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Learning to measure through action and gesture: Children's prior knowledge matters

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ABSTRACT

Learning through physical action with mathematical manipulatives is an effective way to help children acquire new ideas and concepts. Gesture is a type of physical action, but it differs from other kinds of actions in that it does not involve interacting directly with external objects. As such, gesture provides an interesting comparison to action-on-objects and allows us to identify the circumstances under which gesture versus interaction with objects (and the associated effects on the external world) may be differentially beneficial to learning. In the current study, we ask whether individual differences in first grade children's prior knowledge about a foundational mathematical concept – their understanding of linear units of measure – might interact with their ability to glean insight from action- and gesture-based instruction. We find that the children using a more rudimentary pretest strategy did not benefit from producing gestures at all, but did benefit from producing actions. In contrast, children using a more conceptually advanced, though still incorrect, strategy at pretest learned from both actions and gestures. This interaction between conceptual knowledge and movement type (action or gesture) emphasizes the importance of considering individual differences in children's prior knowledge when assessing the efficacy of movement-based instruction.

1. Introduction

We know from decades of experimental psychology research that asking children to act directly on external representations can affect their internal ideas (e.g., Wilson, 2002; Sommerville & Woodward, 2010; James, 2010; Kontra, Goldin-Meadow, & Beilock, 2012; Gerson, Beckering, & Hunnius, 2015; Levine, Goldin-Meadow, Carlson, & Hemani, 2018). In fact, children succeed in solving many problems grounded in the physical world well before they can succeed with abstract, symbolic forms of parallel problems (Bruner, Olver, & Greenfield, 1966; Piaget, 1953). These findings suggest that acting on, or manipulating, objects is a powerful way for children to learn new ideas. Gestures – a special category of action – can represent information, engage the motor system, and reference external representations in an instructional context, but unlike actions-on-objects, gestures are representational and do not create lasting change in the external environment (Novack & Goldin-Meadow, 2017). Here, we directly compare hand gestures to actions-on-objects in a linear measurement lesson with first grade children to investigate whether these different kinds of actions might differentially affect children's understanding of spatial units of measure.

Previous research has identified both benefits and drawbacks of learning through action in math contexts. Using manipulatives, objects designed to represent abstract math concepts in a tangible, physical way is one of the most common ways that action-based learning is instantiated in elementary school math lessons. For example, young children may learn to add using blocks or other sets of small objects before they are able to add Arabic numerals (e.g., Levine, Jordan, & Huttenlocher, 1992). Acting with manipulatives allows children to offload cognition onto the environment and encourages the formation of useful conceptual metaphors (Manches & O'Malley, 2012). It also directs attention to the relevant components of a complex problem (Mix, 2010) and engages young learners with limited attention spans and working memory (Petersen & McNeil, 2008). Yet some recent research cautions against action-based learning, highlighting instances where children may become distracted by irrelevant components of the manipulatives such as color or texture (Petersen & McNeil, 2008), or may see the learned actions as relevant only to a specific set of objects rather than as instantiating a broader mathematical principle (e.g., Uttal, Scudder, & DeLoache, 1997; DeLoache, 2000; Kaminski,

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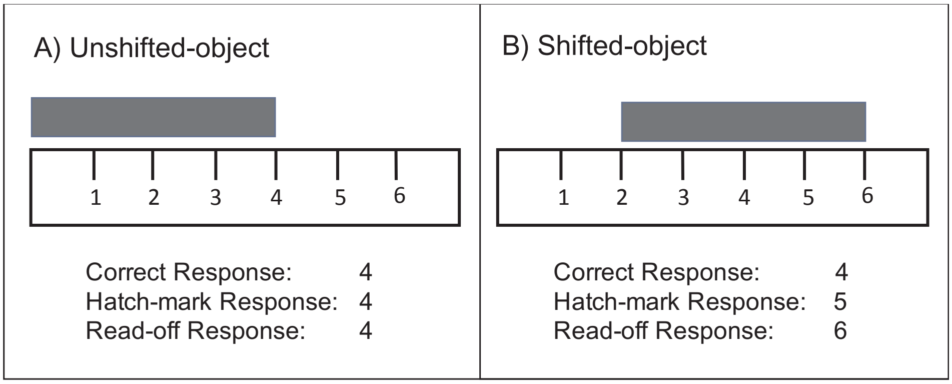

Fig. 1. Illustrations of two types of problem where a to-be-measured object is either (A) aligned with the start of the ruler or (B) shifted away from the start of the ruler. Common student responses are listed below each image.

Sloutsky, & Heckler, 2009).

