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Knowledge Conveyed in Gesture Is Not Tied to the Hands

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Children frequently gesture when they explain what they know, and their gestures sometimes convey different information than their speech does. In this study, we investigate whether children's gestures convey knowledge that the children themselves can recognize in another context. We asked fourth-grade children to explain their solutions to a set of math problems and identified the solution procedures each child conveyed only in gesture (and not in speech) during the explanations. We then examined whether those procedures could be accessed by the same child on a rating task that did not involve gesture at all. Children rated solutions derived from procedures they conveyed uniquely in gesture higher than solutions derived from procedures they did not convey at all. Thus, gesture is indeed a vehicle through which children express their knowledge. The knowledge children express uniquely in gesture is accessible on other tasks, and in this sense, is not tied to the hands.

INTRODUCTION

School-aged children are often able to explain how they solve a problem or perform a task. These verbal explanations are used by experimenters as a source of insight about the children's knowledge. However, there is widespread agreement that verbal reports do not capture all facets of an individual's knowledge—either because such knowledge is not tapped by the methods traditionally used to collect verbal protocol data (Ericsson & Simon, 1980, 1993) or because such knowledge may be inaccessible to verbal report (Berry & Broadbent, 1984; Nisbett & Wilson, 1977; Reber, 1993; Stanley, Mathews, Buss, & Kotler-Cope, 1989). Thus, it is often important to look beyond what children say to accurately characterize what they know.

How might we tap the unspoken knowledge that children may have? One potential source of information about unverbalized mental processes is the spontaneous gestures that accompany speech. If a child's gestures reflect knowledge that the child possesses but does not verbalize, then gestures–which are pervasive, overt, and interpretable—could be a potentially rich source of information about unverbalized knowledge. Indeed, many researchers have argued that gestures can convey substantive information and, as such, provide insight into a speaker's mental representations (Kendon, 1980; McNeill, 1985, 1987, 1992). For example, McNeill (1987) has found that speakers use hand gestures to depict both concrete images (e.g., the actions or attributes of cartoon characters) and abstract concepts (e.g., mathematical concepts, such as quotients, factors, and even limits in calculus).

Several lines of argument support the claim that gesture is a medium through which speakers convey their knowledge. The first is that gesture can be interpreted reliably and consistently. A substantial number of investigators have observed the spontaneous gestures that adults and children produce along with speech in conversations (Kendon, 1980), in narrative expositions (McNeill, 1992), in descriptions of objects and actions (Goldin-Meadow, McNeill, & Singleton, 1996), and in explanations, both in the classroom (Crowder & Newman, 1993) and in one-on-one tutorial situations (Church & Goldin-Meadow, 1986; Evans & Rubin, 1979; Perry, Church, & Goldin-Meadow, 1988). The gestures produced in these situations can be assigned meanings and, most important, independent observers tend to assign the same meaning to the same gesture.

In addition, studies have shown that a child's gestures can be used to predict that child's performance on a learning task. In this sense, gesture is a modality sensitive to at least some aspects of the child's knowledge. For example, Church and Goldin-Meadow (1986) studied the gestures that nonconserving children spontaneously produced when explaining Piagetian conservation tasks. Gestures were categorized according to whether the information they conveyed was the same as (i.e., matched) or different from (i.e., mismatched) the information conveyed in the accompanying speech. Church and Goldin-Meadow found that children varied in whether their gestures tended to match or mismatch their speech and, more important, that children who produced many mismatches were significantly more likely to profit from instruction in conservation than children who produced few

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mismatches. Perry et al. (1988) replicated this phenomenon with another concept, mathematical equivalence, which is the idea that the two sides of an equation represent the same quantity. They found that the proportion of gesture-speech mismatches a child produced on a pretest was a good predictor of how ready that child was to learn the principle of mathematical equivalence. Thus, gesture taken in relation to speech reflects a child's readiness to learn.

When a child produces a gesture-speech mismatch on a given problem, that child by definition conveys different information in gesture and speech. Surprisingly, the information the child expresses in gesture in such mismatches is typically not *ever* conveyed in speech during that assessment period, even across a series of test problems (Alibali & Goldin-Meadow, 1993; Goldin-Meadow & Alibali, 1995). This finding suggests that the child who produces mismatches possesses at least some knowledge that he or she cannot verbalize but can express in gesture, that is, knowledge that is uniquely expressed in gesture. However, this conclusion necessarily rests on the assumption that the child's gestures are an accurate reflection of what the child knows.

