitly referred to the child's gestures. Indeed, some of the adults were very aware of the children's gestures and remarked on them in their assessments. However, these adults were no better at gleaning substantive information from the children's gestures than were the adults who failed to mention gesture. Thus, being explicitly aware of gesture (at least enough to talk about it) is not a prerequisite for decoding gesture. Moreover, teachers were no better at gleaning information from the children's gestures than were the undergraduates. At first glance, this finding seems surprising given that teachers have both more experience with children and more knowledge about learning processes than undergraduates. However, from another perspective, the lack of difference suggests that integrating knowledge from both modalities is, in fact, a basic feature of the human communication system, as McNeill (1992) would predict (see also Kelly, Özyürek, & Maris, 2010, who show that even if people are not told to focus on gesture when identifying a speech target, they are unavoidably influenced by incongruent information conveyed in gesture). Everyone can read gesture, with or without training.

Looking at Adult Reactions to Children Gesturing "Live"

When the very best examples of gesture-speech mismatches are pulled out and shown to adults twice on a videotape so they can hardly help but notice the gesture, untrained adults are able to glean substantive meaning from gesture. But this experimental gesture-reading situation is a bit removed from the real world. At the least, it would be nice to study adults reacting to children producing whatever gestures they please.

Goldin-Meadow and Sandhofer (1999) asked adults to watch children responding to Piagetian conservation tasks "live." After each task, the adult's job was to check off on a list all of the explanations that the child expressed on that task. After all of the data had been collected, the explanations that the children produced were coded and analyzed. The children produced gesture-speech mismatches in a third of their explanations—that is, they conveyed information found *only* in gesture a third of the time. And the adults were able to decode these gestures. They checked explanations that children expressed in the gesture half of a gesture-speech mismatch, and did so significantly more often than they checked those explanations when they were not produced in either gesture or speech. The adults were thus able to glean substantive information from a child's gestures, information that did not appear anywhere in that child's speech, and could do so in a relatively naturalistic context. Listeners can get meaning from gesture even when it is unedited and fleeting.

However, this situation hardly approaches conditions in the real world. The listeners were not really listeners at all—they were "overhearers," observing gesturers but not participating in a conversation with them. Goldin-Meadow and Singer (2003) videotaped eight teachers who had been asked to individually instruct a series of children in mathematical equivalence. They found that all of the teachers were able to glean substantive information from the children's gestures, as measured by the fact that the teachers paraphrased or reiterated explanations that the children produced in the gestural component of a mismatch. Moreover, when they reiterated these explanations, the teachers often "translated" the information conveyed uniquely in child gesture into their own speech, making it clear that they had truly understood the information conveyed in the child's gestures.

Looking at Gesture Comprehension Through the Lens of the Brain

The process by which gesture affects the listener is currently being explored through a variety of techniques designed to probe brain activity and organization. Using functional MRI, researchers have found that gesture activates language processing areas (Skipper, Goldin-Meadow, Nusbaum, & Small, 2007; Willems, Özyürek, & Hagoort, 2007), and that gesture affects processing organization by influencing the connectivity among the relevant brain regions (Skipper et al., 2007). Dick, Goldin-Meadow, Solodkin, and Small (2012a) have begun to explore how the developing brain processes gesture in relation to speech. They scanned 8- to 11-year-old children and adults listening to stories accompanied by gestures, and found that both children and adults recruited brain regions known to be involved in language processing. However, they also found age-related differences in brain activity in regions previously implicated in processing gesture (posterior superior temporal sulcus, inferior frontal gyrus, pars triangularis, posterior middle temporal gyrus).

Dick, Mok, Beharelle, Goldin-Meadow, and Small (2012b) used fMRI to characterize the brain regions involved in integrating the information conveyed in gesture with the information conveyed in the speech it accompanies. They found that three regions—the triangular and opercular portions of the left inferior frontal gyrus and the left posterior middle temporal gyrus—responded more strongly when the speaker's iconic gesture added to the information conveyed in speech (e.g., "he struggled nonstop," accompanied by a flapping gesture, indicating that a bird was doing the struggling) than when the same gesture reinforced the information conveyed in speech ("he flapped nonstop," accompanied by the same flapping gesture); the adults later reported that the struggler was a bird in both conditions, making it clear that they had integrated the information conveyed in gesture with the information conveyed in speech in the first condition. Importantly, the same regions did not show this pattern when speech was presented without gesture (i.e., the regions did not respond more strongly to "he struggled nonstop" presented without gesture than to "he flapped nonstop" also presented without gesture). These findings suggest that the three areas are responding specifically to the task of integrating information across gesture and speech.

Using EEG (electroencephalography), a number of researchers have demonstrated that the relation between gesture and speech can modulate brain activity. Gestures that are semantically anomalous with respect to the accompanying speech are associated with a more negative N400 waveform (Bernardis, Salillas, & Caramelli, 2008; Holle & Gunter, 2007; Kelly, Kravitz, & Hopkins, 2004; Özyürek, Willems, Kita, & Hagoort, 2007; Wu & Coulson, 2005, 2007); the N400 is known to be sensitive to incongruent semantic information (Kutas & Hillyard, 1984). For example, gestures conveying information that is truly incongruent with the information conveyed in speech (gesturing *short* while saying "tall") produce a large negativity at 400 ms (Kelly et al., 2004). Interestingly, gestures conveying information that is different from, but complementary to, information conveyed in speech (gesturing *thin* while saying "tall" to describe a tall, thin container) are processed no differently at this stage from gestures that convey the same information as speech (gesturing *tall* while saying "tall"; Kelly et al., 2004). Neither one produces a large negativity at 400 ms; that is, neither one is recognized as a semantic anomaly. It is important to note, however, that at early stages of sensory/phonological processing (P1–N1 and P2), speech accompanied by gestures conveying different but complementary information (e.g., gesturing *thin* while saying "tall") is processed differently from speech accompanied by gestures conveying the same information (gesturing *tall* while saying "tall"). Thus, complementary differences between the modalities (i.e., the information conveyed in gesture is different from, but has the potential to be integrated with, the information conveyed in speech—what we have referred to as "gesture-speech mismatch") are noted at early stages of processing, but not at later, higher-level stages.

Gesture's Impact on Learning Through Communication

Children have the potential to shape their learning environments just by moving their hands—that is, just by gesturing. This section explores this process, with a focus on what happens in the classroom.

Children's Gestures Shape Their Learning Environment

One of gesture's most salient features is that it is "out there," a concrete manifestation of ideas for all the world to see. Gesture could be a signal to parents and teachers that a particular notion is already in a child's repertoire, although not quite accessible. These listeners could then alter their behavior accordingly, perhaps offering instruction in just these areas. If so, children would be able to shape their own learning environments just by moving their hands. Several facts need to be established in order for this hypothesis to be credible: (a) Ordinary listeners must be able to process the gestures children produce and glean substantive information from them, not just in laboratory situations but in actual interactions with children. (b) Those listeners must change their behavior in response to the children's gestures, treating children differently simply because of the gestures the children produce.

(c) Those changed behaviors must have an effect on the child, preferably a beneficial effect.

We have just reviewed evidence for the first of these points. Adults (teachers and nonteachers alike) can "read" the gestures that children produce in naturalistic situations (point a). Moreover, there is good evidence for the second point. When asked to instruct children, teachers provide different instruction as a function of the children's gestures (point b). Before instructing each child, the teachers in the Goldin-Meadow and Singer (2003) study watched that child explain how he or she solved six math problems to the experimenter. Some children produced mismatches during this pretest. The teachers seemed to notice and adjust their instruction accordingly; they gave more variable instruction to the children who produced mismatches than to those who did not produce mismatches: (1) They exposed the mismatchers to more different types of problem-solving strategies. (2) They gave the mismatchers more explanations in which the strategy that they expressed in gesture did not match the strategy that they expressed in speech; in other words, the teachers produced more of their own mismatches. Thus, the gestures that children produce can influence the instruction they get from their teachers.

The crucial question to address in terms of gesture's role in bringing about cognitive change is whether the instruction that teachers spontaneously offer children in response to their gestures is good for learning (point c). But first we consider why teachers might produce gesture-speech mismatches of their own.

Why Do Teachers Produce Gesture-Speech Mismatches?

It is easy to understand why a teacher might produce a variety of different problem-solving strategies when instructing a child. But why would a teacher present one strategy in one modality and a different strategy in the other modality? In other words, why would a *teacher* produce a gesture-speech mismatch?

Children who produce mismatches are in a state of cognitive uncertainty, possessing knowledge about the task that they cannot quite organize into a coherent whole. Teachers generally are not uncertain about how to solve the math problems they teach. However, they may be uncertain about how best to *teach* children to solve the problems, particularly mismatching children who are producing many inconsistent strategies. It is this uncertainty that may then be reflected in a teacher's mismatches. In general, a mismatch reflects the fact that the speaker is holding two ideas in mind—two ideas that the speaker has not yet integrated into a single unit (see Garber & Goldin-Meadow, 2002; Goldin-Meadow, Nusbaum, Garber, & Church, 1993b)—in the teacher's case, a single instructional unit. This way of describing mismatch is, at least plausibly, as applicable to adults when teaching as it is to children when explaining.

However, teachers' mismatches do differ from the children's (Goldin-Meadow & Singer, 2003), and these differences may be important. Not surprisingly, teacher's mismatches for the most part contain correct problem-solving strategies, often two correct strategies that complement one another. For example, on the problem $7 + 6 + 5 = \_\_ + 5$, one teacher expressed an equalizer strategy in speech ("we need to make this side equal to this side") while expressing a grouping strategy in gesture (point at the 7 and the 6, the two numbers which, if added, give the answer that goes in the blank). Both strategies lead to correct solutions yet do so via different routes. In contrast, children's mismatches contain as many incorrect strategies as correct ones.

Even more important, teachers' mismatches do not contain unique information, but children's mismatches do. Recall that children often convey information in the gestural component of their mismatches that cannot be found *anywhere* else in their repertoires. The children's mismatches thus convey their newest ideas. Although these ideas are not always correct, the experimentation displayed in these mismatches may be essential in promoting cognitive change. The children's mismatches thus display the kind of variability that could be good for learning (cf., Siegler, 1994; Thelen, 1989). In contrast, teachers do not convey unique information in their mismatches (Goldin-Meadow & Singer, 2003). All of the strategies that the teachers express in the gestural component of a mismatch can be found, on some other problem, in their speech. The teachers' mismatches do not contain new and undigested thoughts and, consequently, do not reflect the kind of variability that leads to cognitive change. Indeed, teachers' mismatches can best be characterized in terms of the kind of variability that comes with expertise—the back-and-forth around a set-point that typifies expert (as opposed to novice) performance on a task (cf. Bertenthal, 1999). Both experts and novices exhibit variability. However, the variability that experts display is in the service of adjusting to small (and perhaps unexpected) variations in the task. In contrast, the variability that novices display reflects experimentation with new ways of solving the task and, in this way, has the potential to lead to cognitive change.

In this regard, it is important to point out that mismatch *can* reflect experimentation in adults. When adults are uncertain about how to solve a problem, they too produce mismatches (e.g., Kastens et al., 2008; Perry & Elder, 1997; Ping, Larson, Decatur, Zinchenko, & Goldin-Meadow, 2013), and it is very likely that those mismatches will exhibit the properties found in child mismatches rather than those found in teacher mismatches—that is, information that cannot be found anywhere else in the speaker's repertoire. In other words, when adults are learning a task, their mismatches are likely to exhibit the kind of variability that can lead to cognitive change.

Do Teachers Spontaneously Give Children What They Need?