Gestures differ from actions on manipulatives in that they do not require children to interact directly with physical objects and do not result in changes in the location or orientation of these objects. Importantly, research findings show that asking learners to gesture can promote learning, insight, and retention across a variety of domains including algebra, chemistry, word learning, and even moral reasoning (e.g. Wakefield & James, 2015; Macedonia, Muller, & Friederici, 2011; Ping & Goldin-Meadow, 2008; Goldin-Meadow, Cook, & Mitchell, 2009; Cook, Mitchell, & Goldin-Meadow, 2008; Brooks & Goldin-Meadow, 2015; Beaudoin-Ryan & Goldin-Meadow, 2014). Gesture may be a particularly effective way to help children focus on important relational structures or spatial features of a problem. Consistent with this possibility, children instructed in mathematical equivalence problems (e.g., $3 + 4 + 5 = \_ + 5$) learn more from a lesson that includes a gesture that highlights the two sides of the equation than from verbal instruction alone (Singer & Goldin-Meadow, 2005).

Although both action and gesture can be used as powerful learning tools, there is an open question as to *who* can best take advantage of the properties each type of tool offers. The very features that differentiate gestures from actions (i.e. the fact that they are representational, do not interact with objects, and do not affect change on the external world) may make gestures difficult to understand for some learners. In other words, some children may have trouble either mapping the abstract form of a gesture to its symbolic content, or perhaps keeping all the pieces of a problem actively in mind, which could render gesture ineffective as a teaching tool for that child. In support of this possibility, we know that very young children can understand another person's actions, like demonstrating how to twist off the top of a jar, before they can interpret a gesture that represents that action, like miming a twisting motion near the top of a jar (Novack, Goldin-Meadow, & Woodward, 2015). This evidence suggests that iconic gesture interpretation follows a later and more protracted developmental time span than action interpretation. Consequently, the meaning of iconic gestures may be unclear to some children, particularly if they are unfamiliar with the specific concept being represented by the gesture.

Very few studies have directly compared action and gesture in learning paradigms. In one study, the authors trained kindergarteners on a mental transformation task and found that learning gains in the action group happened immediately after training, while the learning gains in the gesture group occurred over a longer time course (Levine et al., 2018). In a separate study, 3rd grade children were instructed to produce a problem-solving strategy with either an action, a concrete gesture or an abstract gesture in a mathematical equivalence task (e.g., $3 + 7 + 2 = \_ + 2$) (Novack, Congdon, Hemani-Lopez, & Goldin-Meadow, 2014). While children in all groups performed similarly on a post-test, children in both of the gesture conditions performed better than other groups on a near-transfer task, and children in the abstract gesture condition performed best on a far-transfer task. The intriguing findings from these two studies suggest that the features that differentiate gesture from action may be particularly helpful for giving children a flexible, generalizable, and long-lasting understanding of the target learning concepts. Yet this leaves open the question of whether gesture is more helpful than actions-on-objects for all students, even if they have a very rudimentary understanding of a concept.

To address this question, we gave children a lesson with either action or gesture on a linear measurement task. This foundational math concept is one that many children struggle with throughout elementary school and even middle school (Lindquist & Kouba, 1989; Lehrer, Jenkins, & Osana, 1998). While traditional classroom instruction activities are largely ineffective in supporting children's understanding of spatial units, there is some recent work showing that giving children instruction that involves actions on manipulatives and evidence that their pre-existing ideas about linear measurement are wrong –'disconfirming evidence' - can improve learning outcomes (Kwon, Ping, Congdon, & Levine, submitted for publication).

Moreover, children consistently make one of two conceptually interesting errors on linear measurement problems where the to-be-measured object is not aligned with the zero-point on the ruler (shifted-object problems). See Fig. 1 for an example. In the hatch-mark counting error, children count the ruler hatch mark lines encompassing the object being measured instead of counting the intervals of space that fall between an object's left-most and right-most edges. Read-off errors consist of simply reading off the number on the ruler that aligns with the rightmost edge of the object regardless of the location of the object's left most edge on the ruler. Notably, both errors provide the *correct* answer on typical unshifted measurement problems where the object-to-be-measured is aligned with the zero point of the ruler (e.g., Blume, Galindo, & Walcott, 2007; Kamii & Clark, 1997; Lehrer et al., 1998; Solomon, Vasilyeva, Huttenlocher, & Levine, 2015).

Several findings suggest that children who primarily use the read-off strategy on shifted-object problems are further behind in their understanding of linear measurement than those who use the hatch-mark strategy. First, the read-off strategy negatively correlates with both age and socio-economic status (Solomon et al., 2015; Kwon, Levine, Ratliff, & Snyder, 2011). Second, after instruction, some students switch their strategy from read-off to hatch-mark counting, but the reverse pattern is never observed (Kwon et al., submitted for publication). Finally, at a minimum, the hatch mark strategy reflects knowledge that measurement involves counting units that are encompassed by the extent of the object, while the read-off strategy reflects no such knowledge. Taken together, these pieces of evidence suggest that children who use the read-off strategy at pre-test have lower conceptual knowledge of linear measurement than those who use the counting hatch mark strategy at pre-test.

In the current study, we begin by assessing first grade children's