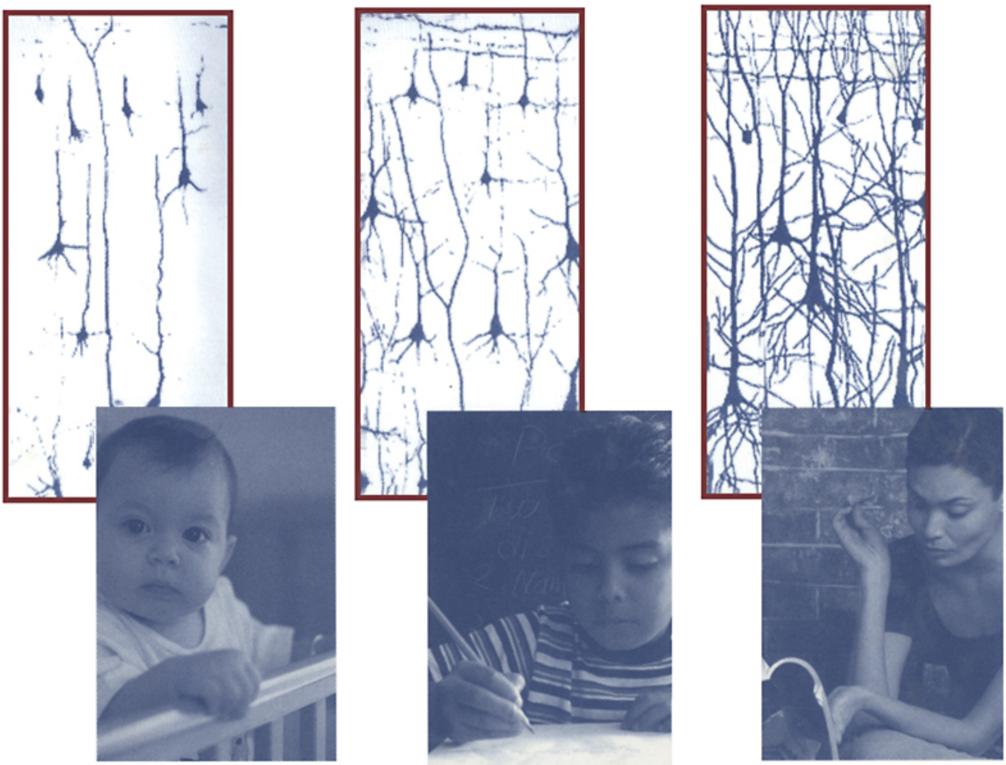
Mechanisms of Cognitive Development

Behavioral and Neural Perspectives



Edited by

James L. McClelland • Robert S. Siegler

Mechanisms of Cognitive Development:
Behavioral and Neural Perspectives

Carnegie Mellon Symposia on Cognition

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Edited by

James L.McClelland
Robert S.Siegler
Carnegie Mellon University

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Preface

This symposium carries on a tradition that began in the Psychology Department at Carnegie Mellon University more than 30 years ago. Each meeting has brought together a small group of leading scientists to explore an issue at the forefront of the study of human cognition or a related area of psychology.

The subject of this symposium can be stated as a simple question: What brings about the emergence of intelligence over the course of early life, and what sustains its further development? This question lay at the heart of the work of Jean Piaget, the 20th century's preeminent developmentalist, and it continues to be fundamental to our efforts to comprehend how we come to represent and reason about the world. Yet, the question has proven devilishly difficult to answer. Piaget himself used the descriptive biological metaphors of assimilation and accommodation to evoke intuitions about the nature of the process. Unfortunately, it has proven very difficult to build from Piaget's descriptions more precise accounts of how these change processes work. In the end, Piaget's primary legacy remains his remarkable and insightful observations about the nature of children's abilities at different points in time, rather than his account of how we get from here to there.

Now, at the beginning of the 21st century, there have been decades of additional research, and our understanding of children's thinking has deepened considerably. Clever experimentalists have devised techniques for demonstrating that infants and young children possess a variety of implicit understandings of basic concepts such as objects, time, space, number, and causality. Research on cognitive development has been broadened to include a wide range of domains, including informal physics, biology, and psychology. Until recently, however, relatively little progress had been made toward understanding what causes cognitive abilities to change over time.

This symposium celebrates the fact that this limited understanding is beginning to grow rapidly, and it brings together many of the researchers who are helping it to grow. The diverse papers in the symposium are united by the goal of determining how experience causes changes in how we think and act, and why it leads to change in some cases but fails miserably to lead to change in others. Before the symposium, all speakers were asked to think about four questions; the issues raised by these questions provide recurrent themes in the papers in this volume. The questions were:

1. Why do cognitive abilities emerge when they do during development?
2. What are the sources of developmental and individual differences, and of developmental anomalies in learning?
3. What happens in the brain when people learn?
4. How can experiences be ordered and timed to optimize learning?

As indicated by the title of this volume, the symposium also celebrates a second important trend in the study of cognitive development: The growing convergence of behavioral and neural approaches to understanding cognitive change. Several factors underlie this trend. One is our growing knowledge and understanding of the biology of brain development. Every day, molecular and developmental neurobiologists gain additional insights into the underlying physiological processes that lead to the emergence of the brain from its embryonic precursors. Among other things, we have learned that the brain is far from fully formed at birth. A considerable body of research now documents the dramatic impact of postnatal experience on the outcome of brain development, and suggests there is an intimate relationship between the structural and functional consequences of experience. New techniques allow us to examine the activity of the brain, and to see how this activity changes with experience. In animals, we may record from many neurons simultaneously to detect how their responses may be altered by experience. In humans, new functional brain imaging techniques allow us to visualize, albeit at a somewhat coarser grain, the consequences of experience for brain activity. Psychologists interested in cognitive change have rushed to embrace these methods, and several contributors to this symposium, among them Haier, Carpenter, Just, Minshew, Keller, Cherkassy, and Roth exemplify this trend.

A second key factor that is promoting increased understanding of change mechanisms at both behavioral and neural levels are new methods for exploring cognitive change. One such approach is the microgenetic method, which provides a child (or other experimental subject) with a great deal of focused experience, and densely samples the changing competence as the changes are occurring. Microgenetic methods are being used by both psychologists and neuroscientists, as is evident in the work of Goldin-Meadow, Siegler, McClelland, Merzenich, Thelen, and Kuhn in this volume. Such methods allow us to observe the often surprising paths that lead to changes in both behavior and brain activity.

A third factor that is promoting understanding of cognitive change is the emergence of computational models that characterize cognitive and behavioral change in terms of underlying neurobiological processes. These models hold promise of providing a synthetic demonstration of how experience can lead to physical changes in the brain, that in turn impact perception, cognition, and action. Such models are prominent in the work of Johnson and deHaan, and McClelland in this volume.

With these trends in view, one begins to feel that we are reaching the point where the distinction between neuroscientific and psychological approaches may be disappearing. Nowhere is this more evident than in the fact that it is not really possible to separate our speakers into those who represent behavioral and those who represent neural approaches. Robbie Case and Michael Mueller, by background psychologists, explore the role of neural processes in the emergence of higher cognitive processes. Michael Merzenich, by background a neuroscientist, describes behavioral studies of remediation of deficits in language perception. Many other examples from the list of speakers could be cited. Clearly, for many of the participants, the neural and behavioral perspectives mentioned in the title of our symposium are already well integrated.

Change occurs over different time spans, and the types of issues that can be investigated and the methods that can be used reflect these varying time spans. The first six chapters in the volume, which correspond to the papers presented on the first day of the conference, focus on changes that occur in response to particular experiences over relatively short spans of time: minutes, days, weeks, or months, rather than years. Repeated sampling of changing competence over these relatively short time spans allows evaluation of detailed and specific proposals concerning change mechanisms. A number of the studies that are reported do not involve children; rather, they involve college undergraduates, nonhuman primates, foreign adults learning English, and artificial neural networks. The basic assumption is that cognitive change in all of these types of learners shares a lot in common. Understanding cognitive changes in these diverse types of learners also provides a basis for distilling what is unique, and what is not, about children's cognitive development.