Teachers instinctively expose children who produce mismatches to instruction containing a variety of problem-solving strategies and many mismatches (Goldin-Meadow & Singer, 2003). Is this instruction good for learning? Mismatching children do indeed profit from the instruction but they, of course, are ready to learn this task. To find out whether this particular type of instruction promotes learning, we need to move to a more experimental procedure.

Singer and Goldin-Meadow (2005) gave 9- and 10-year-old children instruction that contained either one or two problem-solving strategies in speech. In addition, they varied the relation between that speech and gesture. Some children received no gesture at all, some received gesture that matched its accompanying speech, and some received gesture that mismatched its accompanying speech. The results were clear and surprising. One strategy in speech was much more effective than two strategies in speech. Thus, it does not seem to be such a good idea for teachers to offer their students a variety of spoken strategies. However, regardless of whether children received one or two strategies in speech, mismatching gesture was more effective than either matching gesture or no gesture at all. Offering children gesture-speech mismatches does appear to be an effective instructional strategy.

Why might mismatching gestures be so effective in promoting learning? The children in Singer and Goldin-Meadow's (2005) study were able to profit from a second strategy in instruction, but only when that second strategy was presented in gesture in a mismatch. Mismatching gesture provides the learner with additional information, and presents that information in a format that may be particularly accessible to a child on the cusp of learning. The visuospatial format found in gesture not only captures global images easily, but it also allows a second (gestured) strategy to be presented *at the same time as* the spoken strategy. By placing two different strategies side-by-side within a single utterance (one in speech and one in gesture), mismatches can highlight the contrast between the two strategies. This contrast may, in turn, highlight the fact that different approaches to the problem are possible—an important concept for children grappling with a new idea.

Can Gesture Be Put to Better Use?

Teachers spontaneously use gesture to promote learning. But they don't always use it as effectively as possible. Can gesture be put to better use? There are at least two ways in which gesture can be harnessed to promote cognitive change. We can teach adults to be better gesture-readers, and we can teach adults to be better gesture-producers.

Kelly, Singer, Hicks, and Goldin-Meadow (2002) taught adults to read the gestures that children produce on either conservation or mathematical equivalence tasks. Adults were given a pretest, instruction in gesture-reading, and then a posttest. Instruction varied from just giving a hint ("pay close attention not only to what the children on the videotape say with their words, but also to what they express with their hands"), to giving general instruction in the parameters that experts use when describing gesture (handshape, motion, placement), to giving specific instruction in the kinds of gestures children produce on that particular task. The adults improved with instruction, more so when given explicit instruction but even when given a hint. Moreover, the adults were able to generalize the instruction they received to new gestures they had not seen during training. Importantly, improvement in reading gesture did *not* affect the adults' ability to glean information from the children's speech on the conservation task—they identified the child's spoken explanations perfectly before and after instruction. There was, however, a slight decrement in the number of spoken explanations the adults reported after instruction on the math task, although this decrement was offset by an increase in the number of gestured explanations the adults reported after instruction. The challenge for us in the future is to figure out ways to encourage teachers and other adults to glean information from children's gestures while at the same time not losing their words.

Children are more likely to profit from instruction when it is accompanied by gesture than when that same instruction is not accompanied by gesture (Church, Ayman-Nolley, & Mahootian, 2004; Perry, Berch, & Singleton, 1995; Valenzeno, Alibali, & Klatzky, 2003), even when the gestures are not directed at objects in the immediate environment (Ping & Goldin-Meadow, 2008). But the gestures that teachers spontaneously use with their children are not *always* helpful. Take the following interchange that occurred when a teacher was asked to teach a child mathematical equivalence. The teacher had asked the child to solve the problem $7 + 6 + 5 = \_\_ + 5$ and the child put 18 in the blank, using an incorrect "add-numbers-to-equal-sign" strategy to solve the problem. In her speech, the teacher made it clear to the child that he had used this strategy: She said "so you got this answer by adding these three numbers." However, in her gestures, she produced an "add-all-numbers" strategy: she pointed at the 7, the 6, and the 5 on the left side of the equation *and* the 5 on the right side of the equation (see Figure 9.3 and compare it to Figure 9.2). After these gestures, the teacher went on to try to explain how to solve the problem correctly but, before she could finish, the child offered a new solution—23, precisely the number you get if you add up all of the numbers in this problem. The teacher was genuinely surprised at her student's answer, and was completely unaware of the fact that she herself might have given him the idea to add up all of the numbers in the problem. A teacher's gestures can lead the child astray. The larger point, however, is that the gestures teachers produce have an impact on what children take from their lessons and may therefore have an effect on learning. If so, teachers (and other adults) need to be encouraged to pay more attention to the gestures that they themselves produce.

Gesture may require our attention not only in teaching situations but also in legal interviews that involve children. Given the prevalence of gesture, it is not hard to imagine that children will gesture when responding to questions in a forensic interview—and that those gestures will, at times, convey information that is not found in their speech. If so, the interesting question—both theoretically and practically—is whether adult interviewers are able to pick up on the information that children convey uniquely in gesture and, if not, whether they can be trained to do so. The flip side of the question is also of great importance—do adult interviewers convey information in their gestures, information that they do not consciously intend to convey, and if so, does that information influence how children respond to their queries? In other words, is there a sub-rosa conversation taking place in gesture that does not make it onto the transcripts that become the legal documents for forensic interviews (see Broaders & Goldin-Meadow, 2010, for evidence that gesture can play this type of role in an interview situation)? Given that the details children recall of an event can often be influenced by the way in which the interviewer poses the question (e.g., Ceci, 1995), this issue becomes a timely one and one in which attention to gesture might make a difference.

Gesture's Role in Thinking: Does Gesturing Help Us Think?

Gesturing has the potential to play a role in thinking by lightening the speaker's load, but it can also have a more direct effect on thinking by helping to create ideas.

Gesturing Can Lighten the Speaker's Cognitive Load

We have seen that gesture can convey information to listeners. The question we address in this section is whether gesture serves a function for speakers as well as listeners. The fact that we persist in gesturing even when there are no obvious communicative gains (e.g., when talking on the phone) or when silently solving or interpreting a problem (e.g., doing mental abacus, Brooks, Barner, Frank, & Goldin-Meadow, 2011; or reading a problem in geology,

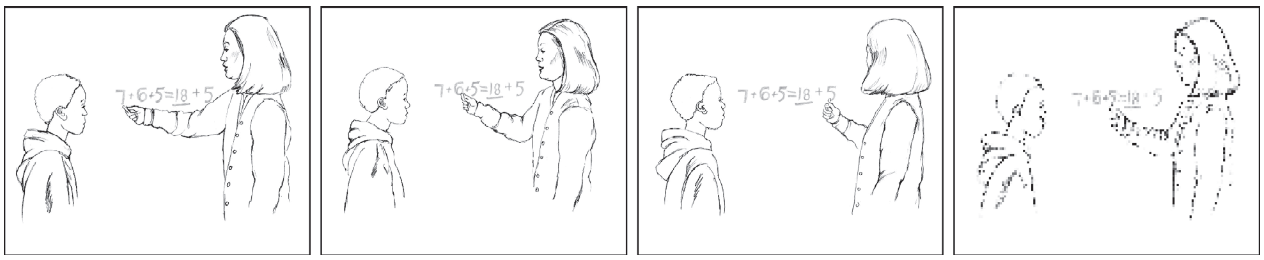

Figure 9.3 The gestures teachers produce can have an impact on the student. In her speech, the teacher points out to the child that he added the first three numbers to get his incorrect answer of 18. However, in her gesture, she points at all of the numbers in the problem, including the last number on the right side of the equation (an add-all-numbers strategy; see Figure 9.2 for an example of a child-produced add-all-numbers strategy). The child's response was to add up all of the numbers in the problem and give 23 as his answer. He had paid attention to his teacher's gestures.

Source: Reprinted from Goldin-Meadow, 2003b.

Liben, Christensen, & Kastens, 2010) propels us to seek a within-speaker function. And there is indeed some evidence that gesturing is a boon to the gesturer. In some circumstances, speakers find speaking cognitively less effortful when they gesture than when they do not gesture.

Goldin-Meadow, Nusbaum, Kelly, and Wagner (2001) asked children and adults to solve math problems (addition problems for the children, factoring problems for the adults). Immediately after solving a problem, the child or adult was given a list of items to remember (words for the children, letters for the adults). The participants were then asked to explain how they solved the math problem and, after their explanation, to recall the list of items. Note that the participants produced their explanations while keeping the list in memory; the two tasks thus made demands on the same cognitive resources. On half of the problems, the participants were given no instructions about their hands. On the other half, they were told to keep their hands still during their explanations of the problems. The participants gave the same types of explanations for the math problems when they gestured and when they did not gesture. However, the number of items they remembered was not the same. Both children and adults remembered significantly more items when they gestured than when they did not gesture, suggesting that a spoken explanation accompanied by gesture takes less cognitive effort than a spoken explanation without gesture.

There is one potential problem with these findings. Perhaps asking people not to move their hands adds a cognitive load to the task. If so, the recall pattern might not reflect the beneficial effects of gesturing but rather the demands of this extra cognitive load. Data from a subset of the participants address this concern. These participants gestured on only some of the problems on which they were allowed to move their hands; as a result, on some problems they did not gesture *by choice*. The number of items that these participants remembered when they gestured was significantly higher than the number they remembered when they did not gesture *by choice* and significantly higher than the number they remembered when they did not gesture *by instruction*. Indeed, the number of items remembered did not differ when the participants did not gesture by choice or by instruction. Thus, the instructions not to gesture did not add to cognitive load and the beneficial effects on recall appear to be attributable to gesture.

Why might gesture lighten a speaker's cognitive load? Perhaps gesture lightens cognitive load by raising the overall activation level of the system (Butterworth & Hadar, 1989). If so, the act of moving one's hands ought to affect recall, not what those hand movements mean. However, the meaning of the gestures does have an impact on recall (Wagner, Nusbaum, & Goldin-Meadow, 2004)—speakers remember fewer items when their gestures do not match their words than when they do, that is, when they convey two messages (one in speech and one in gesture), rather than one (the same message in speech and gesture). Interestingly, this pattern holds for experts, but not for novices—children who are just learning conservation remember *more* items when their gestures do not match their words than when they do match (Ping & Goldin-Meadow, 2010). Note that the novice pattern still indicates that the meaning of gesture matters—it's just that mismatching gesture has a different impact on processing in novices than in experts, an intriguing result that needs to be explored in future research.

Rather than merely adding activation to the system, gesture might help speakers retrieve just the right word in their explanations (which would, in turn, save them cognitive effort so that they could perform better on the memory task). Gesture, particularly iconic gestures, might assist word finding by exploiting another route to the phonological lexicon, a route mediated by visual coding (Butterworth & Hadar, 1989). There is, in fact, some evidence suggesting that gesture can facilitate lexical recall—speakers are more successful at resolving tip-of-the-tongue states when they are permitted to gesture than when they are not, for both adult (Frick-Horbury & Guttentag, 1998) and child (Pine, Bird, & Kirk, 2007) speakers (but see Alibali, Kita, & Young, 2000; Beattie & Coughlan, 1998, 1999).

However, lexical access does not account for all of gesture's beneficial effects. Gesture may also help link or "index" words and phrases to real-world objects. Glenberg and Robertson (1999) argue that indexing is essential for comprehension; once a word is indexed to an object, the listener's knowledge of that particular object can guide his or her interpretation of the language. Making these links might be important, not only for listeners but also for speakers. Alibali and DiRusso (1999) explored the benefits of gestural indexing for preschoolers performing a counting task. Sometimes the children were allowed to gesture, in particular, to tick off the items, while they counted and sometimes they were not. The children counted more accurately when they gestured than when they did not gesture. Thus, using gesture to hook word to world can improve performance on a task.