Indeed, all of the gesture-speech mismatch studies reported have been based on the assumption that gesture is a vehicle through which children can express meaning. The fact that these studies have yielded coherent results provides indirect evidence for this assumption. However, as yet there is no direct evidence that the particular meanings experimenters assign to a child's gestures are, in fact, the meanings the child intends. It is particularly important to verify that experimenters' interpretations of the meanings of children's gestures are accurate, because gesture has the potential to offer a *unique* source of insight into the mind of the child. In this study, we seek empirical evidence about the accuracy of experimenters' assessments of children's gestured knowledge.

The goal of this study is to establish whether children possess and can use the knowledge that experimenters attribute to them on the basis of their gestures. To address this issue, we assess the meanings of children's gestures, using a measure based not on experimenters' interpretations but, rather, on the children's own behavior. We used a task that draws on the conceptual knowledge that children express in gestures, but that does not, in itself, elicit gestures—a rating task. Rating tasks have often been used to tap knowledge that is not verbalized (e.g., Acredolo & O'Connor, 1991; Horobin & Acredolo, 1989; Siegler & Crowley, 1994). Furthermore, previous studies with rating tasks have shown that children frequently acknowledge more than one solution to a problem when they are explicitly permitted to do so.

In the present study, children were first asked to complete an *explanation task* in which they solved a set of mathematical equivalence problems and explained their solutions to those problems. This explanation task was later used to identify the set of procedures each child conveyed uniquely in gesture. After the explanation task, children were given a *rating task* in which they were asked to judge the acceptability of a variety of solutions to a second set of mathematical equivalence problems. Each solution was derived from one of six procedures that children commonly use to solve problems of this type. If gesture is a vehicle through which children express their knowledge—and if we experimenters are correct in our attempts to assess this knowledge—then on the rating task, children should judge procedures that they expressed uniquely in gesture on the explanation task as more "acceptable" than procedures they did not express at all.

METHOD

The Mathematical Equivalence Problems

Mathematical equivalence is the principle that one side of an equation represents the same quantity as the other side of the equation. Most fourth-grade children in American schools do not have a firm grasp of this principle, as evidenced by their incorrect solutions to problems of the form $5 + 3 + 4 = \_\_ + 4$ (Perry, 1985). When asked to explain their solutions, children typically describe the incorrect procedures they used to arrive at these solutions in their speech (Perry et al., 1988). Moreover, most children produce gestures along with their spoken explanations, and those gestures also convey specific procedures for solving the problems (Perry et al., 1988).

At times, the procedure a child conveys in gesture matches the procedure conveyed in the accompanying speech. For example, for the problem above, a child may indicate that he added all of the numbers to get the answer, both in speech (e.g., by saying, "I added 5 plus 3 plus 4 plus 4 equals 16") and in gesture (e.g., by pointing at the 5, the 3, the left 4, the right 4, and then the blank). At other times, the procedure the child conveys in gesture is *not* the same as the procedure conveyed in the accompanying speech. For example, a child may indicate that she added the numbers on the left side of the equation to get the answer (e.g., by saying "I added 5 plus 3 plus 4") but, in gesture, indicate that she considered all of the numbers in the problem (e.g., by pointing at the 5, the 3, the left 4, the right 4, and then the blank).

Thus, mathematical equivalence problems were an ideal task to use in pursuing our goal, because they met three important criteria: (1) when attempting to solve mathematical equivalence problems, children follow systematic (albeit incorrect) procedures; (2) children can describe these procedures in words when asked to explain how they solved the problems; (3) and children frequently use gestures along with their words and, at times, they convey procedures in gesture that are different from the procedures they convey in speech. The problems therefore allow us to probe whether the knowledge that a child expresses uniquely in gesture can be used by that child in another context—a rating task.

Participants

Sixty-four children drawn from fourth-grade classes of parochial schools throughout Chicago were screened for participation in the study. We excluded six children who solved the problems correctly (i.e., who solved three or more of the six problems correctly during the explanation task) to maximize the chances of observing children who expressed some procedures uniquely in gesture. In previous work, we have found that children tend to express procedures uniquely in gesture when they have not yet mastered mathematical equivalence but are on the verge of doing so (Alibali & Goldin-Meadow, 1993; Perry et al., 1988). One additional child was eliminated because the gestures she produced were off-camera and could not be coded, and two children were eliminated because they did not understand the rating task (i.e., they gave the same rating to all solutions). As a result, 55 children composed the final sample.