The next five chapters in the volume, which correspond to the papers presented on the second day of the conference, focus on change over longer time scales. Many of these talks and chapters, like the earlier ones, offer quite specific mechanistic accounts of the changes that we see over these longer scales. The accounts of the long-term changes tend to place greater emphasis on age-related biological changes and their interactions with new experiences, as contributors to cognitive growth. The final four papers, presented on the third day of the conference, focus on developmental disabilities. The existence of these disorders reminds us that there are large individual differences at the neural level, just as there are at the behavioral level. No explanation of cognitive development can be complete without an understanding of how the neural mechanisms enable development to succeed, as it normally does. Thus, Neville and Bavelier examine developmental plasticity in deaf and blind children, Galiburda and Rosen examine it in children with dyslexia, and Casey examines it in children with frontal lobe damage. The study of how development can go awry provides a contrast with the normal situation, and brings out clearly the need to complement an exploration of the role of experience with an understanding of how the complex machinery of the brain enables the normal process of development.

In addition to the speakers, a large number of other people and institutions made vital contributions to the conference, and we would like to thank them. Several groups provided generous support that helped defray the cost of the conference: The National Science Foundation, the National Institute of Mental Health, the National Institute of Child Health and Human Development, and the Psychology Department of Carnegie Mellon University. In addition, the NSF, in granting our request for funding, made a very constructive and welcome stipulation. They required us to raise additional money, so that we could bring a group of junior scientists—graduate students, postdoctoral students, and assistant professors—to Pittsburgh to participate in the Symposium. NIMH and NICHD came through with the extra funds. With the cooperation of matching funds from many of the fellows' home institutions, we were able to award 21 fellowships to such scientists, who came from as far away as The Netherlands and Great Britain. These junior scientists enriched the scientific discourse during the conference, adding excitement, new ideas, and promise for the future. We also would like to thank Mary Anne Cowden and Barb Dorney for their invaluable assistance in organizing the meeting and to recognize Barb Dorney for her invaluable help in preparing the volume as well. Their efforts help make this a memorable symposium for all who participated.

—James L.McClelland
—Robert S.Siegler

Part I

STUDIES OF THE MICROGENESIS OF COGNITIVE CHANGE

BEHAVIORAL APPROACHES

Chapter 1

Giving the Mind a Hand: The Role of Gesture in Cognitive Change

Susan Goldin-Meadow
University of Chicago

Many generations of developmental psychologists have documented the changes children exhibit as they are transformed from less knowledgeable into more knowledgeable members of their cultures. Documenting the changes is comparatively easy. It is accounting for these changes that continues to challenge developmentalists.

Even in domains where scholars are relatively comfortable granting the child some amount of innate knowledge (e.g., language, number, cf. Gelman & Williams, 1998), the problem of learning and change is not solved. Children need some way of cashing in on the knowledge they bring to the learning situation. For example, if we were to grant children a predisposition to develop communication systems equipped with noun-like and verb-like units (cf. Goldin-Meadow, Butcher, Mylander, & Dodge, 1994), children are still faced with the task of identifying nouns and verbs in the particular language they are learning. Thus, by anybody's account of development, we need to identify mechanisms of change.

Some mechanisms of change may be specialized according to domain, with different mechanisms for domains in which children come to the learning situation with more or less innate structure (core as opposed to noncore domains in Gelman and Williams', 1998, terms). Mechanisms of change need not be specialized, however. The same processes could function in areas that children are more or less prepared to learn. For ex-ample, structure mapping—the tendency to find and map inputs to our existing mental structures (Gentner, 1989)—has been proposed as a mechanism to explain learning in both core and noncore domains (Gelman & Williams, 1998).

Here, I consider a set of mechanisms that, in principle, could apply to all domains. The versatility of these mechanisms comes in large part from the fact that the central ingredient is the spontaneous gesture that accompanies talk. Gesture is a pervasive phenomenon, found across cultures (Feyereisen & de Lannoy, 1991), ages (McNeill, 1992), and a wide variety of tasks (Iverson & Goldin-Meadow, 1998a). Even congenitally blind children who have never seen others gesture move their hands spontaneously as they speak (Iverson & Goldin-Meadow, 1997; 1998b). In our previous work, we showed that learners' gestures are distinctive at moments of transition in their acquisition of a task (Goldin-Meadow, 1997; Goldin-Meadow, Alibali, & Church, 1993), thus associating gesture with periods of greatest change.

Identifying the mechanisms responsible for change is perhaps most easily accomplished at moments when change is imminent. Indeed, an entirely new type of study—the microgenetic study (Siegler & Crowley, 1991)—has grown up in large part to allow researchers to focus on the small steps learners take in their acquisition of a task, particularly the steps just prior to progress (e.g., Karmiloff-Smith, 1992; Kuhn, Garcia-Mila, Zohar, & Andersen, 1995; Siegler & Jenkins, 1989). The goal of microgenetic studies is to examine the learner, not just prior to and after instruction as in traditional training studies, but throughout the learning process. Such studies promise to offer insight into the period of transition itself.

The results of previously conducted microgenetic studies provide hints that transitional moments may not be completely captured in children's verbalizations. For example, Siegler found that prior to the acquisition of a new strategy, children become less articulate in speech (Siegler & Jenkins, 1989), and may behave as if they know a strategy although they have no verbal insight into the strategy (Siegler & Stern, 1998). Indeed, there is evidence that, prior to the acquisition of a task, children can demonstrate knowledge through nonverbal means that is not at all evident in their more explicit behaviors. For example, Siegler (1976) found that, although both 5- and 8-year-olds used a weight-only rule in solving a series of balance-scale problems, the 8-year-olds produced head movements that indicated they were also aware of the weights' distance from the fulcrum; the 5-year-olds gave no such evidence and made significantly less progress on the task. As a second example, Clements and Perner (1994) found that, through eye glances, children provided some awareness of the correct answer to a theory-of-mind task, an answer that they gave no evidence of in their speech. These findings suggest that nonverbal indices might go beyond speech in offering insight into moments of change and, perhaps then, into the processes that underlie change.

Our previous work has confirmed these suspicions—gesture, particularly when considered in relation to the speech it accompanies, can be used to identify when a child is in a transitional state. Specifically, children whose gestures often convey different information from their speech about a task, when given instruction, are likely to make progress on that task. In other words, these children are ready to learn the task and, in this sense, are in transition (Church & Goldin-Meadow, 1986; Perry, Church, & Goldin-Meadow, 1988). In this chapter, I ask whether gesture might not only index children who are in transition, but might also play a role in the transition process itself. In other words, I ask whether gesture might itself be involved in mechanisms of change.

The chapter is divided into three parts. In Part One, I review our previous work providing evidence that gesture is indeed a reliable index of children in transition, and that its use during periods of transition is associated with improved learning. Having shown that gesture is correlated with change, I then go on to ask whether it causes change. I consider two different, though not mutually exclusive, possibilities.

In Part Two, I explore the significance of the fact that gesture is "out there," occurring routinely in naturalistic talk of all sorts. Gesture, when interpreted in relation to speech, can signal that the speaker is in transition and open to new input. If communication partners are able to read the signals contained in a child's gestures, they may then be able to alter their interactions with the child accordingly. Gesture, by influencing the input children receive from others, would then be part of the process of change itself.

In Part Three, I consider whether gesture might not be more directly involved in learning, influencing the learners themselves. Gesture externalizes ideas differently and therefore may draw on different resources than speech. Conveying an idea across modalities may, in the end, require less effort than conveying the idea within speech alone; that is, 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.

Gesture Is Associated with Learning

Gesture-Speech Mismatch Indexes Openness to Learning. I begin by describing the basic phenomenon. Consider a child asked to justify why he has just said that spreading out a row of checkers has altered the number of checkers in the row (the standard Piagetian number task). Children often argue that the number in the spread-out row is different "because you spread them out," and they often accompany this justification with a matching gesture—a spreading-out motion indicating how the checkers were moved. However, at times, children will produce this same verbal explanation, but accompany it with a very different gestural explanation—for example, a movement pairing each of the checkers in Row 1 with the checkers in Row 2, thus demonstrating, albeit silently, the fact that the checkers in the two rows can be put in one-to-one correspondence. Responses of this sort have been called gesture-speech “mismatches”—instances where gesture conveys information that is different from the information conveyed in the accompanying speech (Church & Goldin-Meadow, 1986).