Finally, gesturing could help speakers organize information for the act of speaking and in this way ease the speaker's cognitive burden. Kita (2000) has argued that gesture helps speakers "package" spatial information into units appropriate for verbalization. If this hypothesis is correct, speakers should find it easier to convey spatial information when they gesture than when they do not gesture. Rimé, Schiaratura, Hupet and Ghysselinckx (1984) prevented speakers from gesturing and found that these speakers produced less visual imagery in their talk when they did not gesture than when they did. Alibali, Kita, Bigelow, Wolfman, and Klein (2001b) performed the same manipulation and found that their child speakers produced fewer perceptual-based explanations when they did not gesture than when they did.

So what have we learned about gesture's effect on the gesturer? We know that speakers tend to gesture more when the task becomes difficult. They appear to do so not merely as a reflection of the cognitive effort they are expending, but as a way to *reduce* that effort. Giving an explanation while gesturing actually takes *less* cognitive effort than giving an explanation without gesturing. However, we do not yet understand the mechanism by which gesturing lightens the speaker's load.

Gesture's Direct Impact on the Learner: Can Gesturing Create Ideas?

We have seen that gesturing can aid thinking by reducing cognitive effort. That effort can then be used on some other task, one that would have been performed less well had the speaker not gestured on the first task. Gesturing thus allows speakers to do more with what they have and, in this way, can promote cognitive change. But gesturing has the potential to contribute to cognitive change in other ways as well—it could have an impact on the *direction* that the change takes.

Gesture offers a route, and a unique one, through which new information can be brought into the system. Because the representational formats underlying gesture are mimetic and analog rather than discrete, gesture permits speakers to represent ideas that lend themselves to these formats (e.g., shapes, sizes, spatial relationships)—ideas that, for whatever reason, may not be easily encoded in speech. Take, for example, the child described earlier who expressed one-to-one correspondence in gesture but not in speech. This child may find it relatively easy to focus on aligning the two rows of checkers in the visuospatial format gesture offers—and at a time when he does not have sufficient grasp of the idea to express it in words. Gesture provides a format that makes it easy for the child to discover one-to-one correspondence, and thus allows this novel idea to be brought into his repertoire earlier than it would have been without gesture. Once brought in, the new idea can then serve as a catalyst for change.

The suggestion here is that gesture does not just *reflect* the incipient ideas that a learner has, but it actually helps the learner formulate and therefore *develop* these new ideas. One implication of this hypothesis is that thought would have been different had the speaker not gestured. There is evidence that gesturing while explaining how they solved a problem affects how problem-solvers will tackle the next problem. The evidence comes from the Tower of Hanoi (TOH) puzzle. As described earlier, Cook and Tanenhaus (2009) showed that the gestures speakers produces can have an effect on how listeners subsequently solve the TOH puzzle. Beilock and Goldin-Meadow (2010) showed that the gestures speakers produce can have an effect on how the speakers themselves solve the next TOH problem.

Beilock and Goldin-Meadow (2010) asked adults to first solve the Tower of Hanoi problem with real, weighted disks (TOH1). The smallest disk in the tower was the lightest and could be lifted with one hand; the biggest disk was so heavy that it required two hands to lift. The adults were then asked to explain how they solved the problem, gesturing while doing so. After the explanation, they solved the problem a second time (TOH2). For some problem-solvers (*No-Switch Group*), the disks in TOH2 were identical to TOH1 and they, not surprisingly, improved on the task (they solved TOH2 in fewer moves and in less time than TOH1). For others (*Switch Group*), the disk weights in TOH2 were reversed—the smallest disk was now the heaviest and could no longer be lifted with one hand. This group did not improve and, in fact, took more moves and more time to solve the problem on TOH2 than TOH1. Importantly, however, the performance of the *Switch* group on TOH2 could be traced back to the gestures they produced during the explanation task—the more they used one-handed gestures when talking about moving the smallest disk during the explanation, the worse they did on TOH2 (remember that the smallest disk on TOH2 in the *Switch* group could no longer be lifted with one hand). There was no relation between the type of gesture used during the explanation and performance on TOH2 in the *No Switch* group simply because the smallest disk on TOH2 for this group could be lifted using either one or two hands.

Beilock and Goldin-Meadow (2010) suggested that the one-handed gestures speakers produced during the explanation task helped to consolidate a representation of the smallest disk as "light." This representation was incompatible with the action that had to be performed on TOH2 in the *Switch* group but not in the *No Switch* group. If gesturing is responsible for the decrement in performance in the *Switch* group, removing gesturing should eliminate the decrement—which is precisely what happened. In a second experiment that eliminated the explanation phase and thus eliminated gesturing entirely, the *Switch* group displayed no decrement in performance and, in fact, improved as much as the *No Switch* group (Beilock & Goldin-Meadow, 2010). Thus, the switch in disks led to difficulties on TOH2 only when the adults gestured in between the two problem-solving attempts, and only when those gestures conveyed information that was incompatible with the speaker's next moves. The findings suggest that gesture is adding or consolidating action information in the speakers' mental representation of the task, rather than merely reflecting their previous actions.

To examine whether gesture is more (or less) likely than action itself to have an effect on problem-solving, Goldin-Meadow and Beilock (2010) again asked adults to perform the TOH task twice, but in between the two performances some of the adults (in the Action condition) did the task again using the original set of disks, some (in the Gesture condition) as before talked and gestured about how they did the task with the original set of disks. Importantly, the adults in the Action condition moved the smallest disk with one hand as often as the adults in the Gesture condition gestured about the smallest disk with one hand. The researchers replicated the original effect in the Gesture condition—adults who gestured and were in the *Switch* group performed worse on TOH2 than adults who gestured and were in the *No Switch* group. But the researchers did not find a comparable effect in the Action condition—adults who acted in between TOH1 and TOH2 improved on TOH2 whether they were in the *Switch* or the *No Switch* groups. Gesturing about the small disk had an impact on subsequent performance; acting on the small disk did not (see also Trofatter, Kontra, Beilock, & Goldin-Meadow, 2014).

Gesturing about an action can thus solidify in mental representation the particular components of action that are reflected in gesture in adults performing a problem-solving task. But can gesturing help children learn a new task? To find out, we need to manipulate the gestures children produce on a task and observe the effect of that manipulation on their subsequent performance of the task.

LeBarton, Raudenbush, and Goldin-Meadow (in press) manipulated pointing gestures in 17-month-old children by telling them to point at (put their fingers on) pictures in a book. They found that, over a 7-week period, the children increased the rate at which they gestured not only when interacting with the experimenter, but also when spontaneously interacting with their parents. In turn, at the end of the 7-week period, children who had been instructed to gesture (and saw the experimenter gesture) had larger spoken vocabularies than children who had only seen the experimenter gesture, and than children who had neither seen nor produced gestures. Telling children to gesture thus had an effect not only on their gesturing, but also on their word-learning.

Broaders, Cook, Mitchell, and Goldin-Meadow (2007) asked 9- to 10-year-old children to explain how they solved six mathematical equivalence problems (e.g., $6 + 4 + 2 = \_\_ + 2$) with no instructions about what to do with their hands. They then asked the children to solve a second set of comparable problems and divided the children into three groups: Some were told to move their hands as they explained their solutions to this second set of problems; some were told not to move their hands; and some were given no instructions about their hands. Children who were told to gesture on the second set of problems added strategies to their repertoires that they had not previously produced; children who were told not to gesture and children given no instructions at all did not. Most of the added strategies were produced in gesture and not in speech and, surprisingly, most were correct. In addition, when later given instruction in mathematical equivalence, it was the children who had been told to gesture and had added strategies to their repertoires who profited from the instruction and learned how to solve the math problems. Being told to gesture thus encouraged children to express ideas that they had previously not expressed, which, in turn, led to learning.

But can gesture, on its own, create new ideas? To determine whether gesture can create new ideas, we need to teach speakers to move their hands in particular ways. If speakers can extract meaning from their hand movements, they should be sensitive to the particular movements they are taught to produce and learn accordingly. Alternatively, all that may matter is that speakers move their hands. If so, they should learn regardless of which movements they produce. To investigate these alternatives, Goldin-Meadow, Cook, and Mitchell (2009) manipulated gesturing in 9- to 10-year-old children during a math lesson. They taught children to produce a *V*-point gesture to the first two numbers in a mathematical equivalence problem (the 4 and the 3 in the problem $4 + 3 + 6 = \_\_ + 6$), followed by a point at the blank. These movements, which were modeled after the spontaneous gestures of children who know how to solve these problems correctly (Perry et al., 1988), were designed to help students see that the problem can be solved by *grouping* and adding the two numbers on the left side of the equation that do not appear on the right side, and putting the sum in the blank. Children asked to produce these hand movements during a math lesson were able to extract the grouping strategy and improve on a posttest, despite the fact that they were never explicitly told what the movements represented, nor were they taught the grouping strategy by the teacher in either gesture or speech. Another group of children was trained to make a *V*-point to the "wrong" addends (3 and 6 in this example), a partially correct grouping strategy. They also learned grouping and performed better on the posttest than children who were not taught how to move their hands but, importantly, they performed worse than the children who were taught to produce the fully correct grouping strategy. The findings suggest that gesturing not only helps process old ideas but also helps create new ones, and that the particular movements in the gestures have an impact on what those new ideas are.

In addition to helping children learn in the short-term, gesturing also helps make learning last. Cook, Mitchell, and Goldin-Meadow (2008) taught some children a strategy for solving mathematical equivalence problems in speech alone, some the same strategy in gesture alone, and a third group the strategy in both speech and gesture. The children produced the words and/or gestures they were taught throughout a lesson in how to solve the problems. Children in all three groups improved an equal amount after the lesson, but only the children who gestured during the lesson (either alone or with speech) retained what they had learned a month later. Geturing, but not speaking, thus solidified the knowledge gained during instruction, suggesting that gesturing can play a cause roled in learning.

THE NEXT FRONTIER IN GESTURE RESEARCH

We now know that gesture can be a window onto the mind. Its importance stems from the fact that it often offers a different view of the mind than the view offered by speech, and from the fact that using the window provided by gesture requires no training at all—it's something we all do naturally and effortlessly. Gesture can therefore be used not only by researchers, but also by parents, teachers, and clinicians to learn more about the minds of the people with whom they interact.

We also know that gesture does more than reflect thought—it can play an active role in changing thought. As such, it can be brought into homes, classrooms, and clinical settings and used as a tool to promote change. But to use this tool effectively, we need to fully understand why gesture leads to learning. I end the chapter with some promising possibilities.

Gesture Facilitates the Transition From Action to Abstraction

Both action and gesture involve movements of the body, but actions have a direct effect on the world, gestures do not (e.g., twisting a jar lid results in an open jar, gesturing a twisting movement does not). Do the fundamental differences between gesture and action affect the impact each has on learning? Traditional theories of cognitive development suggest that children succeed in solving problems with physical objects before they succeed with symbolic representations (Bruner, Olver, & Greenfield, 1966; Piaget, 1953). But encouraging children to learn by acting on concrete objects has received mixed empirical support (see Sarama & Clements, 2009; Mix, 2010; McNeil & Uttal, 2009). For example, children often view their actions as relevant only to the objects on which they were trained, rather than to a more general concept (Uttal, Scudder, & DeLoache, 1997). Action may thus be helpful in teaching children to solve a particular problem, but may fare less well in teaching them to extend that knowledge to new, more abstract problems. Because gesture has a leg in both concrete action (the *twist* gesture is itself an action) and abstract representation (the *twist* gesture represents an action), it has the potential to help learners make the transition from the concrete to the abstract, from action to abstraction.