Procedure

Each child was tested individually. All components of the study were videotaped, except for the paper-and-pencil part of the explanation task.

Explanation task. Each child was given a paper-and-pencil test containing six addition equivalence problems (e.g., $6 + 3 + 8 = \_\_ + 8$). Upon completing the problems, the child accompanied the experimenter to a chalkboard. The experimenter then wrote the first problem of the test, along with the child's answer, on the board and asked the child to explain how he or she had come to this solution. This procedure was repeated for each of the six problems.

The rating task. The explanation task was followed by a rating task, administered by a second experimenter, in which each child was asked to rate possible solutions for a given problem. The experimenter told the child that more than one solution might be possible for a single problem and that the child could use four possible responses to rate "how good" each solution was: Right, Maybe Right, Maybe Wrong, and Wrong. The experimenter wrote a problem on the blackboard and wrote a possible solution in the blank. The experimenter then asked the child to rate the solution. For example, for the problem $3 + 4 + 5 = \_\_ + 5$, the experimenter wrote 17 in the blank and asked the child to rate this solution (17 is the solution one would get using the *Add-All* procedure, i.e., adding together all four numbers in the problem). The experimenter then wrote up a second possible solution derived from a different procedure, for example, 12 and asked the child to rate this solution (12 is the solution one would get using the *Add-to-Equal-Sign* procedure, i.e., adding together the three numbers on the left side of the equal sign). In this manner, the experimenter asked the child to rate six solutions, presented in random order, for each of six addition problems (i.e., 36 solutions in all).

The six solutions presented for each problem were derived from the six most common procedures 9- and 10-year-old children describe when explaining their responses to problems of this type (Perry et al., 1988). Three of the solutions were derived from incorrect procedures: (1) *Add-All:* add all four numbers (see above); (2) *Add-to-Equal-Sign:* add the numbers on the left side of the equal sign (see above); and (3) *Carry:* place one of the numbers from the left side of the equation in the blank (e.g., a solution of 3 for the problem $3 + 4 + 5 = \_\_ + 5$). The remaining three solutions were derived from correct procedures: (4) *Equalize:* make both sides of the equation sum to the same total (e.g., a solution of 7 for the same problem); (5) *Grouping:* group and add the two numbers that do not appear on both sides of the equation (e.g., again, a final solution of 7, reached by adding 3 plus 4); and (6) *Add-Subtract:* add up all of the numbers on the left side of the equation and subtract the number on the right side of the equation (e.g., again, a final solution of 7, reached by adding the numbers on the left side of the equation to get 12 and then subtracting 5). To distinguish the *Grouping* and *Add-Subtract* procedures from one another and from the *Equalize* procedure in the rating task, the experimenter put the numbers that represent the intermediate steps (e.g., $3 + 4$ for *Grouping* and $12 - 5$ for *Add-Subtract*) in the blank rather than the final solution. Note that, by putting numbers that represent an intermediate step in the blank, we are assuming that

Table 1 **Examples of the Six Target Procedures Conveyed in Speech or Gesture on the Explanation Task**

Type of Procedure	Speech	Gesture
Incorrect procedures:		
Add-All	"I added 3 plus 4 plus 5 plus 5 equals 17"	Point at 3, point at 4, point at 5, point at right 5, point at solution
Add-to-Equal-Sign	"I added 3 plus 4 plus 5 equals 12"	Point at 3, point at 4, point at left 5, point at solution
Carry	"They don't have another 3 like that so I put the 3 over there"	Point at the 3 on the left side of the equation, point at solution
Correct procedures:		
Equalize	"3 plus 4 plus 5 equals 12, so to make both sides equal, you need 7 more with the 5"	Sweep across the 3, 4, and 5 on left side of the equation, point to the equal sign, sweep across solution and 5 on the right side of equation
Grouping	"I just added 3 and 4 and put 7"	Hand grabs below the 3 and 4, point at solution
Add-Subtract	"I added 3 plus 4 plus 5 and that equals 12, and then I subtracted the 5 so the answer is 7"	Point at 3, point at 4, point at 5 on the left side of the equation, pause, hand pulls down under the 5 on the right side of equation, point at solution

Note: The math problem eliciting these explanations is: $3 + 4 + 5 = \_\_ + 5$.

the child has access to these steps. We consider the validity of this assumption in the "Results" section.

