CONVERGING PERSPECTIVES ON CONCEPTUAL CHANGE

Mapping an Emerging Paradigm in the Learning Sciences

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For Lina
For Lella and my students

Rhodes, M., Brickman, D., & Gelman, S. A. (2008). Sample diversity and premise typicality in inductive reasoning: Evidence for developmental change. *Cognition, 108*(2), 543–556.
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GESTURE'S ROLE IN REFLECTING AND FOSTERING CONCEPTUAL CHANGE

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Conceptual change is a powerful process by which people make a qualitative shift in the way they understand a concept. Often researchers consider a child's verbal descriptions when trying to understand the process of conceptual change. In this chapter, we step back from explicit verbal language to argue that another representational format—the spontaneous gestures we produce when we talk—can offer a unique perspective on the *process* of conceptual change. We first describe how gesture[1] can be an indicator of when a child will undergo a shift in conceptual understanding. We then describe how the act of producing gesture, or even seeing gesture, can play a direct role in enhancing and expediting conceptual change by helping the learner to integrate new ideas into their pre-existing conceptual knowledge. We end by briefly discussing some of the mechanisms through which gesture may have its effects, arguing that gesture's influence resides not in a single one of its properties, but in the unique combination of its intrinsic, defining features.

Gesture indexes moments of conceptual change

One of the unique features of gesture is that it happens with the hands, allowing individuals to simultaneously express one idea in their speech and a separate idea in their gesture, so called "gesture–speech mismatches" (Goldin-Meadow, 2003). A mismatch occurs when gesture conveys information that is different from, but has the potential to be integrated with, the information conveyed in the speech it accompanies (e.g., twirling one's hands upward while saying, "he walked up the stairs" to represent a *spiral* staircase). Note that cases where the information in gesture and speech cannot be integrated are considered errors, not mismatches (e.g., saying "left" while pointing to the right). In most cases, when a novice has produced a mismatch, the speaker will not have actually integrated the information in gesture with the information in speech, although the potential to do so is there. Indeed, that potential may be part of the impetus for change. Research shows that when a speaker produces gesture–speech mismatches on a task, the learner is on the verge of conceptual change with respect to that task (Church & Goldin-Meadow, 1986). In other words, mismatches between speech and gesture precede and predict a learner's moment of insight (Goldin-Meadow, 2011).

One example of how gesture predicts children's developing understanding can be found in the classic Piagetian liquid conservation task. If a child who does not yet understand the principle of conservation is asked *why* he believes that the water poured from a tall thin container into a short narrow container is now a different amount, the child may respond with the explanation, "Because this one [the taller container] is bigger than this one [the shorter container]," showing that he is focused on only one dimension—the height of the containers. But examining the child's gesture often reveals that the child knows more than he can say. In a seminal study, Church and Goldin-Meadow (1986) coded the meaning expressed in these gestures, and found that some children produced speech-gesture mismatches. For example, one child used a C-handshape to illustrate the *widths* of the tall and short containers while talking exclusively about the *heights* of the containers. Although this child expressed misunderstanding about the concept of conservation in his speech, his mismatching gesture and speech indicated that he was ready to learn conservation and, indeed, did learn when provided with instruction. In general, children who produce gesture–speech mismatches while explaining a task are particularly likely to benefit from instruction on that task, suggesting that they were ready to learn. In this case, gesture serves as a nonverbal marker for identifying children who are on the brink of understanding this fundamental physical concept.

Gesture also has been found to serve as a marker of change in the domain of mathematical equivalence, where children must understand that two sides of a mathematical equation are equal to each other. Perry, Church, and Goldin-Meadow (1988) found that children would give incorrect strategies in speech, but correct strategies in gesture, while explaining their reasoning to problems such as 3 + 4 + 5 = __ + 5. For example, a child gave 12 as the answer to the previous problem and said, "I added the 3, 4, and 5, and got 12"— a solution that reveals the misconception that an equals sign means *add up the numbers to the left of the equals sign*. However, while explaining this incorrect strategy in speech, that same child pointed to the 3 and the 4, indicating a different, correct strategy for solving the problem, one that would allow her to *group* the first two addends to arrive at the correct solution (because the remaining numbers on each side of the problem are equal addends).[2] Children producing gesture–speech mismatches were again more likely to profit from instruction than children producing gesture–speech matches, suggesting that their gestures served as an indicator that these children were on the brink of conceptual change.

Gesture promotes conceptual change

The work reviewed thus far suggests that spontaneous gesture can serve as an index of a child's readiness to learn a new idea or concept. Yet gesture does more than just index that a child is on the verge of conceptual change—the act of producing gesture is causally linked to the process of conceptual change itself.