In a recent study, Novack, Congdon, Hemani-Lopez, and Goldin-Meadow (2014) asked whether gesturing promotes learning because it is itself a physical action, or because it uses physical action to represent abstract ideas. They taught third-grade children a strategy for solving mathematical equivalence problems that was instantiated in one of three ways: (1) in the physical action children performed on objects, (2) in a concrete gesture miming that action, or (3) in an abstract gesture. All three types of hand movements helped children learn how to solve the problems on which they were trained. However, only gesture led to success on problems that required generalizing the knowledge gained, with abstract gesture producing the highest rates of learning on generalization problems. The results provide evidence that gesture promotes transfer of knowledge better than action, and suggest that the beneficial effects gesture has on learning, and particularly on generalization, may reside in the features that differentiate it from action.

These findings are consistent with the abstraction literature. For example, the "concreteness fading" theory proposes that learning is best supported by first introducing concrete representations and then transitioning learners to more symbolic or abstract representations (Goldstone & Son, 2005; McNeil & Fyfe, 2012). Future research is needed to determine whether movement-based learning is most effective if children are provided with increasingly abstract representations of a strategy; that is, if children are encouraged to begin with action and then move on to gesture. A fading technique of this sort might be particularly effective with children who are struggling with a concept.

Another important question is whether the effectiveness of using action versus gesture to teach ideas depends on whether the idea can be "read off" the manipulated object (see Samara & Clements, 2009). Consider, for example, a mental rotation task where doing the action gives the answer (i.e., once the object is rotated, one can see whether it is the same object in a different orientation or a different object). It is an open question as to whether using action to teach a task like mental rotation is more effective than using gesture to teach such a task. The age of the learner might also have an impact on the relative effectiveness of action versus gesture. Young children are not only believed to internalize ideas through action experience (Vygotsky, 1978), but they also find gesture to be more difficult to interpret than action (Novack, Goldin-Meadow, & Woodward, 2013). Thus, although gestures are better than action in promoting generalization on a math task, additional research is needed to determine the pervasiveness of this effect across domains and ages.

Gesture Spatializes Information

Gesture is an ideal medium for capturing spatial information and may therefore be particularly well suited to promoting learning in spatial tasks. Indeed, gesture's role in learning has been explored primarily in tasks that are inherently spatial (e.g., mental transformation, Goldin-Meadow, Levine, Zinchenko, Yip, Hemani, & Factor, 2012a; mathematical equivalence, Broaders et al., 2007; gears, Alibali, Spencer, Knox, & Kita, 2011). It is therefore possible that gesture is an effective learning tool only in spatial tasks. But speakers gesture even when talking about nonspatial ideals (e.g., moral dillemas, Church, Schonert-Reichl, Goodman, Kelly, & Ayman-Nolley, 1995). Gesturing may allow learners to take a problem that is not spatial and lay it out in space, thus "spatializing" it. Once spatialized, the problem may invite the use of spatial learning mechanisms (Newcombe, 2010) that would not have been applicable had the learner not gestured.

Beaudoin-Ryan and Goldin-Meadow (2014) explored this possibility by requiring children to gesture prior to receiving a lesson in moral reasoning, an inherently nonspatial task. Children who were told to gesture when reasoning about a moral dilemma produced significantly more responses involving multiple perspectives in gesture than children who were told not to gesture and than children who received no instructions about using their hands—the gesturers spatialized different views of the moral dilemma onto their hands, putting one perspective on one hand and the other perspective on the other. In turn, the more multiple-perspective gestures the children produced prior to the lesson, the more multiple-persepctive responses they produced in *speech* after the lesson. When children gesture about a moral dilemma, they are able to capitalize on a lesson in moral reasoning and, as a result, take perspectives that go beyond their own. Gesturing can thus promote learning in at least one nonspatial domain.

Even though gesturing can play a role in a nonspatial task, there still appears to be a tight relation between gesturing and certain domains, for example, geoscience (Kastens et al., 2008; Liben et al., 2010) and stereochemistry (Stieff, 2011; Stieff & Raje, 2010). Anecdotally, it is difficult to find geoscientists or chemists who do not gesture when explaining concepts in their fields, and it seems like it would be easier to explain a literary topic such as Chaucer without gesturing than to explain problems in stereochemistry without gesturing. Future work is needed to explore whether there is, in fact, a tight link between gesturing and scientific domains and, if so, what the implications of such a link might be for teaching and learning in these domains.

Gesture Adds a Second Representational Format

As described earlier, gesture conveys information using a different representational format from the format that supports speech. As a result, when gesture is combined with speech, it has the virtue of adding this format to a speaker's message. But, at the same time, gesture adds a second modality, the manual modality, to the oral modality that supports speech. Gesture's power in a learning situation might therefore come either from the juxtaposition of two distinct representational formats, or from the juxtaposition of two modalities.

Goldin-Meadow, Shield, Lenzen, Herzig, and Padden (2012b) explored these alternative hypotheses by asking signers to solve mathematical equivalence problems and examining the gestures that they produced along with those signs. The gestures signers produce are in the same (manual) modality as their signs. If adding a second modality to speech is what gives gesture its power in a learning situation, then mismatch between sign and gesture (i.e., mismatch within one modality) should *not* predict learning in signers, unlike mismatch between speech and gesture (i.e., mismatch across two modalities), which does predict learning in speakers (see "Gesture Can Reveal Thoughts Not Found in Speech"). Alternatively, if adding a second representational format to speech is what gives gesture its power, then mismatching gesture should predict learning in signers as well as speakers. Goldin-Meadow et al. (2012) found that signers who produced many gestures conveying different information from their signs (i.e., many gesture-sign mismatches) were more likely to succeed after instruction than signers who produced few, suggesting that the representational format gesture adds to speech is important in predicting learning.

Paivio (1971) has argued that both visual and verbal codes for representing information are used to organize information into knowledge. In Paivio's view, visual and verbal are not defined by modality—information is considered verbal whether it is written text or oral speech, and visual whether it is a picture or a nonlinguistic environmental sound. The findings on signers lend credence to this view, and suggest that (in Paivio's terms) sign language is processed as verbal information, gesture as visual. The findings also suggest that gesture's ability to predict learning comes not from the juxtaposition of different information conveyed in distinct modalities (hand versus mouth), but rather from the juxtaposition of different information conveyed in distinct representational formats (a mimetic, analog format underlying gesture, *visual* in Paivio's terms, versus a discrete, segmented format underlying language, sign or speech, *verbal* in Paivio's terms).

Although gesture-speech mismatch can predict learning whether the *verbal* information is conveyed in the manual (sign) or oral (speech) modality, the data leave open the possibility that the *visual* information must be conveyed in the manual modality. The manual modality may be privileged when it comes to expressing emergent or mimetic ideas, perhaps because our hands are an important vehicle for discovering properties of the world (Sommerville, Woodward, & Needham, 2005; Goldin-Meadow & Beilock, 2010). Future research is needed to explore this question.

Gesture Synchronizes Seamlessly With Speech

As we have seen, gesture forms a temporally integrated system with speech (Kendon, 1980; McNeill, 1992). As a result, one of the advantages gesture has over other visual representational formats (e.g., drawings) is that it is synchonized with the words it accompanies. In contrast, speakers need to think about, and plan, how to integrate the aspects of a drawing they wish to highlight with the words they are saying. The powerful effects that gesture has on learning may therefore come, at least in part, from the seamless way gesture synchronizes with speech. Although many studies have explored the synchronization between gesture and speech, to my knowledge, none has examined whether this synchronization is responsible for the impact that gesture has on learning, leaving a hole to be filled in by future research.

Another important area for future research are the gestures produced without speech in noncommunicative contexts. Learners often gesture to themselves when trying to work out a difficult problem. These gestures may, at times, be accompanied by subvocal speech (this too is an area for further research), but there are tasks that elicit gestures for the self and that do not involve sub-vocal speech, for example, the mental abacus. Mental abacus is a system for doing rapid arithmetic by manipulating a mental representation of an abacus, a physical tool on which calculating is done by moving beads along columns representing different place values. Frank and Barner (2012) studied practiced mental abacus users in India and found that their mental calculations were sensitive to motor interference (i.e., asking them to tap their fingers while mentally calculating) but not to verbal interference (asking them to repeat a children's story while mentally calculating), suggesting that mental abacus is a nonlinguistic format for exact numerical computation. Interestingly, children frequently gesture while doing calculations on a mental abacus (Brooks, Barner, Frank, & Goldin-Meadow, 2011); these gestures are not intended for others (i.e., they are not communicative) and, given Frank and Barner's (2012) findings, they are unlikely to be accompanied by subvocal verbalizations. They are gestures for thinking rather than for speaking. Future work is needed to explore whether the cognitive functions gesture serves when it is produced without speech and entirely for oneself are the same as the functions gesture serves when it is accompanied by speech in a communicative context.

Summary

So why do we gesture? Perhaps gesturing is a vestige of the evolutionary process that gave us speech. It could be a hanger-on that accompanies the act of speaking but plays no active role in how we speak or think. If so, gesture would be of interest for what it can reveal to us about the process of speaking or thinking, but it would have no influence on the process itself. This is the least we can say about gesture.

But we now have good evidence that gesture does more than just reflect thought—it shapes it as well. Gesture is pervasive, appearing in a wide range of situations and over all ages and cultures. It is ever-present and we notice it even though we typically do not know we are noticing it. The causal role gesture plays in bringing about change is therefore likely to be widespread.

Gesture has earned its place as a full-fledged part of the conversation. Our job as researchers is to better understand how gesture works so that it can be harnessed in homes, classrooms, and clinical settings to promote change.

REFERENCES

Acredolo, C. & O'Connor, J. (1991). On the difficulty of detecting cognitive uncertainty. *Human Development, 34*, 204–223.

Acredolo, L. P., & Goodwyn, S. W. (1985). Symbolic gesture in language development: A case study. *Human Development, 28*, 40–49.

Acredolo, L. P., & Goodwyn, S. W. (1988). Symbolic gesturing in normal infants. *Child Development, 59*, 450–466.

Acredelo, L. P., & Goodwyn, S. W. (1996). *Baby signs: How to talk with your baby before your baby can talk*. Chicago, IL: NTB/Contemporary Books.

Acredolo, L.P., Goodwyn, S.W., Horrobin, K.D. & Emmons, Y.D. (1999). The signs and sounds of early language development. In C. Tamis-LeMonda & L. Balter (Eds.), *Child psychology: A handbook of contemporary issues* (pp. 116–139). New York, NY: Psychology Press.

Alibali, M. W., Bassok, M., Olseth, K. L., Syc, S. E., & Goldin-Meadow, S. (1999). Illuminating mental representations through speech and gesture. *Psychological Sciences, 10*, 327–333.

Alibali, M. W., & DiRusso, A. A. (1999). The function of gesture in learning to count: More than keeping track. *Cognitive Development, 14*, 37–56.

Alibali, M. W., Flevares, L., & Goldin-Meadow, S. (1997). Assessing knowledge conveyed in gesture and cognitive development: Do teachers have the upper hand? *Journal of Educational Psychology, 89*, 183–193.

Alibali, M. W., Heath, D., C., & Myers, H. J. (2001a). Effects of visibility between speaker and listener on gesture production: Some gestures are meant to be seen. *Journal of Memory and Language, 44*, 1–20.

Alibali, M. W., Kita, S., Bigelow, L. J., Wolfman, C. M., & Klein, S. M. (2001b). Gesture plays a role in thinking for speaking. In C. Cave, I. Guaitella & S. Santi (Eds.), *Oralite et gestualite: Interactions et comportements multimodaux dans la communication* (pp. 407–410). Paris, France: L'Harmattan.

Alibali, M. W., Kita, S., & Young, A. J. (2000). Gesture and the process of speech production: We think, therefore we gesture. *Language and Cognitive Processes, 15*, 593–613.

