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Toddlers' action learning and memory from active and observed instructions

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A B S T R A C T

From early in life, children learn to perform actions on the objects in their environments. Although children learn from observing others' actions, actively engaging with the material to be learned can be important for learning. This study tested whether instruction that included opportunities for children to be active supported toddlers' action learning. In a within-participants design, 46 22- to 26-month-old toddlers (average age = 23.3 months; 21 male) were introduced to target actions for which instruction was either *active* or *observed* (instruction order counterbalanced across children). During active instruction, toddlers were coached to perform a set of target actions. During observed instruction, toddlers saw a teacher perform the actions. Toddlers were then tested on their action learning and generalization. Surprisingly, action learning and generalization did not differ between instruction conditions. However, toddlers' cognitive maturity supported their learning from both types of instruction. One year later, children from the original sample were tested on their long-term memory for information learned from active and observed instructions. Of this sample, 26 children provided usable data for the follow-up memory task (average age = 36.7 months, range = 33–41; 12 male). Children demonstrated better memory for information learned from active instruction than for information learned from observed instruction (odds ratio = 5.23) 1 year after instruction. Active experience

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during instruction appears to be pivotal for supporting children's long-term memory.

Introduction

From early in life, children face the challenging task of learning to perform actions on the objects in their environments. Objects designed by people have associated actions meant to be performed on them (Tomasello, 1999). For example, keys are inserted into locks and twisted to unlock doors, Velcro straps are pressed together to keep children's shoes on their feet, and Mr. Potato Head's arms are inserted into holes on his body to assemble him. Learning to perform these actions appropriately is an important skill for development that is unique to humans (Tomasello, 2001) and begins early in life (Keen, 2011). Without some form of input from experts, children would struggle to learn the actions meant to be performed on objects; they would not know which actions were acceptable to perform with keys, Velcro straps, or Mr. Potato Head's arms. Children observe adults perform actions (Bandura, 1977) or receive instruction (Rogoff, 1990) to learn actions. Yet, children's active experience has been theorized as central for learning (Piaget, 1964). In the current study, we evaluated whether, and how, active experience may support young children's learning about actions from instruction.

Young children learn actions effectively from adults' instruction. Infants are facile imitators of adult action demonstrations (Meltzoff, 1988); for example, 9-month-old infants imitate simple actions on objects (Meltzoff, 1988), and 12-month-old infants imitate two-step actions (Bauer, 1996). Viewing action demonstrations supports learning better than completely independent, unguided child activity (Meltzoff, 1985). Indeed, 16-month-old infants learned to use a new tool more effectively by observing someone else than by engaging in active training (Somogyi et al., 2015). Adult demonstrations can be pedagogical, where teachers intentionally teach children; pedagogy has been theorized as central for learning (Csibra & Gergely, 2009). However, children learn through observing non-pedagogical demonstrations as well (Gaskins & Paradise, 2010; Shneidman & Woodward, 2015). Whether models are provided intentionally or incidentally, children could learn all the necessary information through observation alone. In this study, we asked this question: Is there an added learning benefit for children to be active during instruction?

Active experience has been proposed to be critical for young children's learning (Piaget, 1964). Wide-ranging research, particularly with older children, has lent support to this idea. Active experience benefits learning in contexts that involve instruction about abstract causal systems and mathematical concepts; actively engaging with new material prior to instruction supported 4-year-old children's learning of causal systems (Sobel & Sommerville, 2010), second- to fourth-grade students' math learning (DeCaro & Rittle-Johnson, 2012), and fourth-grade students' science learning (Dean & Kuhn, 2007). Similarly, caregivers who guided their children to actively explore a museum exhibit about gears had children who learned more about the causal structure of gears (Callanan et al., 2020). Consistent with these findings, curricula for preschoolers (Lillard, 2016) and elementary school children (Hmelo-Silver et al., 2007) often feature child activity in a guided context.