Coding Children's Explanations

The verbal explanations that children produced on the explanation task were coded according to the system described by Perry et al. (1988). Like the children in the Perry et al. study, the children in this study described in their speech the six target procedures described above—the three procedures leading to incorrect solutions to the math problems (Add-All, Add-to-Equal-Sign, Carry) and the three leading to correct solutions (Equalize, Grouping, Add-Subtract). Table 1 presents examples of spoken explanations conveying each of the six procedures. When coding the children's speech, the coder turned off the video portion of the tape and relied only on audio.

A second, independent coder then reviewed each of the explanations the child produced, this time coding it for gesture. When coding the children's gestures, the coder turned off the audio portion of the tape and relied only on video. Gestures were transcribed using the gestural lexicon established by Perry et al. (1988). Each of the six spoken procedures had a counterpart in gesture, as exemplified in Table 1.

The final step was to determine whether or not each child expressed each of the six target procedures and, if so, in which modality (speech or gesture). For each child, we first listed all of the target procedures that the child produced in speech across the entire set of six explanations. We then listed all of the target procedures that the same child produced in gesture across the set. The procedures found only on the gesture list were categorized as occurring in *gesture only.* The remaining procedures on the two lists were categorized as occurring in *speech* (with or without gesture). The target procedures that did not appear on either list were those that the child had *not conveyed* in either modality. Note that these categorizations were based on whether a procedure *ever* appeared in a given modality over the set of six problems. Thus, a procedure that was expressed in gesture but not in speech on a single problem would not have been categorized as *gesture only* unless it was not expressed in speech on any of the six explanations.

Reliability was assessed by having a second, independent coder assess a subset of the children's explanations. Agreement between the two coders was 98% ($n = 60$) for coding spoken explanations, 86% ($n = 58$) for coding gestured explanations, and 93% ($n = 56$) for determining the modalities in which a procedure was conveyed over the set of six problems.

Calculating Acceptability Ratings for the Six Procedures

Each child made judgments on six solutions derived from each of the six target procedures listed in

Table 1 (for a total of 36 ratings, one for each procedure for each of the six problems). To calculate the mean rating for the solutions derived from a given procedure, we determined how many ratings of each type (Right, Maybe Right, Maybe Wrong, and Wrong) a child produced for the six solutions derived from that procedure. Right responses were assigned a score of 4, Maybe Right a score of 3, Maybe Wrong a score of 2, and Wrong a score of 1, and a mean was calculated across the six solutions. Thus, each child was assigned a mean acceptability rating (ranging between 1 and 4) for each of the six target procedures.

RESULTS

Children used a variety of procedures to solve the problems on the explanation task. As in previous studies (e.g., Alibali & Goldin-Meadow, 1993), all children expressed at least one procedure in speech (with or without gesture), and some children also expressed one or more procedures uniquely in gesture (and never in speech). Children were divided into two groups based on the modalities in which they expressed the six target procedures on the explanation task. Children were classified in Group 1 if they expressed all of their target procedures in speech, with or without gesture, $n = 37$, M age = 9,5, 16 males and 21 females. Children in Group 1 produced an average of 1.2 ($SD = 0.4$) of the six target procedures in speech (with or without gesture) and, by definition, produced none of these six procedures uniquely in gesture.[1]

Children were classified in Group 2 if they conveyed some of the target procedures in speech and others *only* in gesture, over the entire set of six explanations ($n = 18$, M age = 9,5, 10 males and 8 females). Note that a procedure conveyed in gesture but not speech on a given response could, but need not, be unique to gesture in a particular child's repertoire. In order for a procedure to be considered unique to gesture, it had to appear only in gesture across *all six* of the child's explanations. Children in Group 2 produced an average of 1.4 ($SD = 0.6$) of the six target procedures in speech (with or without gesture) and an average of 1.2 ($SD = 0.4$) of the six target procedures uniquely in gesture.[2] Children in Group 2 consequently produced more target procedures in total than did children in Group 1, Ms 2.6 ($SD = 0.6$) versus 1.2 ($SD = 0.4$). Consistent with previous findings (Alibali & Goldin-Meadow, 1993; Goldin-Meadow, Alibali, & Church, 1993), the "extra" procedures the children in Group 2 produced tended to be expressed uniquely in gesture.