Alibali, M. W., Spencer, R. C., Knox, L., & Kita, S. (2011). Spontaneous gestures influence strategy choices in problem solving. *Psychological Science, 22*(9), 1138–1144.

Allen, R., & Shatz, M. (1983). "What says meow?" The role of context and linguistic experience in very young children's responses to *what*-questions. *Journal of Child Language, 10*, 14–23.

Andersen, E. S., Dunlea, A., & Kekelis, L. S. (1984). Blind children's language: Resolving some differences. *Journal of Child Language, 11,* 645–664.

Andersen, E. S., Dunlea, A., & Kekelis, L. S. (1993). The impact of input: Language acquisition in the visually impaired. *First Language, 13*, 23–49.

Argyle, M. (1975). *Bodily communication*. New York, NY: International Universities Press.

Barsalou, L. W. (1999). Perceptual symbols systems. *Behavioral and Brain Sciences, 22*, 577–660.

Bates, E. (1976). *Language and context: The acquisition of pragmatics*. New York, NY: Academic Press.

Bates, E., Benigni, L., Bretherton, I., Camaioni, L., & Volterra, V. (1979). *The emergence of symbols: Cognition and communication in infancy*. New York, NY: Academic Press.

Bavelas, J. B. (1994). Gestures as part of speech: Methodological implications. *Research on Language and Social Interaction, 27*, 201–221.

Bavelas, J. B., Chovil, N., Lawrie, D. A., & Wade, A. (1992). Interactive gestures. *Discourse Processes, 15*, 469–489.

Beattie, G., & Coughlan, J. (1998). Do iconic gestures have a functional role in lexical access? An experimental study of the effects of repeating a verbal message on gesture production. *Semiotica, 119*, 221–249.

Beattie, G., & Coughlan, J. (1999). An experimental investigation of the role of iconic gestures in lexical access using the tip-of-the-tongue phenomenon. *British Journal of Psychology, 90*, 35–56.

Beattie, G., & Shovelton, H. (1999a). Do iconic hand gestures really contribute anything to the semantic information conveyed by speech? An experimental investigation. *Semiotica, 123*, 1–30.

Beattie, G., & Shovelton, H. (1999b). Mapping the range of information contained in the iconic hand gestures that accompany spontaneous speech. *Journal of Language and Social Psychology, 18*, 438–462.

Beattie, G., & Shovelton, H. (2000). Iconic hand gestures and the predictability of words in context in spontaneous speech. *British Journal of Psychology, 91,* 473–491.

Beaudoin-Ryan, L., & Goldin-Meadow, S. (2014). Teaching moral reasoning through gesture. *Developmental Science*. Advance online publication. doi:10.1111/desc.12180

Beilock, S. L., & Goldin-Meadow, S. (2010). Gesture grounds thought in action. *Psychological Science, 21*, 1605–1610.

Bekken, K. (1989). Is there "Motherese" in gesture? Unpublished doctoral dissertation, University of Chicago, Chicago, IL.

Berger, K. W., & Popelka, G.R. (1971). Extra-facial gestures in relation to speech-reading. *Journal of Communication Disorders, 3*, 302–308.

Bernardis, P., Salillas, E., & Caramelli, N. (2008). Behavioural and neurophysiological evidence of semantic interaction between iconic gestures and words. *Cognitive Neuropsychology, 25*, 1114–1128.

Bertenthal, B. I. (1999). Variation and selection in the development of perception and action. In G. Savelsbergh (Ed.), *Nonlinear analyses of developmental processes* (pp. 105–120). Amsterdam, The Netherlands: Elsevier Science.

Booth, A. E., McGregor, K., & Rohlfing, K. (2008). Socio-pragmatics and attention: Contributions to gesturally guided word learning in toddlers. *Language Learning and Development, 4*, 179–202

Brentari, D., Coppola, M., Mazzoni, L., & Goldin-Meadow, S. (2012). When does a system become phonological? Handshape production in gesturers, signers, and homesigners. *Natural Language and Linguistic Theory, 30*, 1–31.

Broaders, S., Cook, S.W., Mitchell, Z., & Goldin-Meadow, S. (2007). Making children gesture reveals implicit knowledge and leads to learning. *Journal of Experimental Psychology: General, 136*, 539–550.

Broaders, S., & Goldin-Meadow, S. (2010). Truth is at hand: How gesture adds information during investigative interviews. *Psychological Science, 21*(5), 623–628.

Brooks, N., Barner, D., Frank, M., & Goldin-Meadow, S. (2011, July). Gesture and mental abacus calculation. Paper presented at the annual meeting of the Cognitive Science Society, Boston, MA.

Bruner. J. S., Olver, R. R., & Greenfild, P. M. (1966). *Studies in cognitive growth*. New York, NY: Wiley.

Butcher, C., & Goldin-Meadow, S. (2000). Gesture and the transition from one- to two-word speech: When hand and mouth come together. In D. McNeill (Ed.), *Language and gesture* (pp. 235–257). New York, NY: Cambridge University Press.

Butcher, C., Mylander, C., & Goldin-Meadow, S. (1991). Displaced communication in a self-styled gesture system: Pointing at the nonpresent. *Cognitive Development, 6,* 315–342.

Butterworth, G., & Grover, L. (1988). The origins of referential communication in human infancy. In L. Weiskrantz (Ed.), *Thought without language* (pp. 5–24). Oxford, England: Carendon.

Butterworth, B., & Hadar, U. (1989). Gesture, speech, and computational stages: A reply to McNeill. *Psychological Review, 96*, 168–174.

Camaioni, L., Caselli, M.C., Longobardi, E., & Volterra, V. (1991). A parent report instrument for early language assessment. *First Language, 11*, 345–359.

Capirci, O., Montanari, S., & Volterra, V. (1998). Gestures, signs, and words in early language development. In J. M. Iverson & S. Goldin-Meadow (Eds.), *The nature and functions of gesture in children's communications* (pp. 45–60), in the *New Directions for Child Development* series, No. 79, San Francisco, CA: Jossey-Bass.

Cartmill, E., Hunsicker, D., & Goldin-Meadow, S. (2014). Pointing and naming are not redundant: Children use gesture to modify nouns before they modify nouns in speech. *Developmental Psychology*. Advance online publication. doi:10.1037/a0036003

Cazden, C. B. (1965). *Environmental assistance to the child's acquisition of grammar*. Unpublished doctoral dissertation, Harvard University, Boston, MA.

Ceci, S. J. (1995). False beliefs: Some developmental and clinical considerations. In D. L. Schacter (Ed.), *Memory distortion: How minds, brains, and societies reconstruct the past* (pp. 91–125). Cambridge, MA: Harvard University Press.

Chawla, P., & Krauss, R. (1994). Gesture and speech in spontaneous and rehearsed narratives. *Journal of Experimental Social Psychology, 30,* 580–601.

Church, R. B., Ayman-Nolley, S., & Mahootian, S. (2004). The effects of gestural instruction on bilingual children. *International Journal of Bilingual Education and Bilingualism, 7*(4), 303–319.

Church, R. B., & Goldin-Meadow, S. (1986). The mismatch between gesture and speech as an index of transitional knowledge. *Cognition, 23*, 43–71.

Church, R. B., Schonert-Reichl, K., Goodman, N., Kelly, S.D., & Ayman-Nolley, S. (1995). The role of gesture and speech communication as reflections of cognitive understanding. *Journal of Contemporary Legal Issues, 6,* 123–154.

Cohen, A. A., & Harrison, R. P. (1973). Intentionality in the use of hand illustrators in face-to-face communication situations. *Journal of Personality and Social Psychology, 28*, 276–279.

Conrad, R. (1979). *The deaf child*. London, England: Harper & Row.

Cook, S. W., Jaeger, T. F., & Tanenhaus, M. K. (2009). Producing less preferred structures: More gestures, less fluency. In N. A. Taatgen & H. van Rijn (Eds.), *Proceedings of the 31st annual conference of the Cognitive Science Society* (pp. 62–67). Austin, TX: Cognitive Science Society.

Cook, S. W., Mitchell, Z., & Goldin-Meadow, S. (2008). Gesturing makes learning last. *Cognition, 106,* 1047–1058.

Cook, S. W., & Tanenhaus, M. K. (2009). Embodied communication: Speakers' gestures affect listeners' actions. *Cognition, 113,* 98-104.

Coppola, M., & Newport, E. (2005). Grammatical Subjects in homesign: Abstract linguistic structure in adult primary gesture systems without linguistic input. *Proceedings of the National Academy of Sciences, USA, 102,* 19249–19253.

Coppola, M., & Senghas, A. (2010). Deixis in an emerging sign language. In D. Brentari (Ed.), *Sign languages: A Cambridge language survey* (pp. 543–569). Cambridge, England: Cambridge University Press.

Crowder, E. M., & Newman, D. (1993). Telling what they know: The role of gesture and language in children's science explanations. *Pragmatics and Cognition, 1,* 341–376.

de Laguna, G. (1927). *Speech: Its function and development*. Bloomington: Indiana University Press.

De Ruiter, J.-P. (1998). Gesture and speech production. *MPI Series in Psycholinguistics,* no. 6. Max Planck Institute for Psycholinguistics.

Dick, A., Goldin-Meadow, S., Solodkin, A., & Small, S. (2012a). Gesture in the developing brain. *Developmental Science, 15*(2), 165–180.

Dick, A. S., Mok, E. H., Beharelle, A. R., Goldin-Meadow, S., & Small, S. (2012b). Frontal and temporal contributions to understanding the iconic cospeech gestures that accompany speech. *Human Brain Mapping*, doi: 10.1002/hbm.22222

Dienes, Z., & Perner, J. (1999). A theory of implicit and explicit knowledge. *Behavioural and Brain Sciences, 22*, 735–80.

Dunlea, A. (1989). *Vision and the emergence of meaning*. Cambridge, England: Cambridge University Press.

Dunlea, A. & Andersen, E.S. (1992). The emergence process: Conceptual and linguistic influences on morphological development. *First Language, 12,* 95–115.

Ehrlich, S. B., Levine, S., & Goldin-Meadow, S. (2006). The importance of gesture in children's spatial reasoning. *Developmental Psychology, 42,* 1259–1268.

Ejiri, K., & Masataka, N. (2001). Co-occurrence of preverbal vocal behavior and motor action in early infancy. *Developmental Science, 4*, 40–48.

Ekman, P. and Friesen, W. (1969). The repertoire of nonverbal behavioral categories. *Semiotica, 1*, 49–98.

Ekman, P., Friesen, W. V., & Ellsworth, P. (1972). *Emotion in the human face*. New York, NY: Pergamon Press.

Ellis Weismer, S., & Hesketh, L. J. (1993). The influence of prosodic and gestural cues on novel word acquisition by children with Specific Language Impairment. *Journal of Speech and Hearing Research, 36,* 1013–1025.

Evans, J. L., Alibali, M. W., & McNeil, N. M. (2001). Divergence of embodied knowledge and verbal expression: Evidence from gesture and speech in children with Specific Language Impairment. *Language and Cognitive Processes, 16,* 309–331.

Evans, M. A., & Rubin, K. H. (1979). Hand gestures as a communicative mode in school-aged children. *Journal of Genetic Psychology, 135*, 189–196.

Fant, L. J. (1972). *Ameslan: An introduction to American Sign Language*. Silver Springs, MD: National Association of the Deaf.

Feyereisen, P. (1983). Manual activity during speaking in aphasic subjects. *International Journal of Psychology, 18,* 545–556.

Feyereisen, P., van de Wiele, M., & Dubois, F. (1988). The meaning of gestures: What can be understood without speech. *Cahiers de Psychologie Cognitive/European Bulletin of Cognitive Psychology, 8,* 3–25.