Does active experience similarly benefit action learning earlier in development? On the one hand, infants' and toddlers' robust ability to imitate others' actions, even after a considerable delay (Bauer, 1996), indicates that active engagement might not be needed in this context. On the other hand, the findings from older children's causal and academic learning suggest that even when instruction provides all the needed information, active engagement may boost learning. Moreover, active engagement has been linked to infants' development, including infants' object exploration (Needham et al., 2002), understanding of others' actions (Gerson & Woodward, 2014; Sommerville et al., 2005), and knowledge of object properties (Soska et al., 2010). Active experience may support learning for several reasons. Acting integrates multiple systems (perceptual, motor and cognitive, i.e., "embodied cognition"; Wilson, 2002), and self-produced activity may provide different information value to the learner (Schulz et al., 2007). Therefore, we tested whether active experience supported young children's action learning in instructed contexts.

A recent study provided initial evidence that active experience may support young children's action learning during everyday teaching interactions with caregivers (Brezack et al., 2021). The actions to be learned were novel assembly actions on toys, for example, fitting pieces together to create an object. Having been told how the pieces should go together, caregivers taught their 2-year-old children to perform the target assembly actions in whatever way caregivers wanted to do so. Then, toddlers were tested on their ability to perform the target actions by an experimenter who was unaware of which of several toy sets children had been taught. Results indicated that caregiver instructions benefitted learning; children did not spontaneously discover the target actions without instruction. Even so, toddlers who performed more actions during caregiver instruction demonstrated better action learning at test. In contrast, when caregivers demonstrated more actions for their children, children did less well during the test phase. Thus, children's tendency to actively engage rather than simply view caregivers' demonstrations was a positive predictor of learning.

These findings suggest that active experience may be key to toddlers' action learning. However, the prior correlational study leaves open the possibility that the relation between toddlers' active engagement and their learning was due to another factor rather than reflecting the direct effect of active engagement on learning. It is possible that individual differences in toddlers' cognitive maturity drove both their engagement during instruction and their ability to learn the actions. Brezack et al. (2021) attempted to rule out this explanation by controlling for children's skills with objects, measured by their propensity to assemble multi-piece toys for which no instruction had been provided. Children who were better at spontaneously constructing toys learned more from their caregivers; even so, controlling for children's skills, those who were more active during instruction demonstrated better learning. Still, an independent measure of children's cognitive maturity would better elucidate the roles of children's developmental level and active experience in learning.

It is also possible that active experience during instruction could support different aspects of learning. Brezack et al. (2021) tested children's learning of the actions they were taught. However, generalization, or the ability to transfer learned information to new contexts, is an important type of learning (Fiorella & Mayer, 2016). Generalization reflects conceptual or symbolic information (Bruner, 1966) that children apply to new situations (Fiorella & Mayer, 2016). For example, 18-month-old infants who practiced a demonstrated action showed improved action generalization after a delay compared with children who only observed the demonstration (Hayne et al., 2003). Likewise, research with older children in school settings suggests that active experience could specifically support children's generalization of learned information to new contexts (Alfieri et al., 2011; Hmelo-Silver et al., 2007).

Furthermore, active experience may support children's long-term memory for taught information. Toddlers have the capacity for robust long-term memories; young children remember people for years (Lie & Newcombe, 1999). In particular, children have strong memory capacities for actions. Research on deferred imitation demonstrated that infants as young as 6 months remembered actions they were taught in a lab setting (Barr et al., 1996). However, in these studies, young children learned new actions by watching demonstrations only, without enacting the actions to be learned (Meltzoff & Moore, 1998). In contrast, studies on elicited imitation, where children perform actions after viewing a demonstration, have indicated that enacting actions could enhance children's action memory (Bauer et al., 1994, Experiment 3; Meltzoff, 1990). When children performed actions after a demonstration, young children's action memory persisted for months (Bauer et al., 1994) and up to a year after being taught new actions (McDonough & Mandler, 1994). Whereas children learn well from observing actions, active experience may enhance children's long-term action memory.