Children often produce a large number of gesture-speech mismatches in their explanations of Piagetian conservation tasks. What is particularly striking, however, is that the children who produce many mismatches on the conservation task, when given instruction in the task, are significantly more likely to profit from the instruction than children who produce few mismatches (Church & Goldin-Meadow, 1986). Thus, producing different information in gesture on the conservation task is a signal that the child is ready to learn that task.

We have found this same phenomenon in other tasks. For example, when asked to solve addition problems of the following sort, 3+5+4=_+4, fourth-grade children frequently solve the problems incorrectly and offer incorrect explanations for those solutions—the same incorrect explanation in both speech and gesture. Children often say “I added the 3, the 5, the 4, and the 4, and got 16, and put it in the blank,” while pointing at the 3, the 5, the 4 on the left side of the equation, the 4 on the right side, and then the blank (an “add all of the numbers in the problem” explanation). However, some children produce the same verbal explanation, but along with it produce a very different gestural explanation—for example, point at the 3, the 5, and the blank, the two numbers on the left side of the equation that can be added to arrive at the correct sum to put in the blank (a “grouping” explanation). Again, we find that it is those children who produce many gesture-speech mismatches who are significantly more likely to profit from instruction in mathematical equivalence than those children who produce few mismatches (Perry et al., 1988).

Gesture-Speech Mismatch Is a Step in the Learning Process. The studies described thus far have all been traditional—a child’s knowledge is assessed at pretest, instruction is given, and the child’s knowledge is assessed again at posttest. These studies show that gesture-speech mismatch is associated with a propensity to learn, but they do not in any way shed light on the path of learning. To do so, we conducted a microgenetic study, assessing children repeatedly as they were exposed to instruction in mathematical equivalence (Alibali & Goldin-Meadow, 1993).

Children were given instruction in problems of the 3+5+4=_+4 variety, and were assessed three times over the course of the training period. The children began the study at different levels of understanding of mathematical equivalence (although none could solve the problems correctly), and made different gains as a result of instruction. Indeed, some made no progress at all, and a small number regressed. However, the interesting point is that the vast majority of the 35 children who gestured and made progress on the task did so following the same path: (a) Children began by producing the same explanation in both gesture and speech and that explanation was incorrect (Matching Incorrect). (b) The children then produced explanations in gesture that were different from their explanations in speech (Mismatching); the mismatching explanations were either both incorrect, or one (typically gesture) was correct and the other incorrect. (c) Finally, the children returned to producing the same explanation in both gesture and speech, but now the explanation was correct (Matching Correct). Over the course of the study, 11 children traversed the first two steps of the path, 15 traversed the last two steps, and 3 traversed all three steps, accounting for 83% of the 35 children (a number significantly higher than that expected by chance, $p<.001$, binomial test). Only 6 (17%) of the children who gestured and progressed on the task did so by skipping the mismatching step.

In addition to suggesting that gesture-speech mismatch can be a stepping-stone on the way toward mastery of a task, the findings also provide evidence that, when gesture-speech mismatch is a step on a child's path to mastery, learning is deeper and more robust. We compared the children's ability to generalize to multiplication what they had learned on addition problems. This generalization was measured on a posttest immediately following the training, and on a follow-up test 2 weeks after training. We focused on two groups: Children who progressed to a Matching Correct state by passing through a Mismatching state, and children who progressed to a Matching Correct state by skipping the Mismatching state. We found that children who arrived at the Matching Correct state by skipping the Mismatching state were significantly less likely to generalize their knowledge on the posttest, and significantly less likely to maintain their gains on the follow-up test 2-weeks later, than children who reached the Matching Correct state by going through a Mismatching state (Fig. 1.1; Alibali & Goldin-Meadow, 1993). These findings provide the first hint that gesture, when taken in relation to speech, may not only reflect learning, but also contribute to it.

Gesture Conveys Implicit Knowledge. I have shown thus far that gesture, when considered in relation to the speech it accompanies, can index the stability of a child's cognitive state. Can gesture also tell us something about the knowledge that contributes to that state? The information that a child conveys in gesture is a good candidate for implicit knowledge—knowledge that at some level the child *has,* but is not able to articulate (Berry & Broadbent, 1984; Clements & Perner, 1994; Karmiloff-Smith, 1992; Nisbett & Wilson, 1977; Reber, 1993; Stanley, Mathews, Buss, & Kotler-Cope, 1989). There are two steps involved in showing that gesture reflects implicit knowledge.

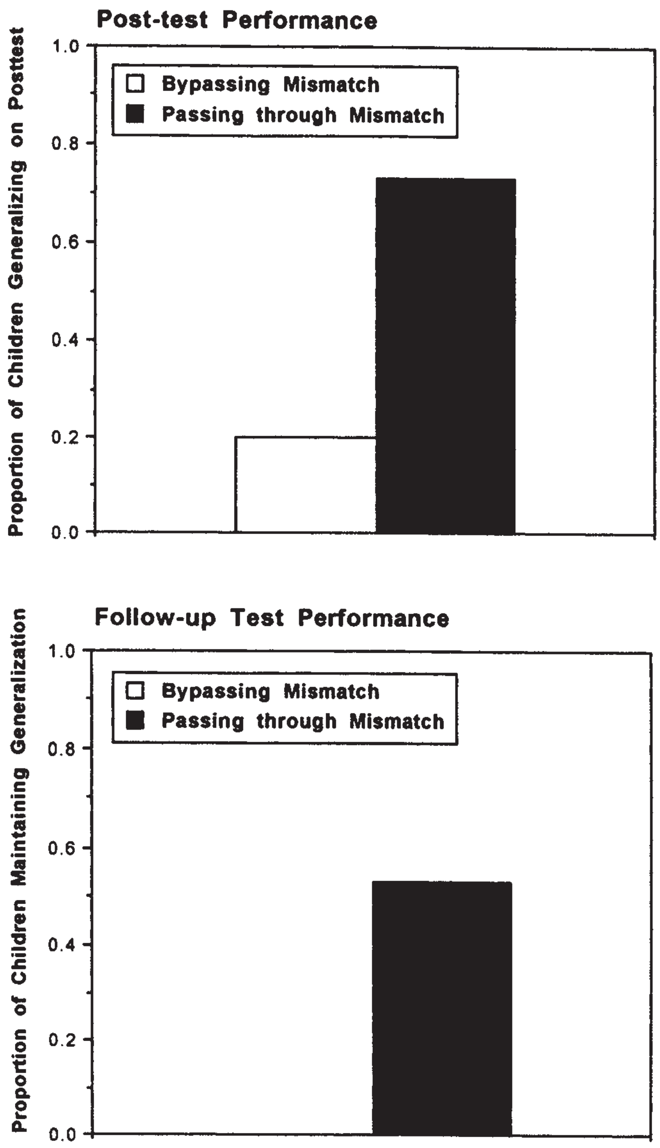

FIG. 1.1. Proportion of children who successfully generalized their mathematical equivalence training to the posttest immediately following the instruction (top graph), and who maintained that progress 2-weeks later on a follow-up test (bottom graph). All of the children had achieved a Matching Correct state by the end of training. Children who arrived at the Matching Correct state by passing through a Mismatching state (black bars) were significantly more likely to generalize their training and maintain that progress than children who arrived at the Matching Correct state by skipping a Mismatching state (white bars).