Frank, M. C., & Barner, D. (2012). Representing exact number visually using mental abacus. *Journal of Experimental Psychology: General, 141*(1), 134–149.

Franklin, A., Giannakidou, A., & Goldin-Meadow, S. (2011). Negation, questions, and structure building in a homesign system. *Cognition, 118*, 398–416.

Frick-Horbury, D., & Guttentag, R. E. (1998). The effects of restricting hand gesture production on lexical retrieval and free recall. *American Journal of Psychology, 111,* 44–61.

Garber, P., Alibali, M. W., & Goldin-Meadow, S. (1998). Knowledge conveyed in gesture is not tied to the hands. *Child Development, 69*, 75–84.

Garber, P., & Goldin-Meadow, S. (2002). Gesture offers insight into problem-solving in children and adults. *Cognitive Science, 26*, 817–831.

Gelman, R., & Gallistel, C. R. (1978). *The child's understanding of number*. Cambridge, MA: Harvard University Press.

Gershkoff-Stowe, L. & Smith, L.B. (1997). A curvilinear trend in naming errors as a function of early vocabulary growth. *Cognitive Psychology, 34*, 37–71.

Glenberg, A. M. (1997). What memory is for. *Behavioral and Brain Sciences, 20*, 1–55.

Glenberg, A.M. & Kaschak, M. (2002). Grounding language in action. *Psychonomic Bulletin and Review, 9*, 558–565.

Glenberg, A. M., & Robertson, D. A. (1999). Indexical understanding of instructions. *Discourse Processes, 28,* 1–26.

Goldin-Meadow, S. (1985). Language development under atypical learning conditions: Replication and implications of a study of deaf children of hearing parents. In K. Nelson (Ed.), *Children's language* (Vol. *5*, pp. 197–245). Hillsdale, NJ: Erlbaum .

Goldin-Meadow, S. (1993). When does gesture become language? A study of gesture used as a primary communication system by deaf children of hearing parents. In K. R. Gibson & T. Ingold (Eds.), *Tools, language, and cognition in human evolution* (pp. 63–85). New York, NY: Cambridge University Press.

Goldin-Meadow, S. (2003a). *The resilience of language: What gesture creation in deaf children can tell us about how all children learning language*. New York, NY: Psychology Press.

Goldin-Meadow, S. (2003b). *Hearing gesture and cognitive development: How our hands help us think*. Cambridge, MA: Harvard University Press.

Goldin-Meadow, S. (2010). Widening the lens on language learning: Language in deaf children and adults in Nicaragua. *Human Development, 53,* 235–312.

Goldin-Meadow, S. & Alibali, M. W. (1994). Do you have to be right to redescribe? *Behavioral and Brain Sciences, 17,* 718–719.

Goldin-Meadow, S., & Alibali, M. W. (1999). Does the hand reflect implicit knowledge? Yes and no. *Behavioral and Brain Sciences, 22*, 766–767.

Goldin-Meadow, S., Alibali, M. W., & Church, R. B. (1993). Transitions in concept acquisition: Using the hand to read the mind. *Psychological Review, 100*, 279–297.

Goldin-Meadow, S. & Beilock, S. L. (2010). Action's influence on thought: The case of gesture. *Perspectives on Psychological Science, 5,* 664–674.

Goldin-Meadow, S., & Butcher, C. (2003). Pointing toward two-word speech in young children. In S. Kita (Ed.), *Pointing: Where language, culture, and cognition meet* (pp. 85–107). Mahwah, NJ: Erlbaum.

Goldin-Meadow, S., Butcher, C., Mylander, C. & Dodge, M. (1994). Nouns and verbs in a self-styled gesture system: What's in a name? *Cognitive Psychology, 27*, 259–319.

Goldin-Meadow, S., Cook, S. W., & Mitchell, Z. A. (2009). Gesturing gives children new ideas about math. *Psychological Science, 20*, 267–272.

Goldin-Meadow, S., Goodrich, W., Sauer, E., & Iverson, J. (2007a). Young children use their hands to tell their mothers what to say. *Developmental Science, 10*, 778–785.

Goldin-Meadow, S., Kim, S., & Singer, M. (1999). What the teacher's hands tell the student's mind about math. *Journal of Educational Psychology, 91*, 720–730.

Goldin-Meadow, S., Levine, S. L., Zinchenko, E., Yip, T. K.-Y., Hemani, N., & Factor, L. (2012a). Doing gesture promotes learning a mental transformation task better than seeing gesture. *Developmental Science, 15*(6), 876–84.

Goldin-Meadow, S., & Morford, M. (1985). Gesture in early child language: Studies of deaf and hearing children. *Merrill-Palmer Quarterly, 31*, 145–76.

Goldin-Meadow, S., & Mylander, C. (1983). Gestural communication in deaf children: The noneffects of parental input on language development. *Science, 221*, 372–374.

Goldin-Meadow, S., & Mylander, C. (1984). Gestural communication in deaf children: The effects and noneffects of parental input on early language development. *Monographs of the Society for Research in Child Development, 49*, 1–121.

Goldin-Meadow, S., & Mylander, C. (1998). Spontaneous sign systems created by deaf children in two cultures. *Nature, 91*, 279–281.

Goldin-Meadow, S., Mylander, C., & Butcher, C. (1995). The resilience of combinatorial structure at the word level: Morphology in self-styled gesture systems. *Cognition, 56*, 195–262.

Goldin-Meadow, S., Mylander, C., & Franklin, A. (2007b). How children make language out of gesture and cognitive development: Morphological structure in gesture systems developed by American and Chinese deaf children. *Cognitive Psychology, 55*, 87–135.

Goldin-Meadow, S., Nusbaum, H., Garber, P. & Church, R. B. (1993b). Transitions in learning: Evidence for simultaneously activated strategies. *Journal of Experimental Psychology: Human Perception and Performance, 19*, 92–107

Goldin-Meadow, S., Nusbaum, H., Kelly, S. D., & Wagner, S. (2001). Explaining math: Gesturing lightens the load. *Psychological Sciences, 12*, 516–522.

Goldin-Meadow, S., & Saltzman, J. (2000). The cultural bounds of maternal accommodation: How Chinese and American mothers communicate with deaf and hearing children. *Psychological Science, 11*, 311–318.

Goldin-Meadow, S. & Sandhofer, C. M. (1999). Gesture conveys substantive information about a child's thoughts to ordinary listeners. *Developmental Science, 2*, 67–74.

Goldin-Meadow, S., Shield, A., Lenzen, D., Herzig, M., & Padden, C. (2012b). The gestures ASL signers use tell us when they are ready to learn math. *Cognition, 123*, 448–453.

Goldin-Meadow, S., & Singer, M. A. (2003). From children's hands to adults' ears: Gesture's role in teaching and learning. *Developmental Psychology, 39*(3), 509–520.

Goldin-Meadow, S., So, W.-C., Özyürek, A., & Mylander, C. (2008). The natural order of events: How speakers of different languages represent events nonverbally. *Proceedings of the National Academy of Sciences, USA, 105*(27), 9163–9168.

Goldin-Meadow, S., Wein, D., & Chang, C. (1992). Assessing knowledge through gesture and cognitive development: Using children's hands to read their minds. *Cognition and Instruction, 9*, 201–219.

Goldstone , R. L., & Son, J. Y. (2005). The transfer of scientific principles using concrete and idealized simulations. *Journal of the Learning Sciences, 14*, 69–110.

Goodwyn, S. W., & Acredolo, L. P. (1993). Symbolic gesture versus word: Is there a modality advantage for onset of symbol use? *Child Development, 64*, 688–701.

Goodwyn, S. W., & Acredolo, L. P. (1998). Encouraging symbolic gestures: A new perspective on the relationship between gesture and speech. In J. M. Iverson & S. Goldin-Meadow (Eds.), The nature and functions of gesture in children's communication *in the* New Directions for Child Development series, No. 79 (pp. 61–73). San Francisco, CA: Jossey-Bass.

Goodwyn, S., Acredolo, L., & Brown, C. A. (2000). Impact of symbolic gesturing on early language development. *Journal of Nonverbal Behavior, 24*, 81–104.

Graham, J. A., & Argyle, M. (1975). A cross-cultural study of the communication of extra-verbal meaning by gestures. *International Journal of Psychology, 10*, 57–67.

Graham, J. A., & Heywood, S. (1975). The effects of elimination of hand gestures and of verbal codability on speech performance. *European Journal of Social Psychology, 2*, 189–195.

Graham, T. A. (1999). The role of gesture in children's learning to count. *Journal of Experimental Child Psychology, 74*, 333–355.

Greenfield, P., & Smith, J. (1976). *The structure of communication in early language development*. New York, NY: Academic Press.

Guillaume, P. (1927). Les debuts de la phrase dans le langage de l'enfant. *Journal de Psychologie, 24*, 1–25.

Gulberg, M. (1998). *Gesture as a communication strategy in second language discourse: A study of learners of French and Swedish*. Lund, Sweden: Lund University Press.

Hadar, U., Burstein, A., Krauss, R. & Soroker, N. (1998). Ideational gestures and speech in brain-damaged subjects. *Language & Cognitive Processes, 13*, 59–76

Hockett, C. F. (1960). The origin of speech. *Scientific American, 203*(3), 88–96.

Hoffmeister, R., & Wilbur, R. (1980). Developmental: The acquisition of sign language. In H. Lane & F. Grosjean (Eds.), *Recent perspectives on American Sign Language*. Hillsdale, NJ: Erlbaum.

Holle, H., & Gunter, T. C. (2007). The role of iconic gestures in speech disambiguation: ERP evidence. *Journal of Cognitive Neuroscience, 19,* 1175–1192.

Holle, H., Obleser, J., Rueschemeyer, S., & Gunter, T. (2010). Integration of iconic gestures and speech in left superior temporal areas boosts speech comprehension under adverse listening conditions. *NeuroImage, 49*, 875–84.

Horobin, K., & Acredolo, C. (1989). The impact of probability judgments on reasoning about multiple possibilities. *Child Development, 60,* 183–200.

Hostetter, A. B., Alibali, M. W., & Kita, S. (2007). I see it in my hands' eye: Representational gestures reflect conceptual demands. *Language and Cognitive Processes, 22*, 313–336.

Hunsicker, D., & Goldin-Meadow, S. (2012). Hierarchical structure in a self-created communication system: Building nominal constituents in homesign. *Language, 88*(4), 732–763.

Iverson, J. M. (1999). How to get to the cafeteria: Gesture and speech in blind and sighted children's spatial descriptions. *Developmental Psychology, 35*, 1132–1142.

Iverson, J. M., Capirci, O., & Caselli, M. S. (1994). From communication to language in two modalities. *Cognitive Development, 9*, 23–43.

Iverson, J. M., Capirci, O., Longobardi, E., & Caselli, M. C. (1999). Gesturing in mother-child interaction. *Cognitive Development, 14*, 57–75.

Iverson, J. M., & Fagan, M. K. (2004). Infant vocal-motor coordination: Precursor to the gesture-speech system? *Child Development, 75*, 1053–1066.

Iverson, J. M., & Goldin-Meadow, S. (1997). What's communication got to do with it: Gesture in blind children. *Developmental Psychology, 33*, 453–467.

Iverson, J. M., & Goldin-Meadow, S. (1998). Why people gesture as they speak. *Nature, 396*, 228.

Iverson, J. M., & Goldin-Meadow, S. (2001). The resilience of gesture in talk: Gesture in blind speakers and listeners. *Developmental Science, 4*, 416–422.

Iverson, J. M., & Goldin-Meadow, S. (2005). Gesture paves the way for language development. *Psychological Science, 16*, 368–371.

Iverson, J. M., Longobardi, E., & Caselli, M. C. (2003). Relationship between gestures and words in children with Down's syndrome and typically developing children in the early stages of communicative development. *International Journal of Language and Communication Disorders, 38,* 179–197.