Active experience when learning similarly benefits adults' memory. Adults had better memory for actions they produced compared with actions they observed (Cohen, 1989). Adults also demonstrated better memory for object locations after performing self-propelled reaching actions compared with robot-propelled reaches (Trewartha et al., 2015). This suggests that initiating motor commands and engaging coordinated muscle movements (Pouw et al., 2014) when acting may underlie active engagement's memory benefits. Indeed, the "motor-induced encoding effect" suggests that when learners engage their motor processes to a greater extent while learning, they form stronger encoded memories (Kinder & Buss, 2021). In addition, physical activity involves sensorimotor associations, including integrating information about how objects look and feel (Minogue & Jones, 2006) with motor commands, which can also strengthen information encoding (Hutmacher & Kuhbandner, 2018) and create richer representations that are more likely to be recalled (Markant et al., 2016).

In the current study, we tested whether active experience during instruction supported learning more than instruction that lacked opportunities for child activity. We used an experimental teaching manipulation that controlled whether children were able to be active during instruction. In a within-participants design, children were introduced to target actions for which instruction was either active or observational. In the active condition, children were coached to perform the target actions themselves; the teacher guided children to perform the correct actions, but children learned via actively engaging in the actions. In the observational context, children saw the teacher produce the actions, but they did not engage in the actions themselves. Both types of instruction allowed children access to two pieces of information to be learned: (a) target actions and (b) the structures of the assembled toys. However, the instructions differed by whether children performed or observed the actions.

Following instruction, children's learning was assessed by an assistant who was unaware of the training configuration to which children had been assigned. Children were also tested on their ability to generalize taught actions to novel toys. In addition, we used an independent measure of children's developmental level to test whether children with greater cognitive maturity learned more effectively from the instructions. We assessed variation in children's readiness to learn via the Cognitive subscale of the Bayley Scales of Infant and Toddler Development–Third Edition (Bayley, 2006), which measured children's cognitive and motor performance on items similar to those learned from active and observational instructions (e.g., assembling puzzles).

In a follow-up memory test, we evaluated whether the instruction conditions led to differences in children's long-term memory for the taught material 1 year after instruction. Specifically, we tested whether active or observational instruction affected children's long-term visual recognition memory for the toy structures. Although active experience might support long-term action memory (e.g., McDonough & Mandler, 1994), given the limitations on in-person data collection due to the COVID-19 global pandemic when this research was conducted, we instead measured children's visual recognition memory for the toys the children had been taught to assemble actively and observationally. Indeed, research with adults has found that physically exploring objects improved adults' memory for objects (Novak & Schwan, 2021). Active experience has been found to specifically improve adults' visual recognition memory (Hutmacher & Kuhbandner, 2018), likely because physically active experience deepens encoding (Kinder & Buss, 2021) and activates visual representations of learned information (Johnson et al., 1989). As with adults, active experience during instruction may similarly facilitate young children's visual recognition memory.

The methods and analyses of the lab visit were preregistered (https://doi.org/10.17605/OSF.IO/Y35DP). After data were collected during the lab visit, the follow-up memory task was designed and preregistered (https://doi.org/10.17605/OSF.IO/K2SX9). Videos from the lab visit and coding manuals can be found in the Databrary video repository (http://doi.org/10.17910/b7.1328).

Method

Participants

A total of 46 full-term toddlers exposed primarily to English participated (average age = 23.42 months, range = 22.17–26.00; 21 male). Approximately half the sample was White (European or White American: 20; African or African American: 11; Asian or Asian American: 2; Hispanic or Latino American: 1; multiple races: 12). The sample had high levels of maternal education (postgraduate degree: 22; bachelor's degree: 12; some college: 8; associate's degree: 2; did not report: 2). An additional 6 children were excluded following preregistered criteria (hearing more than 25% of another language at home [the study was conducted in English]: 3; prematurity: 1; refusal to perform actions during *active* instruction: 2). The preregistered sample size was 48, which was based on a power analysis of pilot data and allowed for full counterbalancing. However, 2 children were excluded after data collection was complete because they did not watch *observed* instruction long enough (as preregistered) for a final sample of 46.