The first is to demonstrate that the knowledge children convey in their gestures is not accessible to speech. To make this case, we examined the entire set of responses that fourth-grade children produced when asked to explain their solutions to the mathematical equivalence task. Looking only at children who gestured on at least some problems, we determined which types of problem-solving procedures were expressed (a) in gesture and never in speech, (b) in speech and never in gesture, or (c) in both gesture and speech. A procedure need not have been produced in gesture and speech on the same problem in order to find its way into the third category; it was sufficient for the child to produce the procedure in gesture on one problem and that same procedure in speech on another problem. Interestingly, we found that very few of the children's procedures were expressed uniquely in speech, that is, without some representation in gesture even if on another problem (Fig. 1.2). The children's procedures were either expressed in both gesture and speech, or uniquely in gesture (Goldin-Meadow, Alibali, & Church, 1993). Thus, most of the information these children possessed about the math problems was accessible to gesture, and some of that information was accessible *only* to gesture.

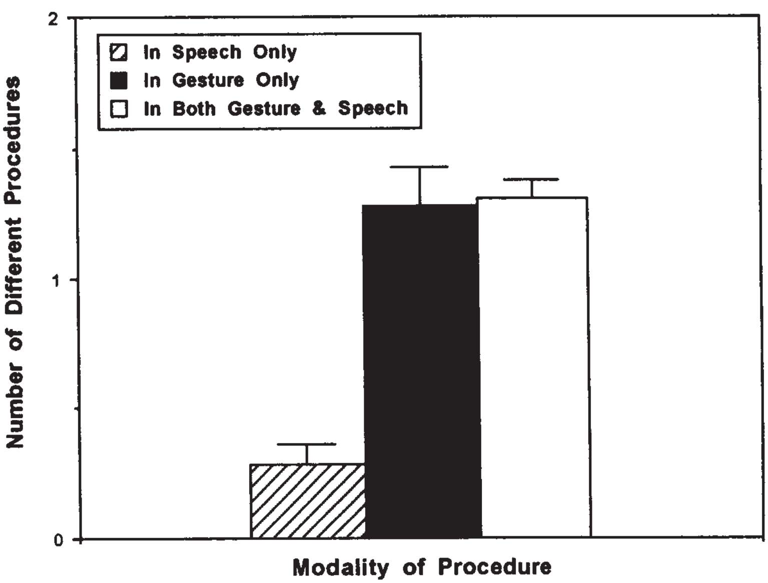

FIG. 1.2. Modalities in which a procedure was conveyed by a child over a series of six mathematical equivalence procedures. Very few procedures were conveyed uniquely in speech. Procedures were either expressed in both gesture and speech, or uniquely in gesture. Bars reflect standard errors.

The second step is to demonstrate that children actually have the knowledge that we impute to them on the basis of their spontaneous gestures. We have assumed that when a string of points is produced along with a spoken problem-solving procedure, those points are conveying a problem-solving procedure. But the pointing gestures could be doing nothing more than directing the listener's attention to the numbers in the problem. There is evidence, however, that the string of gestures, when taken together, does reflect a procedure in its own right. The evidence comes from cases where the child's gestures do *not* match speech. For example, consider a child responding to the same problem described earlier, 3+5+4=_+4. The child articulated an "add the numbers up to the equal sign" procedure in speech, "I added the 3, the 5, and 4, and put 12 in the blank." In gesture, however, the child produced a string of points that appeared to reflect a completely different procedure—point at the 3, the 5, the left 4, the right 4, and the blank, an "add all the numbers in the problem" procedure.

When later asked by a separate experimenter on a separate rating task which answers would be acceptable solutions to this problem (children, on the whole, were happy to accept more than one answer for a single problem), the child, of course, accepted 12—the answer generated by the "add the numbers up to the equal sign" procedure that she had conveyed in speech. More interestingly, when asked whether 16 would also be an acceptable answer—the answer generated by the "add all the numbers" procedure that she conveyed in gesture but not in speech—the child was significantly more likely to say "yes" than she was to answers generated by procedures that she had not produced in either gesture or speech (Garber, Alibali, & Goldin-Meadow, 1998). In other words, the child recognized the solution generated by the procedure that she had produced *only* in her gestures. Thus, strings of gestures can indeed reveal knowledge about problem-solving procedures. Children may not be able to express in speech the problem-solving knowledge that they convey in gesture, but they are able to recognize it on other, gesture-independent tasks. In this sense, the knowledge conveyed uniquely in gesture is implicit.

Gesture as a Mechanism of Learning Through Its Effect on Others

If gesture makes a child's implicit knowledge "visible" to a communication partner, the partner may be able to use that information to alter the way he or she interacts with the child. In this way, gesture could be part of the learning process itself. This hypothetical mechanism can, of course, only work if communication partners are able to interpret the gestures children produce.

Reading Preselected Gestures Off of Videotape. We have taken several steps to explore this hypothesis. We began by asking whether adults, not trained in gesture-coding, could observe children on videotape and glean substantive information from the gestures the children produced. Examples for the videotape were chosen so that half of the children produced gestures that conveyed the same information as their speech (matching explanations), and half produced gestures that conveyed different information from their speech (mismatching explantions). If the adults were able to report the information that the children produced only in gesture and not in speech, that is, on mismatching explanations, we would then have evidence that they can read child gesture.

We conducted two studies, one asking adults to describe what the child on the videotape knew about the conservation task (Goldin-Meadow, Wein, & Chang, 1992), and another asking adults to describe what the child knew about the mathematical equivalence problem (Alibali, Flevares, & Goldin-Meadow, 1997). In both studies, adults were given free rein in their responses: After each videotaped task, the tape was stopped, and the adult was asked to assess the child's understanding of the task. In both studies, we found that the adults were able to glean substantive information from the children's gestures, information that was not displayed anywhere in the children's speech. For example, a child responding to a conservation number task on the tape said that the rows of checkers were different "'cause you moved 'em," but indicated some understanding of one-to-one correspondence in gesture (he moved his pointing hand from each checker in one row to the corresponding checker in the other row). When describing this child's reasoning, adults often commented that the child not only noticed that the checkers had been moved, but that the checkers matched up with one another. Comparable findings have been reported for other tasks (a narrative task, McNeill, Cassell, & McCullough, 1994) and even for child observers (Kelly & Church, 1997, 1998).

Reading Spontaneously Produced Gesture Online. These findings indicate that adults can read a child's gestures when those gestures are carefully chosen by the experimenter and presented twice on videotape. However, the mechanism for cognitive change that I propose requires that gesture be read 'online' in the give-and-take of naturalistic interaction. Our next step then was to ask adults to observe children "live" (GoldinMeadow & Sandhofer, 1999). We asked adults to observe children participating in a series of Piagetian conservation tasks. In order for the adults to be able to assess each child's knowledge online, we gave them a checklist for each task the child performed. The list contained all of the explanations children typically give on tasks of this sort. The adults' job was to check off as many explanations as they thought the child had conveyed.

We first validated this checklist on two groups of adults asked to observe a videotape of children participating in Piagetian conservation tasks (Video Groups 1 and 2). We then asked one of these groups of adults to observe live, a series of children participating in six Piagetian tasks (Live Group 2). The children observed by these adults were randomly chosen from their classes. We found that the adults checked explanations that the children conveyed *only* in their gesture from 32% to 44% of the time in response to both the preselected videotaped gestures and the spontaneously produced online gestures.

These results suggest that the adults were able to read the children's gestures (albeit not all of the time). However, it is possible that the adults checked the explanations that the children conveyed uniquely in gesture, not because they actually read the children's gestures, but because these are the explanations that readily come to an adult's mind on tasks of this sort. To explore this possibility, we first established how often an adult checked a given explanation (e.g., one-to-one correspondence) when that explanation was *not* produced on a particular number task. In other words, we established a base-rate for how often adults erroneously checked one-to-one correspondence on this number task. We then compared this figure to how often adults checked one-to-one correspondence when it *was* conveyed uniquely in gesture on that same number task. We found, in both the video groups and the live group, that adults were significantly more likely to check an explanation when it was produced uniquely in gesture than when that same explanation was not produced at all on the same task (Fig. 1.3). Interestingly, there was no difference between the video and live groups in how much information the adults gleaned from gesture. Adults, then, are able to glean substantive information from the gestures children produce, even if those gestures are unedited and fleeting.

