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Embodied Learning Across the Life Span

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Abstract

Developmental psychologists have long recognized the extraordinary influence of action on learning (Held & Hein, 1963; Piaget, 1952). Action experiences begin to shape our perception of the world during infancy (e.g., as infants gain an understanding of others' goal-directed actions; Woodward, 2009) and these effects persist into adulthood (e.g., as adults learn about complex concepts in the physical sciences; Kontra, Lyons, Fischer, & Beilock, 2012). Theories of embodied cognition provide a structure within which we can investigate the mechanisms underlying action's impact on thinking and reasoning. We argue that theories of embodiment can shed light on the role of action experience in early learning contexts, and further that these theories hold promise for using action to scaffold learning in more formal educational settings later in development.

Keywords: Embodied cognition; Action experience; Development; Education

1. Introduction

The topic of *embodied cognition* has received a great deal of attention within psychological and neuroscience literatures in the last two decades. Theories of embodiment have impacted research across disciplines, ranging from development to social psychology to cognitive neuroscience (Barsalou, 1999; Beer, 1995; Lakoff & Johnson, 1999; Niedenthal, 2007; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996; Smith & Sheya, 2010). Although the term is invoked to describe several subtly different claims (see Wilson, 2002), embodied cognition is based on the idea that our representations of a concept, object, or event often involve perceptual, somatosensory, and motoric re-experiencing (collectively referred to as ''embodiment'') of the relevant event in one's self (Niedenthal, 2007). Embodiment is frequently associated with high degrees of knowledge and skill (Beilock, Lyons, Mattarella-Micke, Nusbaum, & Small, 2008). It is also the case that embodiment is profoundly affected

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by action experience. These ideas point to action experience as a simple yet powerful tool for learning throughout development and into adulthood.

Action experience may refer to the long-term accumulation of expertise or to salient short-term experience. Either way, motor information accrued by the body can affect learning and development by grounding mental representations in motor areas of the cortex and structuring associated perception. Moreover, action experience can come in the form of concrete physical experience such as reaching and grasping, or gross motor patterns learned in the context of sports (Cross, Hamilton, & Grafton, 2006; Daum, Vuori, Prinz, & Aschersleben, 2009). A perhaps more abstract example of action experience is gesture, a representational form of movement that has been shown to affect a wide variety of cognitive processes (Goldin-Meadow & Beilock, 2010).

Motivated by the idea that there is a complex interaction between learning and development (Vygotsky, 1978), we argue that action experience begins to shape our perception of the world around us during infancy and that its influence does not end there. Theories of embodiment provide a structure within which we can investigate the mechanisms underlying action's impact on cognitive changes occurring throughout the lifetime. These theories shed light on the role of action experience in early learning contexts and developmental milestones, and further hold promise for directing the use of action to scaffold learning in more formal educational settings later in development. Simply put, the processes we use to act can subsequently subserve the processes we use to understand.

2. Early sensorimotor learning

The idea that action production and action understanding are related is not new. Classical theories of development describe broad changes in conceptualization that take place with the expansion of a child's sensorimotor repertoire (Piaget, 1952). Early in life, a child's growing motor repertoire has large observable effects on cognition and behavior. In a detailed review, Campos et al. (2000) describe the widespread psychological changes that occur in tandem with the onset of locomotion and the ''experiential contributions to development'' (p. 154). We too focus on the impact of experience; yet we emphasize that in addition to universal developmental milestones, action can impact learning as a function of a person's unique experiences throughout the lifetime. An understanding of the mechanisms behind embodiment in early learning contexts offers valuable insight as we investigate more specialized learning in older children and adults, and attempt to leverage these embodied learning mechanisms in more formal educational settings.

Recent developmental work revealing connections between sensorimotor learning in infancy and changes in social cognition are directly relevant to these goals. For instance, Woodward and colleagues show correlations between infants' skill in grasping behavior and their ability to attribute intentionality to other social agents' grasping and reaching behaviors (Sommerville & Woodward, 2005; Woodward, 2009). Specifically, in visual habituation experiments, Woodward and colleagues habituated infants to a video of repetitive reaches toward one of two objects. Test trials represented either a *changed goal* (the arm reached toward a different object in the original location) or the *same goal* (the arm reached toward the original object in a different location). By 5 months of age, when infants are typically able to reach for and grasp objects they desire, they show increased looking times (indicating recognition of novelty) to the *changed goal* test trials. This response demonstrates a representation of the reaching movements as goal-directed or (at the least) linked to the object and not to the specific pattern in space (Woodward, 1998).