All 46 children were contacted to participate in a virtual memory follow-up task 1 year after the lab visit, and caregivers of 32 children agreed for their children to participate. Of those 32 children, 6 demonstrated a side bias (i.e., they chose the image on the right side of the screen on all four trials) and were excluded from the analyses as preregistered. The final sample consisted of 26 children (12 male; mean age during the lab visit = 23.33 months, range = 22.17–25.30; mean age during the memory task = 36.71 months, range = 33.80–40.63; time difference between the lab visit and the memory task: mean = 13.38 months, range = 10.37–16.97). Children's backgrounds were similar to those of the full sample of children from the lab session (European or White American: 11; African or African American: 3; Asian or Asian American: 2; Hispanic or Latino American: 1; multiple races: 9; postgraduate degree: 18; bachelor's degree: 5; some college: 2; associate's degree: 1).

Procedure

Children participated in a laboratory of a research university in the Chicago area of the U.S. Midwest with a primary caregiver between May and October 2019. Children were recruited from a database of families who had agreed to participate in research. The study had four phases administered in a fixed order: *caregiver teaching* (reported in online supplementary material), *experimenter teaching, test,* and *cognitive maturity assessment* (Fig. 1). Children participated individually in a quiet testing room with an experimenter and one of two trained assistants. Caregivers sat behind toddlers; caregivers were instructed not to interfere and completed a measure of children's productive vocabulary during the study (MacArthur–Bates Communicative Development Inventory, Level II, short form [MCDI]; Fenson et al., 2000). The session lasted approximately 1 h. Video was recorded simultaneously from four webcams, and audio was recorded from one webcam. Families were given $20 and children were given a T-shirt or book and a certificate for participating.

One year later, children were tested on their memory for information they had learned during experimenter teaching in the lab session. After providing informed consent, caregivers and children attended a recorded Zoom session with a trained assistant. Data were collected between July and October 2020. The study took approximately 10 min, and families received a $5 gift card.

Materials

Five novel toys were designed for the study, modeled after toys in Brezack et al. (2021), each with associated target actions to be learned (Fig. 2). Each toy had a base and six pieces. Target actions (*action types;* six per toy) consisted of placing pieces onto the base to assemble a final end state. For example, the action types for the cat toy were ear 1, ear 2, eye 1, eye 2, nose, and mouth. During caregiver teaching, caregivers taught children to assemble a rocket ship toy (*rocket*). During experimenter teaching, the experimenter taught children to perform target actions to assemble one animal face toy (*cat* or *dog*) and one stacking figure toy (*snowman* or *scarecrow*). Children were taught one pair of toys, either the cat and snowman (Pair 1) or the dog and scarecrow (Pair 2). One toy in the pair was taught in an active context, and the other was taught in an observational context (within participants).

Children were tested on all five toys at *test;* the caregiver-taught toy, the two toys taught by the experimenter (*taught toys;* e.g., Pair 1: cat and snowman), and two toys matched to taught toys that were not taught (*generalization toys;* e.g., Pair 2: dog and scarecrow). Actions were designed to transfer between the two animal face toys (cat and dog) and between the two stacking figure toys (snowman and scarecrow) such that at test action performance on the untaught toys reflected children's ability to generalize taught actions to parallel toys. For example, the cat and dog had ears designed to be inserted into slots on the base, but the ears differed in color and shape between toys. A set of four colorful foam blocks was used during the *warm-up* phase that began experimenter teaching.

