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Teachers' gestures facilitate students' learning: A lesson in symmetry

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Abstract

This study investigated whether teachers' gestures influence students' comprehension of instructional discourse, and thereby influence students' learning. Pointing and tracing gestures "ground" teachers' speech by linking abstract, verbal utterances to the concrete, physical environment. We hypothesize that such grounding should facilitate students' comprehension, and therefore their learning, of instructional material. Preschool children viewed one of two videotaped lessons about the concept of symmetry. In the verbal-plus-gesture lesson, the teacher produced pointing and tracing gestures as she explained the concept. In the verbal-only lesson, the teacher did not produce any gestures. On the posttest, children were asked to judge six items as symmetrical or asymmetrical, and to explain their judgments. Children who saw the verbal-plus-gesture lesson scored higher on the posttest than children who saw the verbal-only lesson. Thus, teachers' gestures can indeed facilitate student learning. The results suggest that gestures may play an important role in instructional communication.

1. Introduction

Students do not always understand what their teachers try to tell them. What factors influence whether or not students comprehend and learn from

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instructional discourse? It seems likely that the same factors that influence listeners' comprehension of oral language might influence students' comprehension of instructional discourse. One such factor is the non-verbal support for language comprehension that is provided by speakers' gestures. Previous studies have shown that speakers' gestures facilitate listeners' comprehension of speech, particularly when the verbal message is ambiguous (Thompson & Massaro, 1986), highly complex (Graham & Heywood, 1976; McNeil, Alibali, & Evans, 2000), or uttered in a soft voice (Berger & Popelka, 1971).

Students' comprehension may be challenged by instructional discourse that presents new concepts and uses unfamiliar terms. This study investigates whether teachers' gestures influence students' comprehension of instructional discourse, and thereby influence students' learning. Most previous research on gesture in instructional settings has focused on *children*'s gestures (e.g., Crowder, 1996; Crowder & Newman, 1993; Moschkovich, 1996; Perry, Church, & Goldin-Meadow, 1988) or on whether teachers can glean information from children's gestures (e.g., Alibali, Flevares, & Goldin-Meadow, 1997; Goldin-Meadow, Wein, & Chang, 1992). In contrast, the goal of the present study is to investigate whether children glean information from *teachers*' gestures. We focus on the role of gesture in conveying substantive information relevant to the lesson content, rather than regulatory information (e.g., facilitating turn-taking in classroom interaction) or affective information (e.g., information about attitudes, immediacy, or warmth; Andersen & Andersen, 1982).

There is ample evidence that speakers' gestures can convey meaning in ordinary face-to-face interactions (see Kendon, 1994; for a review). Furthermore, previous research has documented that teachers do indeed use gestures in classroom settings (Flevares & Perry, 2001; Neill, 1991; Neill & Carswell, 1993; Zukow-Goldring, Romo, & Duncan, 1994). However, as yet, there is little empirical evidence about whether teachers' gestures actually affect students' *learning*. Only two studies to our knowledge have directly examined the influence of teachers' gestures on students' understanding (Berch, Singleton, & Perry, 1995; Goldin-Meadow, Kim, & Singer, 1999). Both focused on students learning to solve mathematical equivalence problems (e.g., $3+4+5=3+\_\_$), and both focused on individual interactions between a student and another person. One study examined students' learning from real teachers naive to the experimental hypothesis (Goldin-Meadow et al., 1999), and the other examined students' learning from an experimenter who served as the instructor (Berch et al., 1995).

The Goldin-Meadow et al. (1999) study focused on students' "uptake" of information from the preceding conversational turn. The primary finding was that students were more likely to reiterate the information the teacher conveyed in speech on the preceding turn when the teacher's speech was accompanied by a *matching* gesture, which was defined as a gesture that conveyed the same information as speech, and therefore reinforced the verbal message. In addition, students were less likely to reiterate the information the teacher conveyed in speech on the preceding turn when the teacher's speech was accompanied by a *mismatching* gesture, defined as a gesture that conveyed different information from speech, and therefore did not reinforce the verbal message. Goldin–Meadow et al. concluded that gesture facilitated children's comprehension of teachers' speech when it matched speech, and hindered children's comprehension of teachers' speech when it mismatched speech. However, Goldin–Meadow et al. did not examine whether students' uptake of teacher's information predicted whether or how much students learned from the tutorial interaction.