For our purposes, the critical analysis evaluates children's performance on the rating task in relation to their performance on the explanation task. We sought to determine whether children's acceptability ratings varied as a function of the modality in which they expressed procedures on the explanation task. Specifically, we wished to explore whether information conveyed in children's gestures would be rated differently from information not conveyed at all. This comparison is only possible among children in Group 2, who produced at least some procedures uniquely in gesture. However, before addressing this issue, we sought first to establish whether the ratings are a valid measure of children's knowledge. To assess the validity of the rating measure, we examined the ratings produced by children in Group 1, who conveyed all their target procedures in speech.

Validating the Acceptability Rating as a Measure of the Child's Knowledge

As described above, all of the 1.2 target procedures that the 37 children in Group 1 produced on the explanation task appeared in *speech* (with or without gesture). In addition, each child failed to produce one or more of the six target procedures; that is, for each child, there were some procedures ($M = 4.8$, $SD = 0.4$) that were *not conveyed* at all.

For each child, we calculated mean acceptability ratings for (1) solutions derived from procedures they conveyed in speech, and (2) solutions derived from procedures not conveyed at all. Not surprisingly, children gave significantly higher ratings to solutions derived from procedures they conveyed in speech ($M = 2.92$, $SD = 0.76$) than to solutions derived from procedures they did not convey at all, $M = 1.77$, $SD = 0.57$; paired $t(36) = 6.09$, $p < .001$.

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[1] The children in Group 1 did produce a small number of explanations in which the procedure conveyed in gesture was different from the procedure conveyed in speech (i.e., gesture-speech mismatches, $M = 1.0$, $SD = 1.5$). Although an average of 0.4 ($SD = 0.7$) of these mismatches contained procedures that were unique to gesture, none of these were among the six target procedures. Thus, these children had produced *no* procedures unique to gesture that could be tested on the rating task and, as a result, they qualified for Group 1.

[2] The children in Group 2 produced an average of 3.0 ($SD = 1.3$) gesture-speech mismatches. These mismatches contained an average of 1.8 procedures ($SD = .9$) that were conveyed uniquely in gesture. Of these 1.8 procedures, 1.2 ($SD = .4$) were among the six target procedures tested on the rating task.

This finding suggests that the acceptability ratings are indeed a valid measure of children's knowledge.

Do Children Accept Solutions Derived from Procedures That They Convey Uniquely in Gesture?

We turn now to the ratings provided by the 18 children in Group 2 who conveyed some of the target procedures in gesture only on the explanation task. As described above, children in this group conveyed an average of 1.2 target procedures in *gesture only*, and 1.4 target procedures in *speech* (with or without gesture). In addition, for each of the children, at least two target procedures ($M = 3.4$, $SD = 0.6$) were *not conveyed* in either modality.

We first examined each child's acceptability ratings for solutions derived from procedures they conveyed in speech versus procedures not conveyed at all to determine whether the child had used the rating scale appropriately. In fact, one child was found to rate procedures he did *not* convey as more acceptable than procedures he did convey, suggesting that his ratings were not accurate reflections of his knowledge. This child was eliminated from the subsequent analyses. Each of the remaining 17 children in Group 2 thus gave higher ratings for solutions given in speech than for solutions given in neither speech nor gesture, Ms $= 2.99$ ($SD = 0.7$) versus 1.55 ($SD = 0.5$).

For our interests, the critical test compared the ratings children gave to (1) solutions derived from procedures they conveyed uniquely in gesture (i.e., in gesture but never in speech) and (2) solutions derived from procedures they did not convey at all. As predicted, these 17 children gave significantly *higher* ratings to solutions derived from procedures they conveyed in gesture only ($M = 2.05$, $SD = 0.83$), than to solutions derived from procedures not conveyed at all, $M = 1.55$, $SD = 0.52$; paired $t(16) = 4.14$, $p < .001$; see Figure 1. The fact that the children rated procedures they conveyed only in gesture higher than procedures not conveyed at all suggests that knowledge expressed uniquely in gesture, although never spoken, can nevertheless be accessed and utilized. In this sense, children's gestures reflect substantive knowledge that they possess and that they can use in another context.[3]