Iverson, J. M., Tencer, H. L., Lany, J., & Goldin-Meadow, S. (2000). The relation between gesture and speech in congenitally blind and sighted language-learners. *Journal of Nonverbal Behavior, 24,* 105–130.

Iverson, J. M., & Thelen, E. (1999). Hand, mouth, and brain: The dynamic emergence of speech and gesture. *Journal of Consciousness Studies, 6*, 19–40.

Jancovic, M. A., Devoe, S., & Wiener, M. (1975). Age-related changes in hand and arm movements as nonverbal communication: Some conceptualizations and an empirical exploration. *Child Development, 46*, 922–928.

Karmiloff-Smith, A. (1986). From meta-processes to conscious access: Evidence from children's metalinguistic and repair data. *Cognition, 23*(2), 95–147.

Karmiloff-Smith, A. (1992). *Beyond modularity: A developmental perspective on cognitive science*. Cambridge, MA: MIT Press.

Kastens, K. A., Agrawal, S., & Liben, L. S. (2008). Research in science education: The role of gestures in geoscience teaching and learning. *Journal of Gesocience Education, 54*(4), 362–368.

Kegl, J., Senghas, A., & Coppola, M. (1999). Creation through contact: Sign language emergence and sign language change in Nicaragua. In M. DeGraff (Ed.), *Language creation and language change: Creolization, diachrony, and development* (pp. 179–237). Cambridge, MA: MIT.

Kelly, S. D. (2001). Broadening the units of analysis in communication: Speech and nonverbal behaviours in pragmatic comprehension. *Journal of Child Language, 28*, 325–349.

Kelly, S. D., & Church, R. B. (1997). Can children detect conceptual information conveyed through other children's nonverbal behaviors? *Cognition and Instruction, 15*, 107–134.

Kelly, S. D., Kravitz, C., & Hopkins, M. (2004). Neural correlates of bimodal speech and gesture comprehension. *Brain and Language, 89*, 253–260.

Kelly, S. D., Özyürek A., & Maris, E. (2010). Two sides of the same coin: Speech and gesture mutually interact to enhance comprehension. *Psychological Science, 21,* 260–7.

Kelly, S. D., Singer, M. A., Hicks, J. & Goldin-Meadow, S. (2002). A helping hand in assessing children's knowledge: Instructing adults to attend to gesture. *Cognition and Instruction, 20*, 1–26.

Kendon, A. (1980). Gesticulation and speech: Two aspects of the process of utterance. In M. R. Key (Ed.), *Relationship of verbal and nonverbal communication* (pp. 207–228). The Hague, The Netherlands: Mouton.

Kendon, A. (1994). Do gestures communicate?: A review. *Research on Language and Social Interaction, 27*, 175–200.

Kirk, E., Howlett, N., Pine, K. J., & Fletcher, B. C. (2013). To sign or not to sign? The impact of encouraging infants to gesture on infant language and maternal mind-mindedness. *Child Development, 84*(2), 74–90.

Kita, S. (2000). How representational gestures help speaking. In D. McNeill (Ed.), *Language and gesture* (pp. 162–185). New York, NY: Cambridge University Press.

Kita, S., & Davies, T. S. (2009). Competing conceptual representations trigger cospeech representational gestures. *Language and Cognitive Processes, 24*, 761–775.

Knapp, M. L. (1978). *Nonverbal communication in human interaction* (2nd ed.). New York, NY: Holt, Rinehart & Winston.

Kontra, C. E., Goldin-Meadow, S., & Beilock, S. L. (2012). Embodied Learning across the life span. *Topics in Cognitive Science, 4*, 731–739.

Krauss, R. M., Dushay, R. A., Chen, Y., & Rauscher, F. (1995). The communicative value of conversational hand gestures. *Journal of Experimental Social Psychology, 31*, 533–553.

Krauss, R. M., Morrel-Samuels, P., & Colasante, C. (1991). Do conversational hand gestures communicate? *Journal of Personality and Social Psychology, 61*, 743–754.

Kutas, M., & Hillyard, S. (1984). Brain potentials during reading reflect word expectancy and semantic association. *Nature, 307,* 161–163.

Lakoff, G., & Johnson, M. (1999). *Philosophy in the flesh: The embodied mind and its challenge to western thought*. New York, NY: Basic Books.

Landau, B. & Gleitman, L.R. (1985). *Language and experience: Evidence from the blind child*. Cambridge, MA: Harvard University Press.

LeBarton, E.S., Raudenbush, S., & Goldin-Meadow, S. (in press). Experimentally-induced increases in early gesture lead to increases in spoken vocabulary. *Journal of Cognition and Development.*

Lenneberg, E. H. (1964). Capacity for language acquisition. In J. A. Fodor & J. J. Katz (Eds.), *The structure of language: Readings in the philosophy of language* (pp. 579–603). Englewood Cliffs, NJ: Prentice-Hall.

Leopold, W. (1949). *Speech development of a bilingual child: A linguist's record* (Vol. 3). Evanston, IL: Northwestern University Press.

Leung, E., & Rheingold, H. (1981). Development of pointing as a social gesture. *Developmental Psychology, 17*, 215–20.

Liben, L. S., Christensen, A. E., & Kastens, K. A. (2010). Gestures in geology: The roles of spatial skills, expertise, and communicative context. In C. Holscher et al. (Eds.), *Spatial cognition VII* (pp. 95–111). Berlin, Germany: Springer-Verlag.

Lickiss, K. P., & Wellens, A. R. (1978). Effects of visual accessibility and hand restraint on fluency of gesticulator and effectiveness of message. *Perceptual and Motor Skills, 46*, 925–926.

Lillo-Martin, D. (1999). Modality effects and modularity in language acquisition: The acquisition of American Sign Language. In W. C. Ritchie & T. K. Bhatia (Eds.), *Handbook of child language acquisition* (pp. 531–567). New York, NY: Academic Press.

Macnamara, J. (1977). From sign to language. In J. Macnamara (Ed.), *Language learning and thought* (pp. 11–35). New York, NY: Academic Press.

Marcos, L. R. (1979). Hand movements and nondominant fluency in bilinguals. *Percpetual and Motor Skills, 48*, 207–214.

Marentette, P., & Nicoladis, E. (2011). Preschoolers' interpretations of gesture and cognitive development: Label or action associate? *Cognition, 121*, 386–399.

Masur, E. F. (1982). Mothers' responses to infants' object-related gestures: Influences on lexical development. *Journal of Child Language, 9,* 23–30.

Masur, E. F. (1983). Gestural development, dual-directional signaling, and the transition to words. *Journal of Psycholinguistic Research, 12*, 93–109.

Mayberry, R. I. (1992). The cognitive development of deaf children: Recent insights. In S. Segalowitz & I. Rapin (Eds.), *Child Neuropsychology*. Volume 7 of *Handbook of neuropsychology* (pp. 51–68). Editors-in-Chief: F. Boller & J. Grafman. Amsterdam, The Netherlands: Elsevier.

McGregor, K. K., Rohlfing, K. J., Bean A., & Marschner, E. (2008). Gesture as a support for word learning: the case of under. *Journal of Child Language, 36,* 807–28.

McNeil, N. M., Alibali, M. W., & Evans, J. L. (2000). The role of gesture in children's comprehension of spoken language: Now they need it, now they don't. *Journal of Nonverbal Behavior, 24,* 131–150.

McNeil, N., & Fyfe, E. (2012). "Concreteness fading" promotes transfer of mathematical knowledge. *Learning and Instruction, 22*(6)*,* 440–448.

McNeil , N. M., & Uttal , D. H. (2009). Rethinking the use of concrete materials in learning: Perspectives from development and education. *Child Development Perspectives, 3*(3), 137–139.

McNeill, D. (1985). So you think gestures are nonverbal? *Psychological Review, 92*, 350–371.

McNeill, D. (1987). *Psycholinguistics: A new approach*. New York, NY: Harper & Row.

McNeill, D. (1992). *Hand and mind: What gestures reveal about thought*. Chicago, IL: University of Chicago Press.

McNeill, D., Cassell, J., & McCullough, K-E. (1994). Communicative effects of speech-mismatched gestures. *Research on Language and Social Interaction, 27*, 223–237.

Meadow, K. (1968). Early manual communication in relation to the deaf child's intellectual, social, and communicative functioning. *American Annals of the Deaf, 113*, 29–41.

Meier, R. P., & Newport, E. L. (1990). Out of the hands of babes: On a possible sign advantage in language acquisition. *Language, 66*, 1–23.

Melinger, A., & Kita, S. (2001). Does gesture help processes of speech production? Evidence for conceptual level facilitation. *Proceedings of the Berkeley Linguistic Society, 27*(1), 435–447.

Melinger, A., & Kita, S. (2007). Conceptualisation load triggers gesture production. *Language and Cognitive Processes, 22*, 473–500.

Mix, K. S. (2010). Spatial tools for mathematical thought. In K. S. Mix, L. B. Smith, & M. Gasser (Eds.), *Space and language* (pp. 42–68). New York, NY: Oxford University Press.

Mohay, H. (1982). A preliminary description of the communication systems evolved by two deaf children in the absence of a sign language model. *Sign Language Studies, 34*, 73–90.

Moores, D. F. (1974). Nonvocal systems of verbal behavior. In R. L. Schiefelbusch & L. L. Lloyd (Eds.), *Language perspectives: Acquisition, retardation, and intervention*. Baltimore, MD: University Park Press.

Morford, M., & Goldin-Meadow, S. (1992). Comprehension and production of gesture in combination with speech in one-word speakers. *Journal of Child Language, 19*, 559–580.

Morford, J. P., & Goldin-Meadow, S. (1997). From here to there and now to then: The development of displaced reference in homesign and English. *Child Development, 68*, 420–435.

Morrell-Samuels, P., & Krauss, R. M. (1992). Word familiarity predicts temporal asynchrony of hand gestures and speech. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18*, 615–622.

Murphy, C. M., & Messer, D. J. (1977). Mothers, infants and pointing: A study of gesture. In H. R. Schaffer (Ed.), *Studied in mother-infant interaction*. New York, NY: Academic Press.

Namy, L.L., Acredolo, L., & Goodwyn, S. (2000). Verbal labels and gestural routines in parental communication with young children. *Journal of Nonverbal Behavior, 24*, 63–80.

Namy, L. L., & Waxman, S. R. (1998). Words and gestures: Infants' interpretations of different forms of symbolic reference. *Child Development, 69*, 295–308.

Newcombe, N. (2010). Picture this: Increasing math and science learning by improving spatial thinking. *American Educator*, 29–43.

Newport, E. L., & Meier, R. P. (1985). The acquisition of American Sign Language. In D. I. Slobin (Ed.), *The cross-linguistic study of language acquisition: Vol. 1. The data* (pp. 881–938). Hillsdale, NJ: Erlbaum.

Niedenthal, P. M. (2007). Embodying emotion. *Science, 316*, 1002–1005.

Novack, M., Congdon, E., Hemani-Lopez, N., & Goldin-Meadow, S. (2014). From action to abstraction: Using the hands to learn math. *Psychological Science*. Advance online publication. doi:10.1177/0956797613518351

Novack, M., Goldin-Meadow, S., & Woodward, A. (2013). Learning from gesture and cognitive development: How early does it happen? Under review.

Özçalışkan, S., & Goldin-Meadow, S. (2005a). Gesture is at the cutting edge of early language development. *Cognition, 96*, B01–113.

Özçalışkan, S. & Goldin-Meadow, S. (2005b). Do parents lead their children by the hand? *Journal of Child Language, 32*(3), 481–505.