Berch et al. (1995) compared students' learning from speech accompanied by gesture and speech alone. Students initially received one of two lessons about mathematical equivalence, one that included gestures and one that did not. Following the lesson, students completed a posttest, and students who did not succeed on the posttest then received the other of the two lessons. The primary finding was that more students succeeded on the problems after the verbal-plus-gesture lesson than after the verbal-only lesson. However, the differences were small at each time point, and no statistical analysis was reported, so no firm conclusions can be drawn.

The goal of the present study was to examine the effects of teachers' gestures on children's learning. To address this issue, we selected the concept of bilateral symmetry as the target concept. We chose this concept for three reasons. First, previous work on gesture and learning has focused primarily on mathematical problem solving in the elementary grades. We wished to extend this research to a new task and age group. Second, the concept of bilateral symmetry is fairly simple and can be readily learned by young children, but it is often not directly taught until the early elementary grades. Therefore, we expected that preschool students would not already be familiar with the concept. Third, we wished to use a concept that teachers would ordinarily explain using gestures. Because symmetry is a visuo-spatial concept, it fulfilled this criterion. Indeed, because gestures are themselves visuo-spatial, they may be especially important for communicating about visuo-spatial concepts.

To decide what types of teacher gestures to include in our experiment, we drew on previous research that examined gesture production among real teachers in real classroom settings. One such study showed that teachers frequently use pointing and tracing gestures (Alibali, Sylvan, Fujimori, & Kawanaka, 1997; see also Fujimori, 1997). These investigators analyzed five fifth-grade geometry lessons about how to find the area of a triangle. The lessons had been videotaped in real mathematics classrooms, three in the United States and two in Japan, and were drawn from a dataset collected by Jim Stigler and Giyoo Hatano. Both American and Japanese teachers used gestures primarily to guide students' attention. For example, one American teacher said, "There's another way of writing this" while pointing to a formula written on the board. As a second example, one Japanese teacher said, "See this triangle?" (*Kono sankakkei arimasune*) while tracing the perimeter of a triangle that had been drawn on the board. We suggest that such gestures "ground" teachers' talk by linking the abstract, verbal utterance to the concrete, physical environment. We hypothesize that such grounding should facilitate student's comprehension, and therefore their learning, of instructional material. Therefore, the lessons that we constructed for the present experiment varied the teacher's use of pointing and tracing gestures.

We compared children's learning from two lessons, one that included gestures and one that did not. In the verbal-only lesson, the teacher did not produce any gestures. In the verbal-plus-gesture lesson, the teacher used pointing and tracing gestures, such as pointing to individual shapes or tracing shapes' features. The audio portion of the lesson was *identical* in the two conditions. We hypothesized that children would learn more when teachers used gesture to ground their instructional discourse; therefore, we predicted that children in the verbal-plus-gesture lesson group would be better able than children in the verbal-only lesson group to identify symmetrical and asymmetrical items in a posttest. Furthermore, we predicted that children in the verbal-plus-gesture lesson group would be better able to explain why items are or are not symmetrical. Finally, because pointing and tracing gestures are used to guide students' attention, we hypothesized that students would pay more attention to the verbal-plus-gesture lesson than to the verbal-only lesson.

2. Method

2.1. Participants

Participants were 25 children (12 boys and 13 girls) from two classrooms at a university laboratory preschool. The sample was predominantly Caucasian (84%) and predominantly middle to upper-middle class. The children ranged from 4 years, 2 months, to 5 years, 3 months, with a mean age of 4 years, 6 months.

2.2. Procedure

Children were brought individually to a testing room that contained a table, two chairs and a small television-VCR unit. A video camera was set up approximately 6′ from the table. The child sat in front of the television-VCR, and the experimenter sat across from the child.

2.2.1. Pretest

At the beginning of the session, the experimenter asked the child, "Do you know what it means for something to be symmetrical?" If the child said yes, the experimenter asked the child to explain. Next, each child was given a sheet of paper that contained four pictures: a cross, a letter C, a mitten, and a heart. The symmetrical items (the heart and the cross) were symmetrical only about the vertical axis, and the asymmetrical items (the mitten and the letter C) were asymmetrical about both the horizontal and vertical axes (the letter C that was used was pointed at the bottom and rounded at the top). The child was asked to circle all the symmetrical items.