To address the question of causality, Woodward and colleagues gave 3-month-old infants experience that simulates the reaching behavior they had not yet mastered (Sommerville, Woodward, & Needham, 2005). They used ''sticky mittens,'' velcro-covered mittens that allow infants to ''pick up'' objects by swiping at them. Infants who had been given experience with the sticky mittens showed increased looking times at the novel *changed goal* trials, whereas a control group showed no difference in looking time between the *changed goal* and *same goal* trials. Without action experience, the control group's perception of the reaching movements was not organized in a meaningful, goal-oriented way. Moreover, within the group who had been given sticky mittens experience, there was a significant relation between the extent to which infants produced goal-directed action with the sticky mittens and their subsequent recognition of *changed goal* trials. Variation in the individual infants' own actions positively correlated with variation in their perception of others' actions, providing a strong case for an embodied mechanism behind this universal social skill. Even over the brief time period of an experiment, infants' understanding was bolstered by their own physical repertoire. Rather than being a skill that appears at a set time during infancy, the assignment of goals to others' actions can be traced to an individual child's own motor experience. These studies exemplify the profound effect of early experience shaping observable cognitive, social, and developmental changes (see also Campos et al., 2000, for a thorough discussion of the myriad consequences of locomotion on infants' cognitive and social development).

3. Later sensorimotor influences

As discussed above, action experience can be a driving force during early development. Moreover, although our brains become relatively less malleable over time, the influence of action experience does not end after infancy. Embodied effects on cognition are prevalent throughout childhood and into adulthood as well. The most compelling evidence for this idea comes from research that strives to investigate a causal link between motor experience and subsequent changes in perception or other higher level cognitive processes; as we will see, these studies also implicate the feasibility of targeted educational interventions based on theories of embodied learning.

Take a study conducted by Casile and Giese (2006), in which the authors demonstrate that specific non-visual experience doing an action influences subsequent visual perception of that action. The authors used a novel paradigm to train participants to perform an unfamiliar gait pattern, where the phase difference between arm and leg movements was shifted to 270° (as opposed to the normal 180° difference). This training was purely sensorimotor; participants were blindfolded and received only verbal and haptic feedback. Casile and

Giese (2006) found that performance on a visual discrimination task improved selectively between pre- and posttest for the trained 270° phase difference; in contrast, there was no significant change in performance for other, non-practiced gait patterns (e.g., 225°). The authors argue that this specificity in improvement is due to the covert simulation of learned sensorimotor patterns during subsequent observation of the visual stimuli. In support of this idea, and reminiscent of the infant data published by Woodward and colleagues, individual accuracy in performing the 270° gait pattern at the end of training correlated significantly with posttest visual discrimination of this same pattern. These data demonstrate a highly specific link between non-visual motor experience and subsequent transfer to performance on a visual perception task, suggesting that it is the action experience that drives improvement.

Subsequent work builds on this and other findings to extend the range and complexity of cognition affected by action experience. One such example is work by Beilock et al. (2008), which investigated hockey experts' comprehension of action language. Within the embodied cognition literature, many studies support the link between action language and the body. For instance, work by Hauk, Johnsrude, and Pulvermuller (2004) established that single verbs associated with body parts, such as ''pick'' or ''lick,'' activate cortex in a somatotopically specific manner. If action language is inherently linked to the body in adults with normal experience, we might expect specific differences in linguistic representation for adults who cultivate motor expertise over time. Athletes accrue a vast amount of specific action experience over years of training, and thus might be expected to construct representations that incorporate their experience.

Beilock et al. (2008) measured comprehension of both everyday action sentences (''The individual pushed the cart'') and hockey-specific action sentences (''The hockey player finished the stride''; see Beilock et al., 2008 for methods details). Both hockey experts and novices were equally good at understanding everyday action sentences, which depicted events they were equally practiced at performing. For the hockey action sentences, however, comprehension was significantly correlated with hockey experience; experts > novices. Importantly, the authors collected neural data using fMRI to observe differences in brain activation during passive listening to these hockey-specific action sentences. They then used these data to account for the relationship between hockey experience and hockey language comprehension.

Activity in the left dorsal premotor cortex (dPMc) correlated positively with both hockey sentence comprehension and hockey experience. This region of cortex has been shown to drive high-level action planning for learned skills. Importantly, activation in left dPMc fully mediated (i.e., accounted for) the relationship between hockey experience and hockey action sentence comprehension, suggesting that online instantiation of motor experience by the hockey experts facilitated comprehension. These data support the idea that complex skills like language comprehension can be embodied, and that action experience even into adulthood shapes our everyday cognition. The hockey example above gives us reason to believe that we can train comprehension of complex stimuli using extended motor experience. We return later to the idea of using simple, short-term training to achieve this goal in the context of science education.