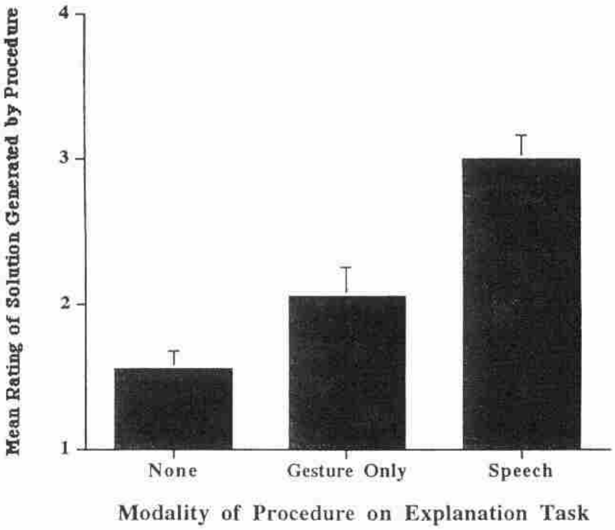

Figure 1 Ratings given by children who conveyed some of the target procedures in speech and others in gesture only. The children rated solutions generated by procedures that they produced in gesture only on the explanation task higher (i.e., more acceptable) than solutions generated by procedures that they did not produce at all on the explanation task. In addition, the children rated solutions generated by procedures that they produced in speech on the explanation task higher than solutions generated by procedures they produced in gesture only. The error bars reflect standard errors.

We also found that information children convey uniquely in gesture is *less* likely to be accessed than information they convey in speech (with or without gesture). The mean rating for solutions derived from procedures conveyed in gesture only ($M = 2.05$, $SD = 0.83$) was significantly *lower* than that for solutions derived from procedures conveyed in speech, $M = 2.99$, $SD = 0.69$; paired $t(16) = 3.29$, $p < .005$; see Figure 1. Thus, solutions derived from procedures children conveyed uniquely in gesture were rated higher than solutions derived from procedures they did not convey, but lower than solutions derived from procedures they conveyed in speech.

In considering these results, it is important to recall that the solutions we used on the rating task to represent two of the correct procedures (Grouping and Add-Subtract) were not the final solution to the

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[3] The same pattern holds if the data are analyzed using categorical methods, with the proportion of ratings at a given level as the dependent variable (rather than the average rating, as used in the paired t tests reported in the text). Children rated a higher proportion of solutions as "Right" for procedures they conveyed in gesture than for procedures that were not conveyed, $T+ = 58$, $n = 11$, $p < .02$, Wilcoxon Signed Ranks test. Similarly, children rated a higher proportion of solutions as either "Right" or "Maybe Right" for procedures they conveyed in gesture than for procedures that were not conveyed, $T+ = 96$, $n = 14$, $p < .005$, Wilcoxon Signed Ranks test. Finally, children rated a higher proportion of strategies as either "Right," "Maybe Right" or "Maybe Wrong" (i.e., any rating other than "Wrong") for procedures they conveyed in gesture than for procedures that were not conveyed, $T+ = 110$, $n = 15$, $p < .002$, Wilcoxon Signed Ranks test. Ns are reduced due to ties.

problem but rather were intermediate steps taken along the way (e.g., we used $3 + 4$ and $12 - 5$ rather than 7 for the problem $3 + 4 + 5 = \_ + 5$). We used these intermediate steps so that we could distinguish Grouping and Add-Subtract from one another and from Equalize, because all three of these procedures lead to the same correct solution. However, it is possible that children do not have access to these intermediate steps (even though they may have used them) and thus might not rate them as acceptable on our task. Moreover, the final solution (7 in this example) should, in principle, also be rated as acceptable (along with the intermediate steps) by children who used Grouping and Add-Subtract. In addition, children who conveyed the Equalize procedure (make both sides of the equation equal) might have actually solved the problem by going through the intermediate steps associated with Grouping and Add-Subtract ($3 + 4$ or $12 - 5$); if so, they might find these solutions, as well as the final solution, acceptable. As a result, any of the correct solutions might, in principle, be acceptable to children who solve the problem using any of the three correct procedures. Thus, it is possible that our findings could be an artifact of the potentially arbitrary pairings that we made between particular correct procedures and particular solutions.