2.2.2. Lesson

Children were randomly assigned to watch either a verbal-only video lesson ($N = 13$) or a verbal-plus-gesture video lesson ($N = 12$). In both lessons, a female teacher explained the concept of symmetry with respect to five shapes, two symmetrical and three asymmetrical, which were attached to the wall and visible in the video (see Fig. 1). Each of the five shapes was referenced during the lesson as an example of either a symmetrical or an asymmetrical shape. The shapes were numbered and were referred to by their numbers (e.g., "shape number one") in the teachers' speech. The asymmetrical shapes represented three different violations of symmetry, which the teacher explained. As seen in Fig. 1, one shape had an extra feature (an oval at one end), one had a mismatching feature (a square rather than an oval), and one had a non-mirror relation (two ovals that were not in mirror-image positions).

In the *verbal-plus-gesture* lesson, the teacher produced pointing and tracing gestures toward the shapes as the concept was explained. The teacher used gestures to indicate the shapes, to delineate the center of each shape, and to show a comparison between the two sides of each shape. In the *verbal-only* lesson, the teacher stood next to the shapes, but did not produce any gestures. The two lessons used the *same audio track*.[1] Thus, the lessons were identical except for the teacher's use of gesture. For each of the asymmetric shapes, the lesson focused on the specific violation of symmetry represented by the shape (extra feature, mismatching feature, or non-mirror relation). A portion of the script is provided in the Appendix.

In both groups, the experimenter and the child watched the video lesson together. If the child asked questions during the video, the experimenter declined to answer.

[1] The audiocassette was made during the initial videotaping of the verbal-plus-gesture lesson. To make the verbal-only lesson, this audio recording was played, and the teacher moved her lips along with the words. Thus, the audio track was identical in the two lessons.

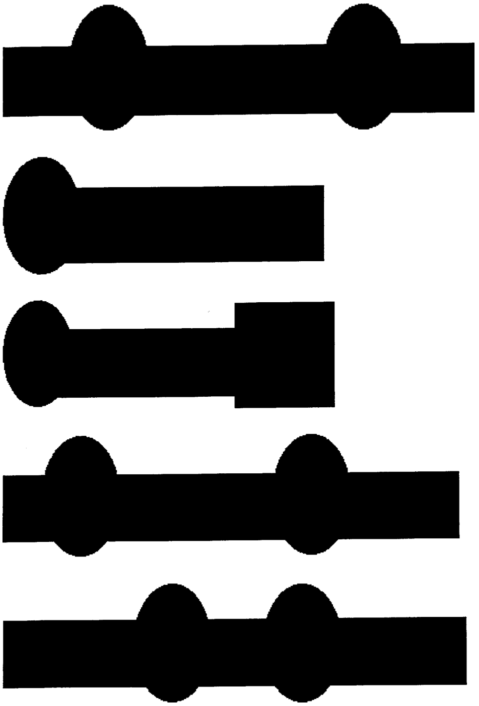

Fig. 1. The five shapes used in the video lessons. The first and the fifth shapes are symmetrical, the second shape is asymmetrical due to an extra feature, the third shape is asymmetrical due to a mismatching feature, and the fourth shape is asymmetrical due to a non-mirror relation between the sides.

2.2.3. Posttest

In the posttest, children were presented with a set of six line drawings of familiar objects (see Fig. 2): a leaf, a pair of pants, a diamond ring, a pair of feet, a cup, and a wristwatch. Each item was laminated and cut in half. The asymmetrical items represented the same three violations of symmetry that were discussed in the lesson: the cup had an extra feature, the wristwatch had a mismatching feature, and the pair of feet had a non-mirror relation.

The experimenter placed the 12 item-halves on the table in front of the child, and asked the child to match the items back together. No child took longer than three minutes to match all the items. After the child completed the matching task, the experimenter corrected any matching errors. Next, the experimenter and child looked at each of the items in turn. For each item, the experimenter first made sure that the child knew the name of the item, saying, “Do you know what this is?” If the child provided an incorrect label or was not sure, the experimenter provided the correct label, saying, “It’s a {ring, leaf, wristwatch, cup, pair of pants, pair of feet}.” Next, the