Does gesture affect the observer's ability to extract information from the *speech* it accompanies? The videotaped examples were selected so that we could examine whether listeners could abstract information from gesture. However, the design of the study also allowed us to explore whether gesture affects how accurately its accompanying speech is interpreted. In six of the examples, gesture conveyed the same explanation as the speech it accompanied; in the other six, gesture conveyed a different explanation. We found that the adults correctly checked off explanations conveyed in speech significantly more often when they were accompanied by a matching gesture than by a mismatching gesture.

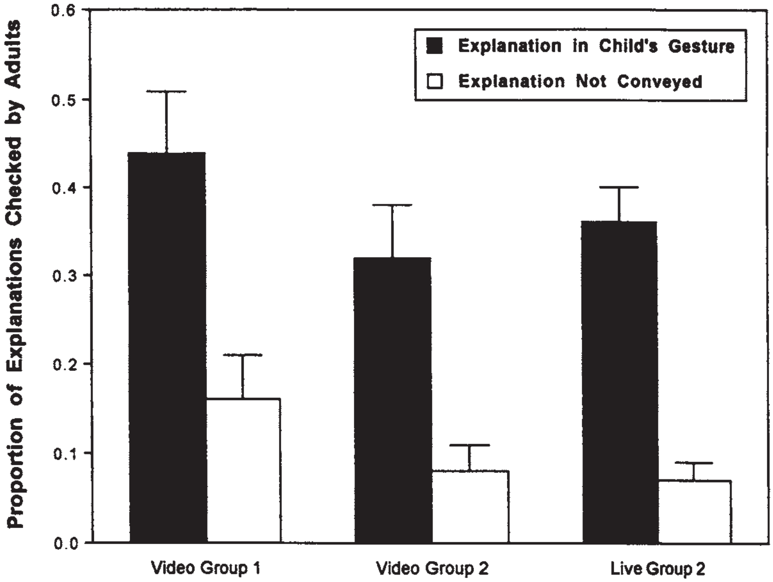

FIG. 1.3. Proportion of explanations identified on a checklist by adults who viewed a series of children participating in a conservation task on a preselected videotape (Video Groups 1 and 2) or in a live situation (Live Group 2). In all three groups, adults were significantly more likely to check an explanation when it was conveyed uniquely in a child's gestures versus when that same explanation was not conveyed at all by the child. Bars reflect standard errors.

To be certain that the differences between the two types of explanations (speech with a matching gesture vs. speech with a mismatching gesture) were attributable to the presence of gesture and not to differences in the speech itself, we presented an additional group of adults with only the audio portion of the videotape (i.e., the picture was turned off). As expected, the differences that we hypothesized to be due to gesture disappeared— the adults were equally likely to correctly check "yes" for the six explanations of each type when there was no picture and therefore no gesture to affect the interpretation of speech.

These results suggest that adults' ability to receive a message in speech is affected by the gestures that accompany that speech. However, it is not clear from these data whether a matching gesture *improves* the adult's ability to recognize an accompanying spoken explanation, or whether a mismatching gesture *diminishes* the adult's ability to recognize an accompanying spoken explanation. The adults in the naturalistic task observed some children producing explanations that contained speech and no gesture at all, a necessary ingredient to explore this hypothesis. Although the adults correctly identified spoken explanations *more* often when those explanations were accompanied by a matching gesture (88%) than when they were accompanied by no gesture at all (82%), this difference was not statistically significant. In contrast, the adults correctly identified spoken explanations significantly *less* often when those explanations were accompanied by a mismatching gesture (70%) than when they were accompanied by no gesture at all (82%). Thus, at the moment, we have no evidence that gesture improves a listener's ability to recognize a message produced in speech if gesture conveys the same message (although such an effect would be difficult to see in these data because accuracy was so high; see Krauss, MorrelSamuels, & Colasante (1991) for whom ceiling effects were not a problem and who also found that matching gesture did not improve comprehension of a message). However, we do have evidence that gesture diminishes a listener's ability to recognize a spoken message if gesture conveys a different message (see also Kelly & Church, 1998).

Responding to Gesture in a Naturalistic Teaching Situation. The findings described thus far set the stage for gesture's participation in the learning process. Observing gesture as a third-party to a conversation is different from observing it as a participant in the conversation. If adults alter the way they interact with a child on the basis of the child's gestures, those adults are going to have to be able to read gesture as they interact with the child. The next study suggests that adults are able to do so.

In an ongoing study Melissa Singer, San Kim, and I asked eight teachers to interact individually with from 5 to 7 children. The teachers' task was to teach each child how to solve the mathematical equivalence problems. To acquaint the teachers with their pupils, before each tutorial, the teacher was requested to observe the child interacting with the experimenter, who asked the child to solve six mathematical equivalence problems and explain how he or she arrived at those solutions. The teacher was given five problems to use in instructing each child. In a previous study designed to explore whether teachers use gesture in math tutorials (Goldin-Meadow, Kim, & Singer, 1999), we discovered that teachers tend to do most of the talking during the tutorials. In order to be able to observe teacher responses to child gestures, we needed to increase student participation in the tutorials. We therefore asked that the teachers request the children to both solve each of the five problems and explain their solutions during the tutorial.

We have thus far coded three of the eight teachers' interactions with their students. The children did indeed produce gestures during the tutorials, and they conveyed problem-solving procedures with those gestures. On average, 39% of the children's turns contained gesture, 21% in which gesture conveyed the same information as their speech, and 18% in which gesture conveyed different information from their speech. We assumed conservatively that the teacher understood a child's gestures when that teacher reiterated on the very next turn the problem-solving procedure that the child had expressed uniquely in gesture. We found that, as in our studies of more constrained situations, the teachers reiterated procedures children expressed uniquely in gesture approximately 30% of the time. Moreover, the children's gestures had an impact on whether their words were heeded: Teachers reiterated the child's problem-solving procedures less often when those procedures were accompanied by child-gesture conveying a different procedure than when the procedures were accompanied by child-gesture conveying the same procedure or no gesture at all (this pattern was not determined by the correctness of the child's procedures; e.g., the pattern held even when we examined teacher reiterations following correct procedures only). Thus, even in a naturalistic situation in which the adult is an active participant, the adult is able to glean substantive, and unique, information from children's gestures.

Using Gesture to Alter Input to the Child. Our final step in exploring the hypothesis that gesture provides a mechanism by which children can shape the input they receive from adults is to show that adults alter their input to the child as a function of the information they glean from that child's gestures. At the moment, the evidence for this hypothesis is purely anecdotal. At times in our math tutorials, the teachers did not reiterate the problem-solving procedure found exclusively in the child's gesture, but rather used it as a stepping-stone for their next move. For example, for the problem 5+3+4=_+4, the child began by pointing simultaneously at the left 4 with her left hand and the right 4 with her right hand. Rather than reiterate the notion that there are equal addends on each side of the equation, the teacher's next move was to articulate the grouping procedure in both speech and gesture—"you can solve the problem by adding the 5 and the 3 and putting the sum in the blank," accompanied by a V-shaped point at the 5 and 3. Note that the grouping procedure works in this problem because there are equal addends, one on each side of the equation, that can be canceled. The fact that the child demonstrated some awareness of equal addends in gesture seemed to give the teacher license to introduce grouping, a procedure that the child then picked up on in her next turn and continued to use throughout the interaction. Our future analyses will explore how often interactions of this sort occur in the math tutorials.

It is important to point out that adults need not be aware of the fact that have been influenced by the child's gesture. Indeed, the adult may get it wrong and still be able to provide useful input to the child. Consider, for example, the following teacher who participated in the study conducted by Alibali et al.