Although cases of motor expertise provide a strong example of embodied effects, so do cases of more prototypical everyday action. Gesture is a form of movement that most adults perform extensively on a regular basis. Gesture is often considered to function primarily for communicative purposes (and thus to primarily impact the listener), but a large body of research investigates the way a speaker's gesture affects his or her own cognition (Broaders, Cook, Mitchell, & Goldin-Meadow, 2007; Cook, Mitchell, & Goldin-Meadow, 2008; Goldin-Meadow & Beilock, 2010). The representational nature of gesture holds interesting implications for embodied research, and it may be an especially relevant tool for a wide range of subject matter in the classroom environment. The trajectory, hand shape, handedness, or size of a gesture may act to represent physical qualities and thus, ground a concept in sensorimotor regions of the cortex (Hostetter & Alibali, 2008). For example, the act of gesturing about a heavy object may subsequently link that object's representation to sensorimotor information about weight. Beilock and Goldin-Meadow (2010) have performed several experiments that support this hypothesis.

Beilock and Goldin-Meadow (2010) used the Tower of Hanoi (TOH) puzzle as a representative task and asked undergraduates to solve the puzzle with four weighted disks. During participants' first solution (TOH1), they manipulated a set of disks whose size was positively correlated with weight. Importantly, the smallest disk could be lifted and moved using one hand, whereas the other disks required two hands. The dependent measures were solution time and the number of moves to reach the final solution. After solving TOH1, some participants were asked to explain their solution to a confederate during which they spontaneously gestured (Explanation condition). Others were given a filler task matched for time (No Explanation condition). Afterward, all participants were asked to solve the task again (TOH2), and they were either given the same set of disks used in TOH1 in which size and weight were positively correlated (No Switch group) or a set of disks in which size and weight were negatively correlated (Switch group). Note that although the weight of the disks is irrelevant to solving the problem (and, indeed, none of the participants ever mentioned weight in their speech), it is impossible not to convey information about weight when gesturing—the gesturer has to use either one or two hands.

The results support the hypothesis that representing weight information via gesture can affect subsequent performance. Participants in the No Explanation condition who never gestured about the disks improved in solution time and number of moves between TOH1 and TOH2, regardless of whether they were in the Switch or No Switch group. However, within the Explanation condition, only participants in the No Switch group improved over time. The Switch group performed worse on TOH2 compared to TOH1 in both time and number of moves. In addition, there was a relation between the way Explanation + Switch participants gestured about the disk and the extent to which their TOH2 performance suffered. The *more* they gestured about the smallest disk with one hand (reinforcing a representation of a small, lightweight disk), the *worse* they did on TOH2 (when the smallest disk was heaviest and could only be moved with two hands).

These data demonstrate how gesture, as a form of action experience, can influence thought and subsequent learning. The brief, online experience of using motion to represent physical objects influenced later performance. Interestingly, in this case, action experience *harmed* subsequent performance on a cognitive task. A clear understanding of when and how specific action experience can affect learning is essential to design targeted training, whatever the desired outcome. Knowledge about gesture as action is relevant to an embodied approach in education, as gesture can represent a wide range of action information that can be enacted within the classroom setting.

The above-mentioned examples begin to tell a story about how action experience alters reasoning in a range of contexts and throughout the life span. Given the influence of various types of action experience on learning, we argue that the next step is to harness action experience in a way that facilitates classroom achievement.

4. Applications in education

Theories of experiential learning have been around for more than a century. John Dewey (1938), followed by Kolb (1984), described a process by which hands-on opportunities in an active learning environment drive knowledge. However, the specific mechanism through which this process occurs has not been well defined. Work in embodied cognition is particularly relevant to these ideas and offers potentially useful tools for educators. Recent research in developmental and cognitive psychology has focused on applying knowledge about embodied cognition to education.

Our current work attempts to use specific motor training to facilitate students' understanding of science, using Physics as a representative discipline. The results confirm a long-standing belief that *doing* a relevant action leads to enhanced learning over passively viewing that action (Kontra et al., 2012). We chose to focus on angular momentum and torque, which are crucial concepts in introductory college-level Physics courses and are easy to experience motorically. Undergraduates were given a pretest torque judgment task (TJT) to evaluate their understanding of factors influencing changes in angular momentum. They were then given 10 minutes of training during which students in one group (*Action*) manipulated a pair of bicycle wheels on an axle under various conditions. Students in a second group (*Observation*) were given the same verbal descriptions and observed another student manipulating the wheels. Participants in both groups received visual information about torque from a laser pointer mounted in the axle. All participants then completed a posttest TJT with instructions to apply what they had learned during the training session.

Although students in the *Action* and *Observation* groups were matched in terms of accuracy on the pretest, students in the *Action* group improved significantly in accuracy at posttest, whereas students in the *Observation* group did not. Something about participants' action experience changed the way they learned. This work has also been translated into the classroom environment (introductory Physics at the college level), and we have found similar patterns of enhanced learning via action experience using more prototypical measures of student comprehension (e.g., quiz and homework grades; Kontra et al., 2012).