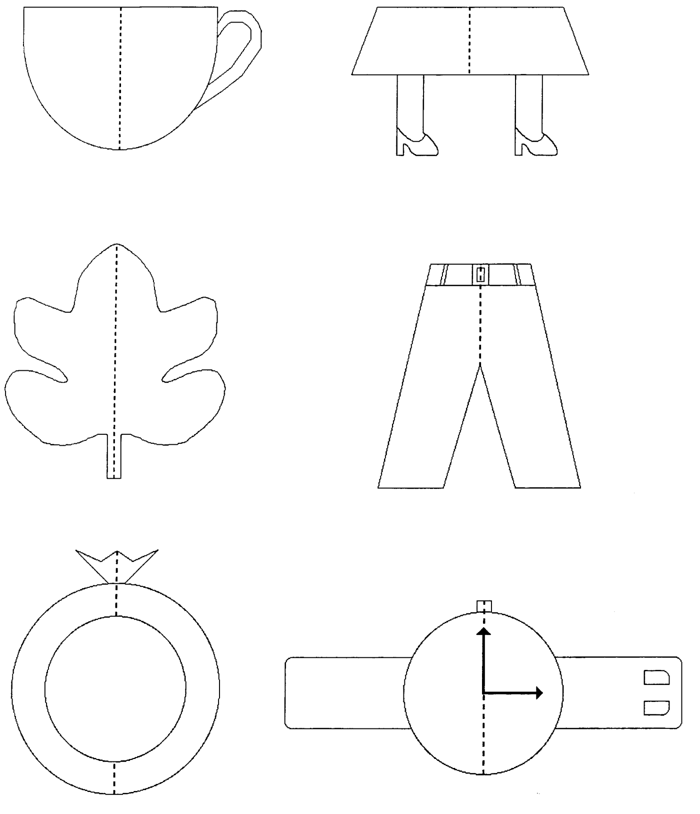

Fig. 2. The six items used on the posttest that followed the lesson. The dotted line on each item indicates where the item was halved for the matching task. The ring, pair of pants, and leaf are symmetrical. The cup is asymmetrical due to an extra feature, the wristwatch is asymmetrical due to a mismatching feature, and the pair of feet is asymmetrical due to a non-mirror relation.

experimenter asked the child whether each item was symmetrical or not symmetrical, and asked the child to explain his or her reasoning, saying, "Why do you think that the {name of item} is {symmetrical/not symmetrical}?" Children's answers were transcribed from the videotape of the session.

2.3. Coding

2.3.1. Symmetry judgments

Children were assigned one point for each correct judgment of whether an item was symmetrical or not symmetrical. Judgment scores ranged from 0 to 6. Note that this measure considers only the child's judgment and not the explanation provided for that judgment.

2.3.2. Symmetry explanations

Three aspects of children's symmetry explanations were coded: (1) content; (2) correctness; and (3) presence of gesture. In the content coding, each explanation was classified into one of the following five categories: (1) *Sides* explanations focus on the identity or non-identity of the two sides of the item; (2) *Mirror* explanations focus on the mirror relation between the two sides, or the lack thereof; (3) *Halves* explanations focus on the fact that the item could be or is split in half; (4) *Irrelevant* explanations focus on something irrelevant to the task; and (5) *Don't know* explanations express lack of knowledge or failure to respond. Examples of responses of each type are presented in Table 2.

Each explanation was also scored as either correct or incorrect. To be scored as correct, the explanation needed to invoke one of the symmetry concepts taught in the video, namely either the identity or non-identity of the sides (e.g., "Because they're the same sides"), or the mirror relation of the sides or lack thereof (e.g., "Because there are two things that go backwards"). Thus, only responses that received a content code of *Sides* or *Mirror* could be classified as correct. In addition, the explanation needed to invoke the concept correctly with respect to the item being explained. For example, for the cup, which was asymmetrical, an explanation that invoked the *non-identity* of the sides (e.g., "Because this side has a handle and this side doesn't") was scored as correct, but an explanation that invoked the *identity* of the sides (e.g., "Because it's the same sides") was scored as incorrect. Note that children received points for correct explanations both for asymmetrical items and for symmetrical ones. Children's explanation scores ranged from 0 to 6.

Finally, each child's explanation for each item was also coded as either including one or more spontaneous gestures or not including gestures. Most of the gestures that children produced were pointing or tracing gestures.

2.3.3. Head turns

As a rough measure of children's attention to the video lessons, the number of times each child turned his or her head away from the video during the lesson was coded.