Studies in which gesture is explicitly encouraged, rather than fortuitously observed, offer some evidence for this claim. For example, Broaders, Cook, Mitchell, and Goldin-Meadow (2007) manipulated the rate of children's gesture production in a math problem-solving paradigm. At the beginning of the experimental procedure, all children were asked to solve and explain their answers to six mathematical equivalence problems (e.g., 6 + 3 + 8 = __ + 8) to establish a baseline rate of spontaneous gesture production. Then, children were asked to solve and explain six more problems, but, this time, one group of children was told to keep their hands still, one group was told to gesture, and the final group was not told anything specific about hand movements. Although participants in all three groups produced the same number of different problem-solving strategies in speech after the manipulations, children in the "told to gesture" group produced significantly more problem-solving strategies in gesture than the other two groups—strategies that they had not produced during baseline and that, for the most part, were correct. Moreover, the children who had begun producing new ideas in gesture when told to move their hands were more likely to learn when subsequently given equivalence instruction. These effects suggest that being told to gesture can lead to increased rates of gesture–speech mismatches, which, in turn, lead to learning.

In other work, researchers have facilitated conceptual change by asking children to produce *specific* mismatching gestures. For example, in one study, children were taught to produce a grouping gesture (a *v-point* to the first two addends on the left-hand side of the equation, followed by a *one-finger point* to the blank) while saying the equalizer strategy aloud ("I want to make one side equal to the other side") (Goldin-Meadow, Cook, & Mitchell, 2009). In the equation, 4 + 2 + 7 = __ + 7, the children would make a *v-point* gesture to the 4 and the 2, then a single point to the blank. A second group was taught the same mismatching speech and gesture, but were taught to produce the grouping gesture under the incorrect grouping addends (2 and 7 in this example). A third group was taught only to reproduce the spoken equalizer strategy. Children who produced the correct gesture and mismatching speech learned significantly more from a math lesson than children who did not produce any gesture. This result makes it clear that being instructed to produce mismatching gesture and speech promotes conceptual change. Surprisingly, children who produced the *grouping* gesture but pointed it at two incorrect numbers also learned more from the math lesson than children in the speech alone condition, although they learned less than children in the fully correct gesture condition. This pattern suggests that gesture did more than just draw the learner's attention to particular numbers since, in this condition, the learner's attention was drawn to the wrong two numbers. The children also gleaned the idea of grouping two numbers from the gestures they produced, as evidenced by the fact that they (and the children in the fully correct gesture group) incorporated the grouping strategy into their spoken explanations after training. The children had learned and internalized a new problem-solving strategy that they had only ever produced in gesture.

Gestures are not the only type of movement commonly produced in instructional settings. Actions on representational objects, such as mathematical manipulatives, are often used to help children gain insight into difficult problems. Yet recent work has demonstrated that children who learned mismatching strategies through speech and gesture learn more flexibly than children who learned mismatching strategies through speech and actions-on-objects. In this study, Novack, Congdon, Hemani-Lopez, and Goldin-Meadow (2014) taught children to produce either a grouping gesture (*v-point to the first two addends followed by a point to the blank*) or a grouping action (*picking up number tiles from the first two addends and holding them in the blank*). Children in both groups initially learned how to solve problems, but only children in the gesture group were able to flexibly transfer that understanding to novel problem contexts and solve problems of a different format than they had seen in training. Thus, in this case, learning through mismatching speech and actions-on-objects led to shallow understanding, whereas learning through mismatching speech and gesture supported deep conceptual change that could be flexibly applied and generalized.

Mechanisms of gesture

We have shown that gesture can reflect the process of conceptual change. We also reviewed evidence suggesting that gesture can play a causal role in bringing conceptual change about—giving learners new ideas. How does gesture play a role in conceptual change? We argue that gesture promotes conceptual change, not through a single property or mechanistic pathway, but rather through a combination of properties that it naturally brings together. To conclude this chapter, we briefly discuss three of these properties: gesture's relation to spoken language, its reliance on the manual modality (and thus engagement of the manual motor system), and its status as a representational symbol. Although this list of gesture's properties is not all-inclusive, it does emphasize how gesture's different facets can combine to promote conceptual change.

First, because gesture and speech occur in two different modalities, gesturing allows for the *simultaneous* expression of two ideas (i.e., mismatches). Asking children to conceptually activate two pieces of information at the same time, in this case, through speech and gesture, has been found to have positive effects on learning (Alibali & Goldin-Meadow, 1993). This effect may occur, in part, by helping learners activate and integrate multiple hypotheses while in a state of conceptual uncertainty. Indeed, children learn more from instruction

that contains two different strategies, one in speech and the other in gesture, than from instruction containing the same two strategies in speech (Singer & Goldin-Meadow, 2005). Critically, the timing of the bimodal information is important—children learn best when the two different strategies are presented simultaneously (one in speech *at the same as* the other in gesture), and not when the two strategies are presented sequentially (one in speech *followed by* the other in gesture, Congdon et al., 2017).