To deal with this issue, we reanalyzed the data for each comparison. Rather than pairing a particular correct solution with a particular correct procedure, we considered any of the three correct solutions on the rating task (e.g., 7, $3 + 4$, or $12 - 5$ for the problem $3 + 4 + 5 = \_ + 5$) to be possible solutions for any of the three correct procedures on the explanation task (Equalize, Grouping, or Add-Subtract). Thus, if a child conveyed Grouping in gesture only on the explanation task, that child's ratings for all three correct solutions (7, $3 + 4$, and $12 - 5$) would be averaged together to generate a single rating for the child's procedures in gesture only.

The results were unchanged. The rating for solutions derived from procedures conveyed in gesture only ($M = 1.86$, $SD = 0.80$) was significantly higher than the rating for solutions derived from procedures not conveyed at all, $M = 1.25$, $SD = 0.28$; paired $t(15) = 4.08$, $p < .001$, and significantly lower than the rating for solutions derived from procedures conveyed in speech, $M = 3.03$, $SD = 0.69$, paired $t(15) = 4.10$, $p < .001$.[4] Thus, even when we collapse the data for the correct procedures and consider any of the three correct solutions to be derived from any of the three correct procedures, children judged procedures that they conveyed uniquely in gesture as more acceptable than procedures that they did not convey at all.

We have argued that children rated solutions derived from procedures that they expressed uniquely in gesture as more acceptable than solutions derived from procedures that they did not express at all. However, because many children expressed correct procedures uniquely in gesture, it is also possible that our findings could be due to children's rating *correct* solutions higher than incorrect ones. To address this issue, we reanalyzed the data once again, this time eliminating the ratings for all of the solutions derived from correct procedures (that is, using only the ratings of solutions derived from the three incorrect procedures; we therefore included in this analysis only those eight children who conveyed *incorrect* procedures in gesture only on the explanation task). The data confirm the robustness of the phenomenon. Again, the average rating for solutions derived from procedures conveyed in gesture only ($M = 2.31$, $SD = 0.90$) was significantly higher than that for solutions derived from procedures not conveyed at all, $M = 1.17$, $SD = .25$; paired $t(7) = 4.03$, $p < .005$, and lower (although not significantly) than that for solutions derived from procedures conveyed in speech, $M = 3.17$, $SD = 0.62$; paired $t(7) = 1.88$, $p = .10$. Thus, even when we restrict the sample to children who conveyed incorrect procedures in each modality, children judged procedures that they conveyed uniquely in gesture as more acceptable than procedures that they did not convey at all.

DISCUSSION

This study demonstrates that the gestures children produce when explaining mathematical equivalence problems are *not* random movements of the hands. Instead, the gestures reveal substantive knowledge that children possess—knowledge that not only is evident to experimenters who interpret children's explanations but that also can be utilized by children themselves on another task that does not involve gesture at all. In this study, children who expressed problem-solving procedures uniquely in gesture on an explanation task were able to draw upon this knowledge when they performed a rating task in

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[4] One of the 17 children was dropped from the reanalysis because, after his correct explanations were reclassified, he no longer produced a procedure uniquely in gesture. In the reanalysis, in order for a child to be classified in the gesture only category for correct procedures, that child had to produce no correct procedures at all in speech. This child produced a correct procedure in speech along with a (different) correct procedure in gesture, and thus did not meet the criterion.

which gesture played no role. They rated solutions derived from procedures that they expressed uniquely in gesture as more acceptable than solutions derived from procedures that they did not express at all. This finding provides direct evidence that gesture is a vehicle through which children express knowledge that they can call upon in other contexts.

The Experimenter's Best Guess at the Meaning of a Child's Gestures Is an Accurate One

Our data underscore an important methodological point—the particular meanings that we experimenters assigned to the children's gestures were indeed the meanings the children intended. In this and in previous studies, the system we use to code the children's gestural explanations on the mathematical equivalence explanation task has been shown to result in reliable data. That is, when one experimenter attributed a particular meaning to a gesture, a second experimenter was very likely to attribute this same meaning to the gesture. However, until now, it has been an open question whether the child who produced the gesture intended to convey this particular meaning (i.e., whether the interpretations were valid).