2.4. Reliability

To establish reliability on coding symmetry explanations, a second coder rescored the data for a subsample of seven children from the verbal transcripts. Agreement between coders was 88% for the content codes and 93% for correctness ($N = 42$ explanations). To establish reliability on head turns, a second coder viewed the videotapes for a subsample of seven children and rescored the data. The correlation between coders was $r = .94$.

3. Results

3.1. Pretest performance

None of the children succeeded on both parts of the pretest. When asked what it means for something to be symmetrical, two children provided a reasonable answer. However, both of these children circled non-symmetrical items when asked to find the items that were symmetrical on the pretest worksheet (one circled the mitten, and the other circled both the mitten and the letter C). Another child circled the correct items (the cross and the heart) when asked to find the items that were symmetrical; however, this child did not provide a reasonable answer when asked to explain what it means for something to be symmetrical.

3.2. Posttest performance

To evaluate posttest performance, we assessed the number of items for which each child both made a correct judgment *and* provided a correct explanation. This is a stringent measure of success, and it is unlikely to be contaminated by guessing or by simple repetition of the teacher's words. We also report results for children's symmetry judgments on their own (i.e., not in conjunction with explanations), and we describe general patterns in children's symmetry explanations.

For all statistical analyses, we assessed performance both across participants and across items. Because all hypotheses were directional, one-tailed tests of significance were used. Cohen's d was used to index effect sizes.

3.2.1. Combined judgments and explanations

Children in the in the verbal-plus-gesture lesson condition provided correct judgments and explanations on more items than did children in the verbal-only lesson condition ($M = 2.08$, $SE = 0.57$, vs. $M = 0.85$, $SE = 0.41$), $t(23) = 1.79$, $d = 0.75$, $p < .05$, one-tailed. This effect also held when the three children who succeeded on part of the pretest were excluded from the sample, $t(20) = 1.75$, $d = 0.78$, $p < .05$, one-tailed. Because scores in the verbal-only lesson condition approached floor, we also evaluated the hypothesis using a non-parametric test, the Mann–Whitney U test, and found the same result, $U = 45.5$, $z = 1.86$, $p < .05$, one-tailed.

This effect was also highly reliable across items, paired $t(5) = 7.52$, $d = 3.36$, $p < .001$. As seen in Table 1, for every one of the six items, more children in the verbal-plus-gesture condition than in the verbal-only condition provided correct judgments and explanations. Children's level of success differed across the three asymmetric items. The item with the extra feature (the cup) was judged and explained correctly by the greatest number of children, followed by the item with the mismatching feature (the

Table 1
Percent of children in each group who performed correctly on each measure for each item

Item	Judgments plus explanations		Judgments alone	
	V Only	V plus G	V Only	V plus G
Symmetrical items				
Ring	15	42	38	67
Pants	15	25	46	36
Leaf	15	42	31	58
Asymmetrical items				
Cup (extra feature)	23	42	62	50
Watch (mismatching feature)	8	33	54	67
Feet (non-mirror relation)	8	25	54	42
Average	14	35	47	53

Note. V Only = Verbal-only condition; V plus G = Verbal-plus-gesture condition.

wristwatch). The item with the non-mirror relation (the pair of feet) was the most difficult for the children.

3.2.2. Judgments alone

Next, we examined children's symmetry judgments on their own (i.e., considered apart from explanations). Children in the verbal-plus-gesture condition made more correct judgments than did children in the verbal-only condition, but only by a small and non-significant margin ($M = 3.17$, $SE = 0.41$, vs. $M = 2.85$, $SE = 0.32$), $t(23) = 0.63$, $d = 0.26$, *ns*. The item analysis was also non-significant. As seen in Table 1, for three of the six items, more children in the verbal-plus-gesture condition than in the verbal-only condition made correct judgments, and for the remaining three items, more children in the verbal-only condition made correct judgments. It is possible that, at least in some cases, children may have guessed about whether the items were symmetrical or not symmetrical. It is also possible that they had sufficient knowledge to make a correct judgment, but not to articulate its basis.

3.2.3. Explanations

Finally, we examined children's symmetry explanations. We first considered whether children in the two conditions were differentially likely to produce gestures along with their explanations. We found no significant difference in the number of explanations in which children produced gestures (verbal-only $M = 3.92$, $SE = 0.52$, vs. verbal-plus-gesture $M = 3.75$, $SE = 0.63$), $t(23) = 0.21$, $d = -0.09$, *ns*.