For the memory task, children's long-term visual recognition memory was measured using computer-drawn versions of each experimenter-taught toy (*target toys:* cat, dog, snowman, scarecrow), which were created using Pixlr. A foil image was drawn to match each target toy; foils were designed to be equally salient with structures similar to those of the target toys (cat–fox, dog–panda,

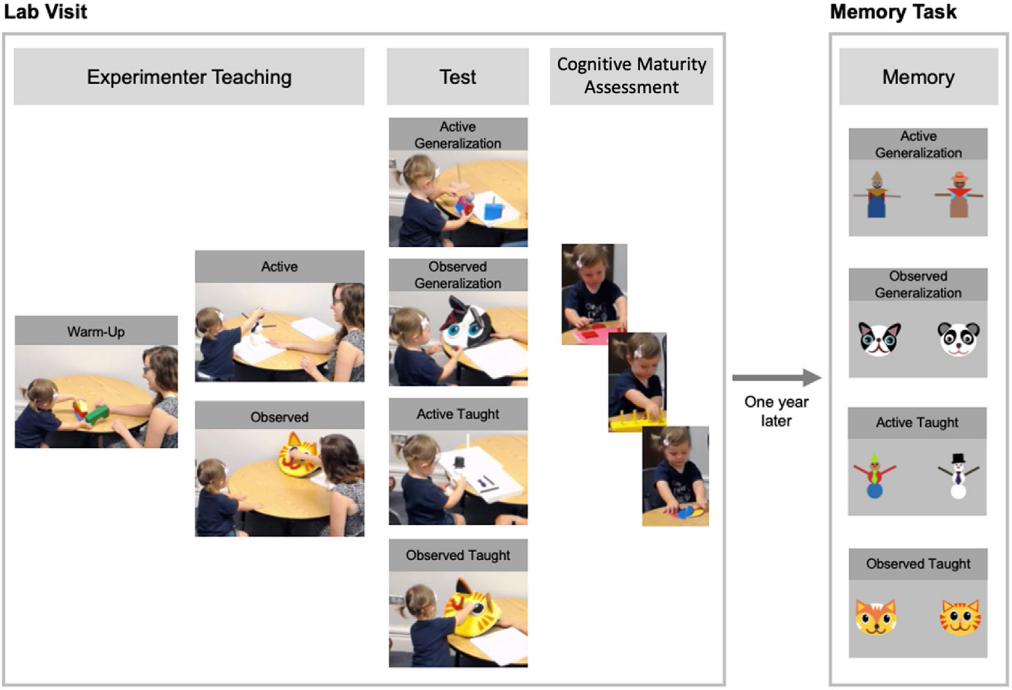

Fig. 1. Study design. Lab visit: After caregiver teaching (see online supplementary material), toddlers were taught by the experimenter (experimenter teaching): Children experienced a warm-up and were then taught actions in active and observed styles (here: active—snowman, observed—cat). Children were then tested on the taught toys (here: active generalization—scarecrow, observed generalization—dog, active taught—snowman, observed taught—cat). Toddlers then completed the Cognitive subscale of the Bayley Scales of Infant and Toddler Development–Third Edition (cognitive maturity assessment; Bayley, 2006). Memory task: One year later, children participated in a memory task where they saw each target toy from the lab visit paired with a matched foil image (here: active generalization—scarecrow, foil—cowboy; observed generalization—dog, foil—panda; active taught—snowman, foil—clown; observed taught—cat, foil—fox) and were asked which toy they remembered.

snowman–clown, scarecrow–cowboy) (Fig. 1). Each target toy and its corresponding foil image were presented side by side in the same fixed order for all children with the target toy side counterbalanced. In addition, the warm-up and caregiver-taught toys were drawn with foil images and were used to familiarize children with the procedure. Two practice trials (orange circle and blue circle, yellow star and green heart) were used to prepare children for the task. To remind children about their original lab visit, three images from children's sessions (caregiver and child, experimenter and child, assistant and child) were taken from the video recordings.

Caregiver teaching

At the beginning of the lab session, caregivers taught their toddlers to perform target actions to assemble the rocket. Caregivers were told to teach their toddlers in whatever way felt natural to them. Teaching sessions ended when 5 min had elapsed or caregivers indicated that they were done teaching, whichever occurred first (see supplementary material).