(1997). The child said he solved the problem 5+6+7= _+7 by adding the 5, 6, and 7 (an "add numbers up to the equal sign" procedure), while pointing only at the 5 and 6 (a "grouping" procedure). After observing this child, the teacher said that the child did *not* understand the grouping procedure: "What I'm picking up now is [the child's] inability to realize that these (indicates 5 and 6) are meant to represent the same number … there isn't a connection being made by the fact that the 7 on this side of the equal sign (indicates left side) is supposed to also be the same as this 7 on this side of the equal side (indicates right side), which would, you know, once you made that connection it should be fairly clear that the 5 and 6 belong in the box." Note that, at some level the teacher was incorrect—the child did indeed have an understanding, however implicit, of the grouping procedure that he expressed only in gesture. It is possible that the teacher chose the grouping procedure to highlight as the one the child did not know because she detected the procedure in the child's gestures. The fact that the teacher did not *explicitly* recognize the child's grasp of this procedure may not matter if, in instructing the child, the teacher were to focus on what she thought the child needed most—input about the grouping procedure. Instruction about grouping might be especially effective for this particular child because it might help him to transform or "redescribe" his emerging knowledge into a problem-solving procedure that he could apply and articulate in speech (cf. KarmiloffSmith, 1992).

To summarize thus far, gesture routinely accompanies speech and appears to provide an undercurrent of conversation that participants may or may not explicitly notice but detect nonetheless. Teachers do pick up on at least some of the information children convey uniquely in gesture. Moreover, gestural communication is not a one-way street. Teachers produce gestures of their own, many of which express information that is different from the information they express in speech—and children pick up on those gestures, even if they convey (unintended) incorrect procedures (Goldin-Meadow, Kim, & Singer, 1999). Thus, gesture is an inevitable part of conversation, received as well as produced by the child. Adult gesture can therefore be a source of usable input for the child.

However, as I have shown here, gesture also allows the child to signal (perhaps without intending to do so) that he or she is on the cusp of insight. In this sense, gesture is comparable to a pheromone—a signal to a member of the species that the child is ready for input. The signal may be taken as a general one—a "teach me-I'm ready" announcement that elicits instruction, any sort of instruction, from a communication partner. Or, the signal may be taken as a specific call for input of a certain sort. If, in fact, gesture does pinpoint those areas in which the child is ready to learn, gesture may be functioning as an externalized index of the child's *proximal zone* (Vygotsky, 1978)—the range of skills on which a child can make progess if given appropriate assistance. As such, gesture may provide a concrete, externalized mechanism by which adults can calibrate their input to the child's most pressing needs.

Gesture as a Mechanism of Learning Through Its Effect on the Learner

I turn now to the second type of learning mechanism in which gesture may play a role. In addition to signaling the learner's cognitive state to others, gesture may function in some beneficial way for the learner him or herself. There are indeed a number of hints that gesture is there when good things happen. For example, Fisher and Brennan (personal communication, June 3, 1998) found that better recall was associated with gesture. Children observed a Red Cross lecture/demonstration, which they were asked to recall after a week had passed. Although accuracy of recall was generally high (80%), it was much higher (99%) when the children gestured along with their recalled responses.

Gesture was not a manipulated variable in Fisher and Brennan's study—it arose as a serendipitous finding. In contrast, Iverson (personal communication, June, 1998) deliberately manipulated gesture to determine its effects on recall. Adults were shown a cartoon and asked to retell the story immediately after viewing it. During the immediate retelling, half of the adults were told to keep their hands still on the arms of the chair, and half were given no particular instructions. The second group gestured in retelling the cartoon, and the first obviously did not. There were no differences between the groups in the number of story details that were recalled during the immediate retelling. Both groups were then asked to retell the cartoon again 1 week later, and this time none of the adults was restricted in their movements. Interestingly, the group that was initally allowed to gesture recalled more details about the cartoon than the group that was initially prevented from gesturing. Gesturing during the first retelling appeared to enhance the likelihood that the information would be retained and recalled during the second retelling. Although it is not yet clear what role gesture is playing in memory (e.g., at what point in the memory process does gesture make its contribution?), these studies do strongly suggest that gesture plays a beneficial role in recall or, at the least, that gesture is an important encoding factor that can affect memory if it is (or is not) replicated at the time of recall.

There is, in addition, some suggestion from our previous work that gesturing is associated with learning (Alibali & Goldin-Meadow, 1993). Several of the children in our microgenetic study of mathematical equivalence failed to gesture during the study. These children did less well on the posttest and the follow-up test than the children who gestured throughout the study, although the difference between groups did not quite reach statistical significance. Thus, when required to generalize what they had learned during instruction and retain that understanding over a 2-week period, children who gestured during the process showed a tendency to outperform children who did not gesture.

Finally, in a conservation training study, Church (1999) found that across-modality variability (that is, the number of gesture-speech mismatches the child produced at the start of the study) was a significantly better predictor of learning than within-modality variability (the number of different strategies the child produced in speech, either within a trial or across trials). Thus, it is not only the number of different strategies that matters in predicting learning, but whether those strategies are produced in gesture. Why might gesture be associated with learning?

Gesture Is Where Children Experiment. One possibility is that gesture is the place where learners experiment. Recall that in our microgenetic study (Alibali & Goldin-Meadow, 1993), children who gestured and progressed to a correct understanding of mathematical equivalence by going through a mismatching state (one in which they produced gestures that conveyed different information from their speech) did better on both a posttest and follow-up test than children who gestured but progressed to the same correct state without going through a period of gesture-speech mismatch.

To better understand this phenomenon, we examined the modality in which children produced each of the procedures in their repertoires prior to instruction (Alibali & Goldin-Meadow, 1993). Children who gestured and produced many matching explanations were identical to children who gestured and produced many mismatching explanations in two respects: Both groups expressed very few procedures *only* in speech (that is, without also expressing that procedure in gesture at some time over the set of six problems), and both groups expressed a relatively large, and equal, number of procedures in both speech and gesture (not necessarily in both modalities on the same problem, but across six problems). Where the matching and mismatching children differed was in procedures accessible to gesture: The mismatching children expressed a significantly larger number of procedures *only* in gesture compared to the matching children. Overall, the mismatching children expressed a wider variety of procedures than the matching children—and all of that variety resided in gesture. Thus, the variability that many theorists consider essential to developmental progress (e.g., Siegler, 1994; Thelen, 1989) is indeed present in these children—in their gestures.

This phenomenon is not only found across children but within-child as well (Alibali & Goldin-Meadow, 1993). Children who, with instruction, progressed from an incorrect matching state to a mismatching state significantly *increased* the number of procedures they expressed uniquely in gesture. Conversely, children who progressed from a mismatching state to a correct matching state significantly *decreased* the number of procedures they expressed uniquely in gesture. Thus, children have the largest number of different procedures in their repertoires when they are in a mismatching state, and the influx of new procedures is found uniquely in gesture.

In an attempt to observe the smallest steps children make when learning a task, Alibali (1994) gave children minimal instruction in mathematical equivalence. Not surprisingly, she found that, at best, children made only minimal progress; indeed, some appeared to make no progress at all, and some even regressed. Predictably, children who progressed from an incorrect matching state to a mismatching state *increased* the total number of different procedures in their repertoires; children who regressed from a mismatching state to an incorrect matching state *decreased* their total number of procedures; children who remained in an incorrect matching state or a mismatching state retained the same number of different procedures, a *low* number for the incorrect matchers, a *high* number for the mismatchers.

Alibali (1994; Goldin-Meadow & Alibali, 1995) then observed the way in which the children's repertoires changed over the course of instruction. A large number of children in all four groups were found to *maintain* at least one procedure over the study, suggesting that change may be more gradual than abrupt (cf. Alibali, 1999; Kuhn & Pearsall, 1998; Siegler & Chen, 1998). What about *abandoning* old procedures or *generating* new ones? As we might expect, children who progessed from an incorrect matching state to a mismatching state, not only maintained old procedures, but generated new ones (thus enlarging their repertoires). Children who regressed from a mismatching state to an incorrect matching state abandoned old procedures but did not generate new ones (thus shrinking their repertoires).

The interesting contrast comes from children who remained in the same state throughout the study. Children who remained in an incorrect matching state, predictably, neither abandoned old procedures nor generated new ones—they maintained the same number of procedures in their repertoires by not changing those repertoires at all. In contrast, children who remained in a mismatching state maintained the same number of procedures in their repertoires by *continuously revamping those repertoires,* generating new procedures while abandoning old ones. Thus, children in a mismatching state not only had a large number of different procedures in their repertories, but those procedures were continuously changing, providing the kind of variability that may be necessary for change. Important for the argument I am making here, all of this "experimentation" with new ideas took place in gesture. Many of the newly generated procedures were incorrect, and were quickly abandoned. Gesture thus appears to be a place where children can air ideas that may not, in themselves, be all that sound but may be able to serve as stepping-stones for progress nonetheless.