We next evaluated the content of children's explanations, based on the coding scheme presented in Table 2. Table 3 presents the mean number of explanations of each type produced by children in each condition, and

Table 2
Explanation categories, definitions, and examples

Type of explanation	Definition	Examples
Sides	Focus on the fact that the two sides are identical or not identical. May do so by referring to features on one or both sides.	"Because they're both the same." "Because the sides are different." "Because this side has a handle and this side doesn't."
Mirror	Focus on the mirror relation or lack of mirror relation between the two sides. May do so by describing orientation.	"Because they're facing a different way." "They aren't backwards." "Because they're going in the same direction."
Halves	Focus on the fact that the item can be or is split in half.	"Because it can come apart." "Because they're put together."
Irrelevant	Focus on something irrelevant to the task, or provide an uninterpretable answer.	"Because it's on a tree." "Because if you broke it, you wouldn't have it anymore." "They're both not the right thing."
Don't know	Express lack of knowledge or decline to respond.	"Because, um, I don't know."

Table 3
Mean number of responses of each type (out of 6) produced by children in each condition

Type of explanation	Verbal only	Verbal plus gesture
Sides	2.15 (0.71)	2.42 (0.69)
Mirror	0.62 (0.37)	1.75 (0.69)
Halves	0.77 (0.43)	0.25 (0.25)
Irrelevant	1.92 (0.54)	0.42 (0.19)
Don't know	0.54 (0.29)	1.08 (0.67)

Note. The values in parentheses are standard errors.

Table 4 presents the proportion of children in each group who used each type of explanation for each of the items. As seen in Table 3, children in the verbal-plus-gesture condition produced more Mirror explanations, and children in the verbal-only condition produced more Irrelevant explanations. Children in the two conditions produced Sides explanations about equally often. As seen in Table 4, these same patterns were borne out in the item analysis.

Finally, we focused on the two explanation types that invoked symmetry concepts (Sides and Mirror), and we examined whether children in the two groups tended to invoke these concepts correctly. In the verbal-only condition, children produced an average of 1.54 explanations ($SE = 0.45$) that used the concepts correctly and 1.23 ($SE = 0.52$) explanations that used the concepts incorrectly. In the verbal-plus gesture condition, children produced an average of 2.75 ($SE = 0.41$) explanations that used the concepts correctly, and 1.42 ($SE = 0.26$) explanations that used the concepts

Table 4
Percent of children in each group who used explanations from each category for each item

Item	Sides		Mirror		Halves		Irrelevant		Don't know	
	VO	VG	VO	VG	VO	VG	VO	VG	VO	VG
Symmetrical items										
Ring	31	33	15	25	8	0	31	17	15	25
Pants	31	42	8	25	8	0	46	8	8	17
Leaf	31	33	8	33	23	8	31	8	8	17
Asymmetrical items										
Cup (extra feature)	38	50	8	25	15	8	31	0	8	17
Watch (mismatching feature)	54	50	8	33	8	0	31	0	0	17
Feet (non-mirror relation)	31	33	15	33	15	8	23	8	15	17
Average	36	40	10	29	13	4	32	7	9	18

Note. VO = Verbal-only condition; VG = Verbal-plus-gesture condition.

incorrectly. Of the 36 Sides or Mirror explanations produced by children in the verbal-only condition, 55% were correct, whereas of the 50 such explanations produced by children in the verbal-plus gesture condition, 66% were correct.

On the whole, the explanation data suggest that children in the verbal-plus-gesture condition produced somewhat more advanced explanations than did children in the verbal-only condition. Children in the verbal-plus-gesture condition produced more explanations that invoked symmetry concepts, and in particular, more explanations that focused on the mirror relation between the two sides. Further, among explanations that invoked symmetry concepts, those produced by children in the verbal-plus-gesture condition were more likely to be correct.

3.3. Attention to the video lesson

The results thus far indicate that children learned more from the lesson that included both speech and gesture. We next considered whether this effect was due to heightened attention in the verbal-plus gesture lesson. To evaluate this possibility, we compared the number of head turns produced across conditions. Because the distribution was non-normal and included an extreme score, we used a non-parametric test, the Mann–Whitney test. As expected, children turned their heads away from the video more often during the verbal-only lesson than during the verbal-plus-gesture lesson ($M = 13.5$, $SE = 1.7$, vs. $M = 9.6$, $SE = 1.8$), $U = 47$, $z = 1.69$, $p < .05$, one-tailed. Thus, it appears that children were indeed more attentive to the verbal-plus-gesture lesson.