Özçalişkan, S. & Goldin-Meadow, S. (2009). When gesture-speech combinations do and do not index linguistic change. *Language and Cognitive Processes, 24*, 190–217.

Özçalişkan, S. & Goldin-Meadow, S. (2011). Is there an iconic gesture spurt at 26 months? In G. Stam & M. Ishino (Eds.), *Integrating gestures: The interdisciplinary nature of gesture* (pp. 163–174). Amsterdam, The Netherlands: John Benjamins.

Özçalişkan, S. Gentner, D., & Goldin-Meadow, S. (2013). Do iconic gestures pave the way for children's early verbs? *Applied Psycholinguistics*, doi:10.1017/S0142716412000720.

Özyürek, A., Furman, R., & Goldin-Meadow, S. (in press). On the way to language: Emergence of segmentation and sequencing in motion event representations without a language model. *Journal of Child Language.*

Özyürek, A., Willems, R. M., Kita, S., & Hagoort, P. (2007). On-line integration of semantic information from speech and gesture and cognitive development: Insights from event-related brain potentials. *Journal of Cognitive Neuroscience, 19*, 605–616.

Paivio, A. (1971). *Imagery and verbal processes*. New York, NY: Holt, Rinehart & Winston.

Perry, M., Berch, D., & Singleton, J. (1995). Constructing shared understanding: The role of nonverbal input in learning contexts. *Journal of Contemporary Legal Issues, 6*, 213–235.

Perry, M., Church, R. B., & Goldin-Meadow, S. (1988). Transitional knowledge in the acquisition of concepts. *Cognitive Development, 3*, 359–400.

Perry, M., & Elder, A. D. (1997). Knowledge in transition: Adults' developing understanding of a principle of physical causality. *Cognitive Development, 12*, 131–157.

Petitto, L.A. (1988). "Language" in the pre-linguistic child. In F. Kessel (Ed.), *The development of language and language researchers: Essays in honor of Roger Brown* (pp. 187–221). Hillsdale, NJ: Erlbaum.

Phillips, S. B., Goldin-Meadow, S., & Miller, P. J. (2001). Enacting stories, seeing worlds: Similarities and differences in the cross-cultural narrative development of linguistically isolated deaf children. *Human Development, 44*, 311–336.

Piaget , J. (1953). How children form mathematical concepts. *Scientific American, 189*(5), 74–79.

Pine, K. J., Bird, H., & Kirk, E. (2007). The effects of prohibiting gestures on children's lexical retrieval ability. *Developmental Science, 10*, 747–754.

Pine, K. J., Lufkin, N., & Messer, D. (2004). More gestures than answers: Children learning about balance. *Developmental Psychology, 40*, 1059–106.

Ping, R. M., & Goldin-Meadow, S. (2008). Hands in the air: Using ungrounded iconic gestures to teach children conservation of quantity. *Developmental Psychology, 44,* 1277–1287.

Ping, R., & Goldin-Meadow, S. (2010). Gesturing saves cognitive resources when talking about nonpresent objects. *Cognitive Science, 34*(4), 602–619.

Ping, R., Larson, S. W., Decatur, M-A., Zinchenko, E., & Goldin-Meadow, S. (2013). Gesture predicts readiness-to-learn in adults: The case of organic chemistry. *Journal of Research in Science Teaching*, revision under review.

Rauscher, F. H., Krauss, R. M., & Chen, Y. (1996). Gesture, speech, and lexical access: The role of lexical movements in speech production. *Psychological Science, 7*, 226–231.

Richardson, D. C., Spivey, M. J., Barsalou, L. W., & McRae, K. (2003). Spatial representations activated during real-time comprehension of verbs. *Cognitive Science, 27*, 767–780.

Rimé, B. (1982). The elimination of visible behaviour from social interactions: Effects on verbal, nonverbal and interpersonal variables. *European Journal of Social Psychology, 12*, 113–129.

Rimé, B., Schiaratura, L., Hupet, M. & Ghysselinckx, A. (1984). Effects of relative immobilization on the speaker's nonverbal behavior and on the dialogue imagery level. *Motivation and Emotion, 8*, 311–325.

Riseborough, M. G. (1981). Physiographic gestures as decoding facilitators: Three experiments exploring a neglected facet of communication. *Journal of Nonverbal Behavior, 5*, 172–183.

Rizzolatti, G., Fadiga, L., Gallese, V., Fogassi, L. (1996). Premotor cortex and the recognition of motor actions. *Cognitive Brain Research, 3*, 131–141.

Rogers, W. T. (1978). The contribution of kinesic illustrators toward the comprehension of verbal behavior within utterances. *Human Communication Research, 5*, 54–62.

Rowe, M. L., & Goldin-Meadow, S. (2009). Differences in early gesture explain SES disparities in child vocabulary size at school entry. *Science, 323*, 951–953.

Sarama, J., & Clements, D (2009). Concrete computer manipulatives in mathematics education. *Child Development Perspectives, 3*(3) 145–150.

Sauer, E., Levine, S. C., & Goldin-Meadow, S. (2010). Early gesture predicts language delay in children with pre- and perinatal brain lesions. *Child Development, 81*, 528–539.

Saxe, G. B., & Kaplan, R. (1981). Gesture in early counting: A developmental analysis. *Perceptual and Motor Skills, 53*, 851–854.

Senghas, A. (2003). Intergenerational influence and ontogenetic development in the emergence of spatial grammar in Nicaraguan Sign Language. *Cognitive Development, 18,* 511–531.

Senghas, A., & Coppola, M. (2001). Children creating language: How Nicaraguan Sign Language acquired a spatial grammar. *Psychological Science, 12,* 323–328.

Senghas, A., Coppola, M., Newport, E. L., & Supalla, T. (1997). Argument structure in Nicaraguan Sign Language: The emergence of grammatical devices. *Proceedings of Boston University Child Language Development, 21*, 550–561.

Senghas, A., Kita, S., & Özyürek, A. (2004). Children creating core properties of language: Evidence from an emerging Sign Language in Nicaragua. *Science, 305,* 1779–1782.

Senghas, A., Özyürek, A., & Goldin-Meadow, S. (2010). The evolution of segmentation and sequencing: Evidence from homesign and Nicaraguan Sign Language. In A. D. M. Smith, M. Schouwstra, B. de Boer, & K. Smith (Eds.), *Proceedings of the Eighth Evolution of Language Conference* (pp. 279–289). Singapore: World Scientific.

Shatz, M. (1982). On mechanisms of language acquisition: Can features of the communicative environment account for development? In E. Wanner & L. R. Gleitman (Eds.), *Language acquisition: The state of the art* (pp. 102–127). New York, NY: Cambridge University Press.

Siegler, R. S. (1994). Cognitive variability: A key to understanding cognitive development. *Current Directions in Psychological Science, 3,* 1–5.

Siegler, R. S., & Crowley, K. (1991). The microgenetic method: A direct means for studying cognitive development. *American Psychologist, 46*(6), 606–620.

Silverman, L., Bennetto, L., Campana, E., & Tanenhaus, M. K. (2010). Speech-and-gesture integration in high functioning autism. *Cognition, 115*, 380–393.

Singer, M. A., & Goldin-Meadow, S. (2005). Children learn when their teachers' gestures and speech differ. *Psychological Science, 16,* 85–89.

Singleton, J. L., Morford, J. P., & Goldin-Meadow, S. (1993). Once is not enough: Standards of well-formedness in manual communication created over three different timespans, *Language, 69*, 683–715.

Skipper, J. I., Goldin-Meadow, S., Nusbaum, H. C. & Small, S. L. (2007). Speech-associated gestures, Broca's area, and the human mirror system. *Brain and Language, 101*, 260–277.

Sommerville, J. A., & Woodward, A. L. (2005). Pulling out the intentional structure of human action: The relation between action production and processing in infancy. *Cognition, 95*, 1–30.

Stieff, M. (2011). When is a molecule three dimensional? A task-specific role for imagistic reasoning in advanced chemistry. *Science Education, 95*(2), 310–336.

Stieff, M., & Raje, S. (2010). Expertise algorithmic and imagistic problem solving strategies in advanced chemistry. *Spatial Cognition & Computation, 10*(1), 53–81.

Stone, A., Webb, R., & Mahootian, S. (1991). The generality of gesture-speech mismatch as an index of transitional knowledge: Evidence from a control-of-variables task. *Cognitive Development, 6*, 301–313.

Tervoort, B. T. (1961). Esoteric symbolism in the communication behavior of young deaf children. *American Annals of the Deaf , 106*, 436–480.

Thal, D., Tobias, S., & Morrison, D., (1991). Language and gesture in late talkers: A one year follow-up. *Journal of Speech and Hearing Research, 34*, 604–612.

Thelen, E. (1989). Self-organization in developmental processes: Can systems approaches work? In M. Gunnar & E. Thelen (Eds.), *Systems and development: The Minnesota Symposium on Child Psychology* (pp. 77–117). Hillsdale, NJ: Erlbaum.

Thompson, L., & Massaro, D. (1986). Evaluation and integration of speech and pointing gestures during referential understanding. *Journal of Experimental Child Psychology, 42,* 144–168.

Thompson, L. A., & Massaro, D. W. (1994). Children's integration of speech and pointing gestures in comprehension. *Journal of Experimental Child Psychology, 57,* 327–354.

Trofatter, C., Kontra, C., Beilock, S., & Goldin-Meadow, S. (2014). Gesturing has a larger impact on problem-solving than action, even when action is accompanied by words. *Language, Cognition and Neuroscience*. Advance online publication. doi:10.1080/23273798.2014 .905692

Uttal , D. H. Scudder, K. V. DeLoache, J. S. (1997). Manipulatives as symbols: A new perspective on the use of concrete objects to teach mathematics. *Journal of Applied Developmental Psychology, 18*, 37–54.

Valenzeno, L., Alibali, M.W., & Klatzky, R. (2003). Teachers' gestures facilitate students' learning: A lesson in symmetry. *Contemporary Educational Psychology, 28*, 187–204.

Vygotsky, L. (1978). Interaction between learning and development. *Mind and society*. Cambridge, MA: Harvard University Press.

Wagner, S., Nusbaum, H., & Goldin-Meadow, S. (2004). Probing the mental representation of gesture and cognitive development: Is handwaving spatial? *Journal of Memory and Language, 50*, 395–407.

Wang, X-L., Mylander, C., & Goldin-Meadow, S. (1993). Language and environment: A cross-cultural study of the gestural communication systems of Chinese and American deaf children. *Belgian Journal of Linguistics, 8,* 167–185.

Wesp, R., Hesse, J., Keutmann, D., & Wheaton, K. (2001). Gestures maintain spatial imagery. *American Journal of Psychology, 114*, 591–600.

Willems, R. M., Özyürek, A., & Hagoort, P. (2007). When language meets action: The neural integration of gesture and speech. *Cerebral Cortex, 17*, 2322–2333.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review, 9*(4), 625–636.

Wu, Y. C., & Coulson, S. (2005). Meaningful gestures: Electrophysiological indices of iconic gesture comprehension. *Psychophysiology, 42,* 654–667.

Wu, Y. C., & Coulson, S. (2007). How iconic gestures enhance communication: An ERP study. *Brain and Language, 101,* 234–245.

Wundt, W. (1973). *The language of gestures*. The Hague, The Netherlands: Mouton. (Originally published in 1900)

Wynn, K. (1990). Children's understanding of counting. *Cognition, 36,* 155–193.

Zinober, B., & Martlew, M. (1985). Developmental changes in four types of gesture in relation to acts and vocalizations from 10 to 21 months. *British Journal of Developmental Psychology, 3*, 293–306.

Zwaan, R. A., Stanfield, R. A., & Yaxley, R. H. (2002). Language comprehenders mentally represent the shape of objects. *Psychological Science, 13*, 168–171.