In this study, the gestures the children produced on the explanation task were classified according to the particular procedure the experimenter thought the gestures conveyed. On a separate and independently administered rating task, the children were asked to judge the acceptability of a standard set of solutions derived from procedures that children typically use in math problems of this type. We found that a child was likely to judge a solution acceptable if that solution could be derived from a procedure that we had attributed to the child based uniquely on the gestures the child produced on the explanation task. Thus, the child's judgments on the rating task verified our classifications of that child's gestures on the explanation task. In addition, the fact that there was a systematic relation between the child's rating of a *solution* and the presence of the *procedure* that generated that solution in the child's explanations (a relation that held even for procedures expressed only in gesture) suggests that we are justified in attributing *procedural* meanings to the child's gestures. That is, the present results support the view that children's gestures reflect their knowledge of problem-solving procedures.

In sum, these findings verify that the particular meanings the experimenters assigned to the children's gestures were, in fact, the meanings the children intended. The study thus buttresses a research methodology that captures knowledge that would be missed using a purely verbal protocol.

Knowledge Conveyed Only in Gesture: Is It Tied to the Hands?

In many of the explanations given in our study, the children conveyed one procedure in gesture and a different procedure in speech. Moreover, when children produced such mismatches, they often did not produce the gestured procedure in *any* of their spoken explanations across the set of problems—thus, the procedure was conveyed *uniquely* in gesture. Thus, at that particular moment in the child's understanding of mathematical equivalence, knowledge of the procedure appeared to be encoded uniquely in a nonverbal representational system and not in a verbal one. What is the status of such knowledge, detectable only if one looks at, as well as listens to, the child?

In previous work, we have argued that the gestures children produce in problem explanations reflect their emerging knowledge (Alibali, Garber, & Goldin-Meadow, 1993). Two pieces of evidence support this view. First, when children generate new procedures for solving problems, they initially express these new procedures uniquely in gesture, particularly when they are generated in the absence of direct instruction (Alibali, 1997). Second, the knowledge conveyed in gesture during such transitional periods often foreshadows the child's next developmental step. Church and Goldin-Meadow (1986) found that the strategies children expressed in gesture prior to training on a conservation task were precisely the strategies that the children spontaneously produced after training. Taken together, these studies suggest that children's gestures reflect their first steps in learning a concept.

We argue here that this emerging knowledge, which is initially expressed only in gesture, is neither fully implicit nor fully explicit. Instead, gestures that mismatch speech represent a middle point along a continuum of knowledge states that ranges from the fully implicit and embedded in problem-solving procedures, to the fully explicit and accessible to verbal report (see Goldin-Meadow & Alibali, 1994; Karmiloff-Smith, 1986, 1992). As the present study has shown, knowledge expressed uniquely in gesture is not fully implicit. Children do have access to this knowledge, and they can apply it in another task.

However, we suggest that the knowledge expressed in gesture is also not fully explicit, simply because in many instances it is not found anywhere in a child's speech and thus appears to be inaccessible to verbal report (Alibali & Goldin-Meadow, 1993). Consistent with this interpretation, children in the present study rated solutions derived from procedures they expressed in gesture lower than solutions derived from procedures expressed in speech. It is, of course, not possible to show that children *cannot* verbalize the knowledge that they convey uniquely in gesture, but only that they *do not* do so. In this study, when we assigned children's procedures to modality categories, we considered all six of their problem explanations. Children were classified as expressing problem-solving information uniquely in gesture only if they did not produce that information in speech in any of the six explanations. Thus, the procedures the children expressed uniquely in gesture were, at the least, unverbalized throughout the study.

We argue that knowledge expressed uniquely in gesture is represented in a symbolic but nonverbal format. Further, we suggest that the likely developmental course for such knowledge is to be transformed into a verbalizable format. However, we stress that this process is not merely one of "translating" gesture into words. If so, it would not require the state of readiness that has been found to be necessary for the transformation process to take place (cf. Alibali & Goldin-Meadow, 1993; Goldin-Meadow et al., 1993). Rather, the process is truly one of transformation—the knowledge must be reencoded and altered from a format that is easily conveyed in gesture into the codified format that speech demands. If this view is correct, then having the ability to convey knowledge in gesture marks an important step along the route to full understanding. In summary, we have shown that the gestures children produce in their explanations of mathematics problems are not random movements of the hands. Instead, gestures reveal children's substantive knowledge about the problems. Furthermore, even though children do not express this knowledge in speech, they can recognize it in another context. In this sense, knowledge conveyed uniquely in gesture is not tied to the hands.

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