4. Discussion

In brief, children who viewed the lesson that included gestures learned more than children who viewed the lesson that did not include gestures. Thus, teachers' pointing and tracing gestures can indeed facilitate student learning. This study adds to the growing body of evidence showing that gestures do play a role in language comprehension. Further, this study illustrates this point in a context in which comprehension is of great importance—a lesson in which a new concept is being presented. We believe that gesture may be especially important in instructional settings, because instructional discourse often presents new concepts and uses complex language that may challenge students' comprehension.

By what mechanism might teachers' gestures facilitate students' learning? We have argued that gesture facilitates learning by facilitating comprehension. We suggest three, non-mutually-exclusive mechanisms by which this may occur.

One possibility is that teachers' gestures facilitate students' comprehension because they *capture and maintain students' attention*. Consistent with this possibility, we found that children who viewed the verbal-only lesson were less attentive to the video than children who viewed the verbal-plus-gesture lesson.

A second, related possibility is that teachers' gestures facilitate students' comprehension because they *provide redundancy in the message*. Because gesture is a second communicative channel, a student has two "opportunities" to comprehend a message that is expressed in both speech and gesture. In the verbal-plus-gesture lesson used this study, all gestures conveyed the same message as the accompanying speech. For example, at one point, the teacher said, "Look at shape number one on the wall." In the verbal-plus-gesture condition, the teacher pointed to shape number one during this utterance. A student who missed the verbal message in the verbal-only condition would not know which shape to focus on, but a student who missed the verbal message in the verbal-plus-gesture condition might gain this information from the gesture.

A third, related possibility is that teachers' gestures facilitate students' comprehension because they *ground speech in the concrete, physical environment*. In so doing, gestures clarify the meanings or referents of terms used in the verbal message. For example, in the lessons used in the present study, the teacher said, "Imagine a line from top to bottom down the center of the shape." In the verbal-plus-gesture condition, the teacher traced an imaginary line down the center of the shape during this utterance. This visual support for speech (the action of tracing the line directly on the shape) may help to clarify just what is meant by "a line from top to bottom down the center of the shape." Students who do not receive this support may have difficulty imagining the position or orientation of the line, so they may less effectively represent the two halves of the shape, and as a consequence, they may have difficulty grasping the concept of bilateral symmetry. Thus, gestures may help to clarify the meanings of key aspects of a verbal message by linking the abstract, verbal utterance to the concrete, physical environment.

This notion of grounding speech in the physical environment is related to Glenberg and Robertson's (1999, 2000) notion of *indexing*. According to Glenberg and Robertson, people comprehend speech by indexing, or by referring words and phrases to objects in the environment or to analog representations of objects (e.g., mental images of objects, or more formally, perceptual symbols as described by Barsalou, 1999). Such indexing is important for comprehension because many concepts and their perceptual features are not pre-existing, but instead must be learned by interacting with the environment (Schyns, Goldstone, & Thibaut, 1998). In the present study, children could index the teacher's speech to the shapes seen on the wall in the video. Since the shapes were visible in both video lessons, this indexing was possible in both conditions. We suggest that gestures may facilitate indexing, and thereby facilitate comprehension and learning. Indeed, in an experimental test of indexing, Glenberg and Robertson (1999) manipulated indexing by varying whether or not gestures were used in a videotaped lesson about how to use a compass. Consistent with our results, participants who saw pictures with gestures learned more than participants who saw pictures without gestures.

It should be apparent that these three possible mechanisms are not mutually exclusive. Gestures may serve to capture students' attention precisely *because* they link speech to the physical environment. Similarly, the benefits of redundant messages may derive from attentional processes, insofar as redundant messages more effectively guide students' attention to key aspects of the physical environment. The present study was not designed to test among these different mechanisms by which gestures might facilitate comprehension and learning, but rather to test the more fundamental question of *whether* gestures facilitate comprehension and learning in an instructional setting. The study focused only on pointing and tracing gestures, which serve to link speech to the concrete physical environment. To help clarify the mechanisms by which gesture facilitates comprehension and learning, future studies might contrast pointing and tracing gestures with other types of gestures that do not directly link speech to the environment, such as ordinary iconic gestures (e.g., tracing a shape in the air). Alternatively, future studies might contrast gestures with other methods of providing redundancy in the verbal message, such as providing closed captioning.