Why experiment in gesture? One might imagine that gesture would be an ideal place to try out untried ideas, simply because there is essentially no social constriction on the gestures people produce (aside from the often rude gestural "emblems," which are conventional, frequently produced without any speech, and qualitatively different from the gestures we are considering here, cf. Ekman & Friesen, 1969). Or, perhaps gesture is the ideal place for experimentation because the ideas themselves are easier to express in the manual modality. This may be particularly true for domains such as mathematics, which lend themselves to visual thinking (Hadamard, 1945).

Gesture May Ease the Cognitive Burden. Another possiblility, and one we are currently exploring (Goldin-Meadow, Nusbaum, Kelly, & Wagner, under review) is that gesturing itself can reduce cognitive effort, perhaps in the same way that writing a problem down can reduce the effort needed to solve the problem (see Alibali & DiRusso, 1999, who make this very argument with respect to pointing and learning to count). If gesture does serve as a kind of cognitive prop, the effort saved as the result of gesturing could be allocated toward working out new ideas that could, in turn, lead to progress in the task. We tested this hypothesis by asking whether gesturing on a task frees up effort that can then be used on another task. We gave fourth-grade children two tasks to perform simultaneously—(a) explain their solutions to a mathematical equivalence problem, and (b) recall a list of words (either a short list containing a single word, or a longer list containing three words). On each trial, children first solved the mathematical equivalence problem. After solving the problem, the child was given the list of words to be recalled, and was asked to explain how he or she had solved the math problem. After completing the explanation, the child was then asked to recall the list of words.

The children were asked to do these tasks under two conditions—one in which they were told to hold their hands completely still within the handprint drawn on a sheet of paper that we supplied (the gesture-prevented condition), and a second in which they were told that they could use their hands freely (the gesture-permitted condition). Our goal was to observe every child gesturing and not gesturing. A priori, we might expect gesturing to *increase* cognitive load simply because the gesturer must plan and execute communication in two modalities. If so, we would expect the children to remember fewer words when they gestured than when they did not gesture. Alternatively, gesturing might *decrease* cognitive load by increasing resources available to the child, for example, by shifting the burden from verbal to spatial memory. If so, we would expect the children to remember *more* words when they gestured than when they did not gesture.

Children did follow our instructions in the gesture-prevented condition—none produced any gestures on these problems. However, and perhaps not surprisingly, children did not gesture on every single problem in the gesture-permitted condition either. Indeed, some children did not gesture on any problems at all; we call these six children the No-Gesturers and set them aside for the moment. Turning to the 10 Gesturers, we ignored the condition (gesture-prevented vs. gesture-permitted) to which a problem had been assigned, and categorized each problem according to whether the child had actually gestured when explaining that problem. We then calculated the proportion of correctly recalled one- and three-word lists following problems on which the child gestured versus problems on which the child did not gesture.

Figure 1.4 displays the proportion of word lists correctly recalled following gesture problems versus no-gesture problems. Not surpisingly, children correctly recalled significantly more one-word lists than three-word lists ($F(1, 9)=19.33$, $p<.01$). If gesturing on the explanation task frees up space in working memory (perhaps by shifting some of the load from verbal working memory to spatial working memory), then we would expect children to be able to remember more words on the recall task when they gesture on the explanation task than when they do not—but only when their memories are taxed, that is, only on the three-word lists. In other words, we would expect an interaction between word list length and presence of gesture which, in fact, we found ($F(1, 9)=10.73$, $p<.01$). Children were essentially at ceiling in recalling the one-word lists, whether or not those lists followed gesture versus no-gesture problems. The crucial comparison involves the three-word lists, which were designed to tax the children's memory skills. Here we see that the children recalled significantly more three-word lists following problems on which they gestured than following problems on which they failed to gesture ($p<.01$, Newman-Keuls). These findings suggest that the act of gesturing may have eased the child's cognitive burden in the explanation task, freeing effort up for the word-recall task.

It is important to note that it is not just having the opportunity to gesture that is associated with improved recall, it is necessary for the child to actually do the gesturing for memory to be affected. Thus, if we ignore whether the child actually gestured and compare word-recall on the problems originally assigned to the gesture-permitted versus gesture-prevented conditions, the effect disappears. The effect is also not there for nongesturers, who do not produce gestures on any of their trials and thus obviously cannot reap the benefits of gesturing.

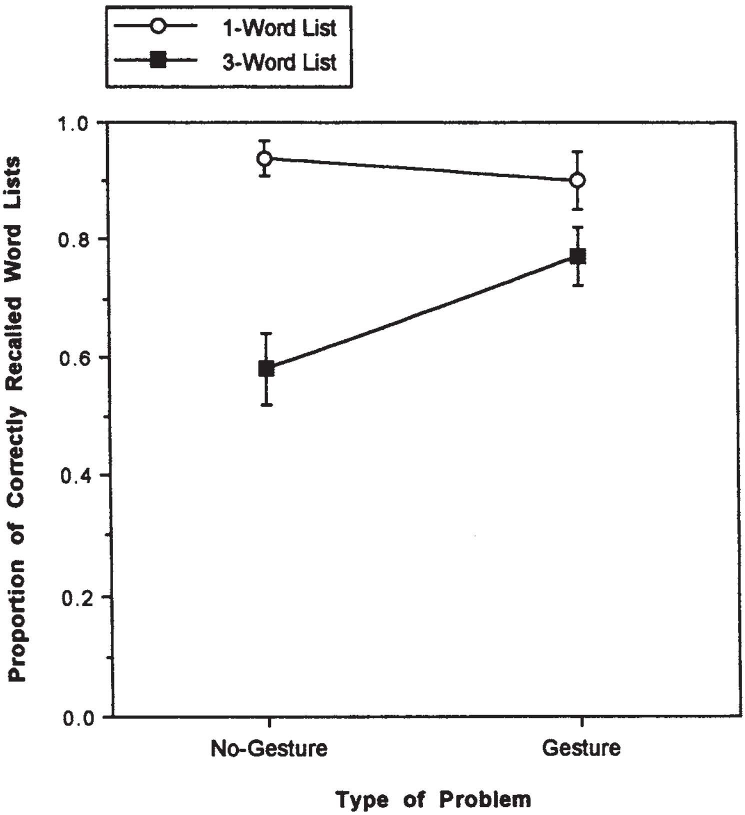

FIG. 1.4. The proportion of word lists that children recalled correctly following problems on which they gestured versus problems on which they did not gesture. When their memories were taxed (that is, on the three-word lists), the children recalled a significantly higher proportion of word lists following Gesture problems than No-Gesture problems, suggesting that the act of gesturing may have freed up cognitive effort that could then be used on the recall task. Bars reflect standard errors.

It is possible, however, that our gesture-prevented condition actually imposes a discomfort burden on the child. If so, this burden may be decreasing recall in the gesture-prevented condition relative to the gesture-permitted condition (as opposed to gesture enhancing recall in the gesture-permitted condition relative to the gesture-prevented condition). This possibility is unlikely for two reasons. First, when we divide problems in the gesture-permitted condition into those on which the child actually gestured versus those on which the child did not gesture (all of the problems were of equal difficulty), we find the same pattern seen in Fig. 1.4— and these particular no-gesture problems were not experimentally created and thus not obviously subject to the discomfort concern. Note that the children whom we included in this analysis were not nongesturers, but merely gesturers who did not use gesture on every problem. Importantly, these children were equally successful (or unsuccessful) at solving problems on which they gestured and problems on which they did not gesture.