Another important property of gesture may be its specific reliance on the manual modality. Although it is possible to simultaneously express multiple ideas through other modalities (e.g., visual/pictorial information can be combined with auditory/verbal information, see Mayer, 2005), these non-body-based modalities may fall short, relative to gesture. Indeed, we know that gesture enhances learning even if it offers no new information beyond speech, but presents the same information in a different format. For example, children taught to produce the same strategy in gesture and speech during math instruction retained what they learned longer than children taught to produce the strategy only in speech (Cook, Mitchell, & Goldin-Meadow, 2008). As another example, children taught to produce the same information in gesture and speech learned more about a language concept than children taught to produce the information only in speech (Wakefield & James, 2015). Even gestures produced without any speech at all can have positive effects on thinking and learning (e.g., Brooks & Goldin-Meadow, 2016; Cook et al., 2008). Taken together, these findings suggest a second mechanism through which gesture may be able to support learning and conceptual change—its capacity to engage the manual motor system. Neural evidence from previous work in the action learning literature suggests a long-lasting benefit of learning through engaging the manual motor system (James & Swain, 2011), and recent work shows a similar effect after information has been learned through gesture (Wakefield, Congdon, Novack, Goldin-Meadow, & James, under review).

Finally, although engaging the manual motor system clearly is important, not *all* manual motor activity is useful for learning. For example, meaningful gesture facilitates learning better than meaningless gesture-like hand movements (Brooks & Goldin-Meadow, 2016), and supports transfer better than hand actions on objects (Novack et al., 2014). Thus, a third important feature of gesture, its status as a *representational* action, is likely to be critical in gesture's success as a tool for conceptual change (Novack & Goldin-Meadow, 2017). As representational action, gesture differs from other types of actions (such as object-directed actions) in that it occurs in the air, *off* objects, and therefore transiently represents or references ideas, rather than creating change in the physical world. Object-directed actions can cause learners to focus on irrelevant physical features of objects or to be distracted by the alternative functions of the objects (Uttal, O'Doherty, Newland, Hand, & DeLoache, 2009). Gestures, by contrast, are not beholden to the affordances of any single object or set of objects, but instead provide an abstract representation that highlights selected features of a concept or idea. This physical and metaphorical "distance" from physical objects and real-world actions might allow learners to form a flexible representation of a new idea that is broadly applicable to novel contexts and situations. As gestures are abstracted representations, they may even evoke schematic knowledge structures, similar to Jean Mandler's (2004) *image schemas*, schematic conceptualizations that exist at a level between sensorimotor functions and language, and that help individuals organize perceptual information into abstract concepts.

Conclusion

We have shown that gesture is a powerful non-verbal cue that promotes and reflects conceptual change. Like language itself, gesture provides a window into a learner's thinking and provides an avenue through which new information can infiltrate the learner's cognitive system. But despite its power to affect thinking and learning, gesture is comparatively understudied and its influence is often ignored in instructional settings. Here we emphasize the importance of taking gesture and its relation to spoken language into account when researching conceptual change and when developing learning interventions or instructional techniques. We have proposed mechanisms that may help explain *why* gesture is such a powerful learning tool, paving the way for a better understanding of when and how to harness it for learning. We suggest that gesture may be most useful in promoting conceptual change not because of any single feature it possesses, but because it brings together a number of powerful mechanisms within a single process. In other words, although it is possible for other cues to engage the manual motor system, to occur at the same time as speech, or to serve as representational symbols, no single tool performs *all* of these functions and at the same time. Gesture's power may stem from a unique combination of properties that collaborate to form a useful tool for conceptual change.

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Notes

1 Here, 'gesture' refers to iconic, metaphoric and deictic gestures as defined by McNeill (1992).

2 The add-to-equal-sign strategy expressed in speech seems, on the surface, to be incompatible with the grouping strategy expressed in gesture. However, the strategy in speech reveals that the child has, at some level, recognized that the equal sign divides the problem into two parts, an insight that has the potential to be integrated with the grouping strategy expressed in speech.

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10

IMPLICIT CONCEPTUAL DYNAMICS AND STUDENTS' EXPLANATORY MODEL DEVELOPMENT IN SCIENCE

David E. Brown

The work I discuss here is complementary to work done focusing on conceptual metaphor and learning in science (e.g., Amin, 2009, 2015; Dreyfus, Gupta, & Redish, 2015; Jeppsson, Haglund, & Amin, 2015). Both explore unconscious, implicit image schemas and how they influence conscious thinking and reasoning. Researchers focusing on conceptual metaphor look at the interaction of these implicit image schemas with conscious, linguistically articulated ideas. In my work I focus attention more on conscious *imagistic* reasoning, with a recognition of the importance of linguistic resources (Cheng & Brown, 2010). Amin (2009, 2015) has used the term "construal" to indicate the interplay of conscious language-based resources with implicit conceptual metaphors in interpreting the meaning of linguistic expressions of both students and experts. To consideration of these "linguistic construals" I would like to add consideration of "imagistic construals" as students make meaning of conscious images of phenomena or models through connection with implicit image schemas.

Recently I have written about the need to consider students' conceptions as dynamically emergent structures rather than as more static, mechanistic structures. This general dynamic view has a number of advantages over the intuitively seductive and linguistically supported mechanistic view of students' conceptions (Brown, 2014; Brown & Hammer, 2013), but it remains a view of the general nature of students' ideas rather than an exploration of specific student ideas. Here I will discuss an interpretive stance on students' specific conceptions, which focuses on conscious ideas, implicit ideas, and their interplay.

Exploring conscious and implicit ideas

In the early 1990s, I conducted some interviews with high school students, exploring their ideas of electricity and simple circuits. Much prior work had been