In addition to their relevance for understanding students' comprehension of instructional discourse, our findings also shed light on why the concept of bilateral symmetry is difficult for young children. Children in this study mastered some principles of symmetry but not others. Specifically, children found the extra feature violation of symmetry the easiest to understand, and the mismatching feature and non-mirror violations of symmetry to be more difficult.[2] Of course, the present study does not allow firm conclusions to be drawn about the order of acquisition of symmetry concepts. However, it is worth noting that children performed most poorly on difficult items in the verbal-only condition. We suggest that nonverbal support for instruction may be especially important for more difficult concepts.

Several other limitations of this experiment must also be acknowledged. First, the results may be specific to the types of gestures used in the present experiment, namely, gestures that are redundant with the accompanying speech. Of course, gestures produced in naturalistic settings are not always

[2] It is possible that children had difficulty with the non-mirror violation because the particular stimulus item used (a pair of feet) is symmetrical in "real life," even though the line drawing used in the experiment was not symmetrical (see Fig. 2). Thus, children's difficulty with this particular item may be due to their interpretation of the picture, rather than to the inherent difficulty of the non-mirror relation.

redundant with the accompanying speech (Church & Goldin-Meadow, 1986; Perry et al., 1988), and if mismatching or complementary gestures had been used in the present experiment, the results would likely have been different. In some cases, mismatching gestures appear to hinder comprehension of the speech they accompany (Goldin-Meadow & Sandhofer, 1999; McNeil et al., 2000). It is possible that such gestures might actually hinder students' learning (Goldin-Meadow et al., 1999).

Second, the present results may not generalize to other types of lesson content. Gestures may be especially important in communicating about visuo-spatial information, such as the symmetry concept used in this study. For lesson content that is not visuo-spatial in nature, instructors' gestures may not contribute to students' comprehension.

Third, the experiment did not test a realistic instructional setting, but instead used a videotaped lesson, which children viewed individually. Although this may be a realistic model of some distance learning settings, it is not a realistic model of classroom instruction, especially in the elementary grades. It remains to be tested whether the present results would generalize to other types of instructional settings, as well as other age groups and other types of lesson content.

Despite its limitations, the present study represents one step toward the broad goal of understanding factors that influence students' comprehension in instructional settings. Gestures play a potentially important role in facilitating comprehension, and this may be especially true when challenging new concepts and complex language are introduced. The present experiment showed in particular that teachers' pointing and tracing gestures can promote students' learning of visuo-spatial concepts from instructional discourse. We suggest that teachers would be well advised to utilize such gestures when they teach.

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Appendix

Excerpt from the verbal lesson with accompanying gestures in curly brackets { }.

Sample of the lesson for a symmetrical shape: Now look at shape number 1 on the wall {point to shape #1}. Imagine a line from top to bottom down the center of the shape {trace a line down the vertical center of the shape}. Now you have split it into two sides {point to each side, one at a time}. Look at the two sides {point to each side, one at a time}. One side has half of an oval with a bar sticking out from it {trace the perimeter of the first side}. The other side has half of an oval with a bar sticking out from it too {trace the perimeter of the second side}. The two sides look just like each other {point to each side, one at a time} only they go in different directions {trace each side from the middle of the figure out to the edges, simultaneously}. They are backwards from each other, so this shape {point to a spot underneath the vertical center of the shape} is symmetrical.

Sample of the lesson for an asymmetrical shape: Now look at shape number 4 on the wall {point to shape #4}. Imagine a line from top to bottom down the center of the shape {trace a line down the vertical center of the shape}. Now you have split it into two sides {point to each side, one at a time}. Look at the two sides {point to each side, one at a time}. One side has an oval with a bar going through it {trace the perimeter of the first side}. The other side has an oval with a bar going through it too {trace the perimeter of the second side}. The two sides look just like each other {point to the two sides, one at a time}, but they go in the same direction {trace both sides from their leftmost to rightmost edge, simultaneously}. They are not backwards from each other, so this shape {point to a spot underneath the vertical center of the shape} is not symmetrical.

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