The next step is to ask whether this enhanced comprehension of Physics concepts stems from simulating the relevant motor experience, as has been found in other domains (e.g., Beilock et al., 2008 hockey study mentioned above). Follow-up experiments are currently exploring the mechanism driving learning. If improvement in the *Action* group's performance is a direct result of the sensorimotor experience the participants received during training, and their understanding of torque is subsequently grounded in the motor system, we should find neural differences between the *Action* and *Observation* groups during posttest TJT performance. As in the work with hockey players by Beilock et al. (2008), motor simulation instantiated in the dPMc would, for example, offer support for the idea that understanding a concept (e.g., torque) is enhanced by specific physical experiences.

Although torque and angular momentum are readily experienced as physical force, many difficult-to-understand concepts in education are not. Nonetheless, it is still possible that action experience can influence learning. One potentially influential form of action experience in these cases, as we saw in the TOH example described earlier, is gesture. Speakers often convey knowledge in gesture that is not present in speech. Thus, the act of gesturing may allow for greater understanding of the concept(s) at hand by providing students with a physical medium with which to experience and express knowledge.

Goldin-Meadow, Cook, and Mitchell (2009) conducted an experiment to manipulate students' gesture during a lesson about mathematical equivalence. Third- and fourth-grade students were asked to solve pretest problems of the type: $3 + 5+8 = \_\_+8$, and were then asked to explain how they had arrived at each solution. During a training phase, three groups differed in the gestures they were required to perform during each training problem. The No Gesture group produced no gestures, the Correct Gesture group produced a grouping strategy in gesture (e.g., for the problem $3 + 5+8 = \_\_+8$, they placed a ''V'' hand under the 3 and 5 and then pointed at the blank), and a Partially Correct group produced a grouping strategy but toward the wrong numbers (they placed a ''V'' hand under the 5 and 8 and pointed at the blank). Throughout the experiment, students were given no feedback about their solutions. After the lesson, students were given posttest problems to solve and asked to explain their reasoning.

Goldin-Meadow et al. (2009) found that students' accuracy on the posttest problems was correlated with group (Correct gesture > Partially Correct gesture > No gesture). Furthermore, this effect was fully mediated by whether students added the grouping strategy to their spoken explanations during posttest. Students' explicit knowledge of the concept of grouping, and their ability to apply it effectively, was affected by the type of gesture they performed during the lesson. Even though the concept of mathematical equivalence is not inherently motor based, it too can be facilitated by action experience (see also Broaders et al., 2007).

More recent work expands the idea of gesture as a tool for learning and applies it to Organic Chemistry. Adults learning Organic Chemistry must be able to create stereoisomers (alternative spatial configurations) of three-dimensional molecules. To do so, they must construct and rotate a mental image of the molecule from a two-dimensional representation. Gesture may be a potentially powerful tool to support the stereoisomer task, serving as a way to act out the spatial and motoric imagery. In a pretest—Training—posttest design, undergraduate participants with no knowledge of Organic Chemistry were introduced to the concept of stereoisomers. The spontaneous gestures produced by participants during explanations of their solutions on the pretest predicted their ability to profit from instruction during training and improve on the posttest. Namely, the more they expressed correct conceptual information in gesture that they did not verbalize in speech, the more they were subsequently able to learn (Ping, Larson, Decatur, Zinchenko, & Goldin-Meadow, Submitted). Current experiments are designed to again tackle the question of causality by manipulating gesture. This work is testing whether action experience in the form of gesture can facilitate learning of complex math and science concepts in adults, as it has been found to do in children.

5. Conclusions

Action experience is ubiquitous, and its influence may therefore be easy to overlook. Yet not only does movement have a powerful effect on learning at the beginning of life, but it continues to impact the way we experience the world throughout development and into adulthood. In a recent review, Smith and Sheya (2010) discuss the important theoretical shift toward considering cognition as arising from sensory and motor experiences (i.e., as being ''embodied''), rather than as an abstract entity entirely divorced from sensorimotor experience. Others have focused on embodiment as a way to address a new type of question about development and learning—when and how learners sometimes pull away from the actions that instantiate a particular concept to establish an abstract representation of that concept (Novack & Congdon, 2012). This acknowledgment of the body's role in cognition has inspired a prolific trend in the psychological literature, and it is an essential piece of the puzzle in understanding learning and development. Developmental psychologists have long recognized the extraordinary influence of action on learning (Held & Hein, 1963; Piaget, 1952). Theories of embodied cognition have the potential to deepen our understanding of the mechanisms underlying early developmental changes driven by action experience, as well as our understanding of learning in a broad, lifelong sense.

Recent work applying theories of embodied cognition to science education shows exciting potential, and it may be a defining trend in the future directions of our discipline. Research exploring embodiment from early childhood through adulthood will not only create a clear understanding of the mechanisms driving learning through action, but will also likely prove essential for narrowing the search space for targeted and optimally effective interventions within education.

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