Second, we have begun running children in a discomfort control condition and the results from a single child are promising. This child, who also participated in the hands-still study (and gestured on every problem in the gesture-permitted condition), was asked to do precisely the same task but this time she was to keep her feet completely still within a set of footprints stenciled on a sheet of paper. If discomfort is impeding recall, the results of the feet-still study should look just like the results of the hands-still study. However, if gesturing actually improves memory, then the results should be unaffected by holding one's feet still (unless, of course, keeping one's feet still affects gesturing which, for this child, was not the case—she gestured on

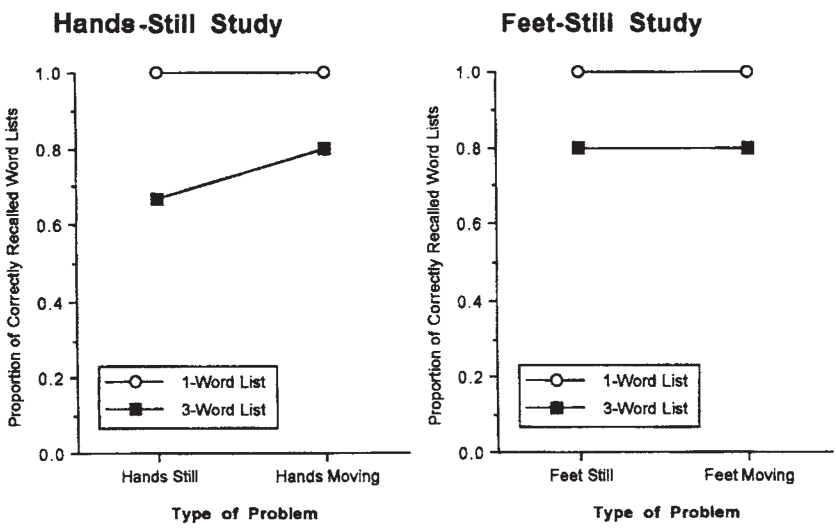

FIG. 1.5. The proportion of word lists that a single child recalled after explaining math problems under two different conditions: (a) holding her hands still when explaining half of the math problems (Hands-Still study, left graph), and (b) holding her feet still when explaining half of the problems (Feet-Still study, right graph). The child spontaneously gestured on all of the problems in the Feet-Still study, and on all of the problems in the Hands-Moving condition of the Hands-Still study. She recalled a lower proportion of three-word lists when she was prevented from gesturing in the Hands-Still condition of the first study than in the Hands-Moving condition. This relatively poor performance was not due merely to the discomfort of a keeping a body part still, as the same decrement was not found in the Feet-Still study.

every problem in the feet-still study). The results for the child, who appeared to find it just as disconcerting to keep her feet still as to keep her hands still, are presented in Fig. 1.5. The patterns suggest that holding one's feet still does not affect memory, but that holding one's hands still—which prevents gesturing—does. Thus, if children gesture on a task, they appear to have more cognitive effort left over for doing other things than if they do not gesture on the task. Gesturing can ease the child's cognitive burden.

What might gesturing be doing to ease the child's cognitive burden? The act of conveying information, whatever that information might be, in a second modality may make the task easier for the child. In other words, using two modalities rather than one may be the key, independent of the type of information that is expressed. However, the message itself may matter. When gesture conveys the same information as speech, it could be making the task easier for the child by adding redundancy. On the other hand, when gesture conveys different information from speech, it could be making the task easier by providing a vehicle that allows the child to express thoughts that he or she cannot yet express in speech. Future analyses of how the gestured explanations the children produced in the hands-still study affect their recall of the word lists will hopefully allow us to explore these possibilities.

Gesture's Role in Cognitive Change

Gesture is implicated in cognitive change. It is, of course, possible that gesture is nothing more than an epiphenomenon of change, associated with it but not in any way central to its causes. However, evidence is mounting that gesture may be involved in the process of change itself, communicating silent aspects of the learner's cognitive state to potential agents of change, or helping more directly to ease the learner's cognitive burden.

If gesture is causally involved in change, its effect is likely to be widespread. Gesture has been found to express substantive information, often information that differs from the information expressed in the speech it accompanies, in a variety of tasks and over a large age range: in toddlers going through a vocabulary spurt (Gershkoff-Stowe & Smith, 1997); preschoolers explaining a game (Evans & Rubin, 1979); elementary school children explaining mathematical equations (Perry et al., 1988) and seasonal change (Crowder & Newman, 1993); children and adults discussing moral dilemmas (Church, Schonert-Reichl, et al., 1995); adolescents explaining Piagetian bending-rods tasks (Stone, Webb, & Mahootian, 1991); and adults explaining gears (Perry & Elder, 1996; Schwartz & Black, 1996) and problems involving constant change (Alibali, Bassok, et al., 1995, 1999). Some of the tasks on which gesture has been found might be considered to be core tasks in Gelman and Williams' (1998) terms, others are more likely to be noncore. The fact that gesture is found in both types of tasks may mean that it has the potential to be involved in innately driven as well as non-innately driven learning, that is, to be a general mechanism of change.

Previous studies have shown that asking children to explain their responses to a problem has a beneficial effect on learning (e.g., Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Siegler, 1997). Being forced to come up with an explanation encourages learners to articulate their, perhaps previously unexamined, presuppositions and to put their ill-formed ideas into words. This self-examination may be what is important in eliciting explanations from learners. Yet, requesting explanations may also be effective because it elicits gesture from the learner. Gesture offers the opportunity to explain in another modality, one that has very different representational demands and possibilities than does speech.

McNeill (1992) argued that gesture and speech form complementary components of a single, integrated system, with each modality best suited to expressing its own set of meanings. Gesture reflects a global-synthetic image. It is idiosyncratic and constructed at the moment of speaking—it does not belong to a conventional code. In contrast, speech reflects a linear-segmented, hierarchical linguistic structure, utilizing a grammatical pattern that embodies the language's standards of form and drawing on an agreed-on lexicon of words. Consider, for example, a speaker describing the coastline of the east coast of the United States. One well-formed gesture can do much more to convey the nuances of the coastline to a listener than even the best-chosen set of words (cf. Huttenlocher, 1976). Gesture thus allows speakers to convey thoughts that may not easily fit into the categorical system that their conventional language offers (GoldinMeadow & McNeill, 1999). Taken together, gesture and speech offer the possibility of constructing multiple representations of a single task, and these multiple perspectives may prove useful, particularly in learning complex tasks.

In addition, because gesture is not regulated by an acknowledged codified system, the notions that are expressed in this modality can easily go unchallenged. Rarely are speakers criticized for their gestures, while the same message expressed in speech may well elicit comment and disapproval. Not only are the notions conveyed in gesture likely to go unchallenged by others, but they are also likely to go unchallenged by the self. A speaker can sneak in an idea, perhaps an ill-formed one, in gesture that does not cohere well with the set of ideas expressed in speech. Gesture may be an ideal place to try out inchoate, untamed, and innovative ideas simply because those ideas do hot have to fit. Much experimentation may take place, and remain, in gesture, never reaching the conventionally shared spoken system; but the experimenation itself may be useful. Indeed, it may be that gesture is the place where we can expect to see children's worst guesses about how a task works.

Gesture is pervasive, routinely accompanying speech of all varieties. It is, however, not subjected to the same standards of approval as speech simply because it is not an explicit representational system in the same way speech is. On the other hand, gesture is symbolic in its own right. Gesturing about a procedure is not the same thing as enacting that procedure. Gesture reflects implicit knowledge that is at least one step removed from actually performing a procedure. Expressing knowledge in gesture may therefore represent an important step in the redescription process that Karmiloff-Smith (1992) describes, a process culminating in explicit awareness. As such, gesture has a unique status and may play a unique role in learning.

In sum, previous work has established that gesture is associated with learning. It can index moments of cognitive instability and reflect thoughts not yet found in speech. Here, I have raised the possibility that gesture might do more than just reflect learning—it might be involved in the learning process itself. I have considered two non-mutually exclusive possibilities. First, gesture could play a role in the learning process 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. Second, gesture could play a role in the learning process more directly by providing another representational format, one that would allow the learner to explore, perhaps with less effort, ideas that may be difficult to think through in a verbal format. Thus gesture has the potential to contribute to cognitive change, directly by influencing the learner and indirectly by influencing the learning environment.

ACKNOWLEDGMENTS

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