Experimenter teaching

Experimenter teaching consisted of three parts: warm-up, active, and observed. The order of active and observed instructions was counterbalanced across children. The warm-up familiarized toddlers with the procedure used later during active and observed instructions; sometimes children performed actions (active), and sometimes the experimenter performed actions (observed). During the warm-up

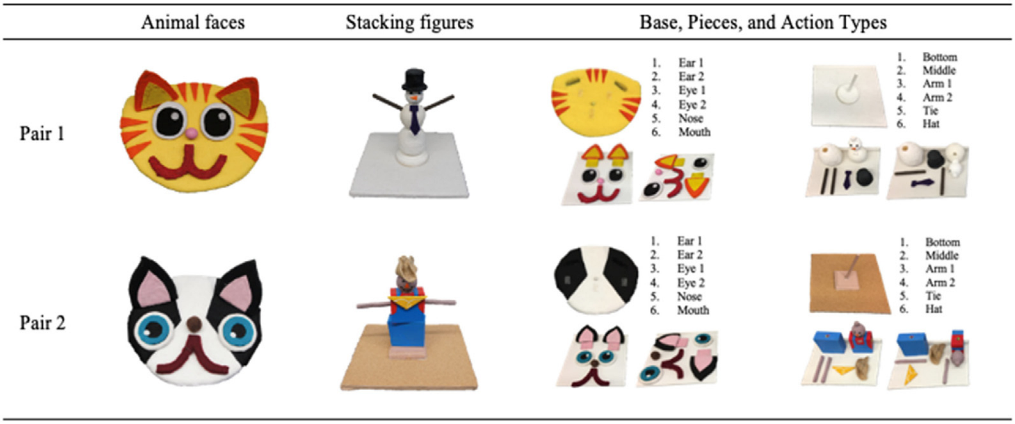

Fig. 2. Materials: Experimenter teaching. Four toys with six novel target assembly actions (action types) used in experimenter teaching are shown: two animal faces (cat and dog) and two stacking figures (snowman and scarecrow). The experimenter taught one pair (Pair 1: cat and snowman; Pair 2: dog and scarecrow). Each taught toy had a matched toy parallel in structure but with pieces that differed in color, shape, and texture (generalization: cat–dog, snowman–scarecrow). Toddlers were tested on all toys at test. Bases, pieces, and action types (within each cell): Each toy had a base (top left) onto which six pieces were placed (bottom). Six action types (top right) were taught in a fixed order. Children were presented with the base and pieces in an organized array during experimenter teaching (bottom left) and in a shuffled array during test (bottom right).

children built a block tower and then the experimenter built the tower. This procedure was repeated (four sequences total: child, experimenter, child, experimenter) to provide toddlers with familiarity with performing actions on their turn and observing actions on the experimenter's turn.

During active instruction, children were coached by the experimenter to perform a series of target actions to assemble a toy. Prior to performing each action, the experimenter provided instructions about how to perform the action with language and pointing. She then handed toddlers the associated piece so that they could perform the action (e.g., cat: "First you do the ear. The ear goes right here [pointing]. Can you do that? [handing piece to children]"). The experimenter assisted children in performing the correct actions if necessary by repeating instructions or using pointing gestures, finishing children's actions, adjusting placements, hovering pieces over their correct locations, or briefly demonstrating actions. This process occurred for each action in the sequence in the same fixed order (e.g., cat: ear 1, ear 2, eye 1, eye 2, nose, mouth).

During observed instruction, toddlers learned the target actions on a different toy by watching the experimenter perform the actions. As in the active sessions, the experimenter provided instructions for each action with language and pointing. However, the experimenter then performed each action in the sequence (e.g., cat: "First I'll do the ear. The ear goes right here [pointing]. I'll do that [placing piece in correct location]."). The procedure was matched between active and observed sessions, with the only difference being the person performing the actions; children performed target actions during active sessions, and the experimenter performed actions during observed sessions. Instruction order (active or observed first), taught toy pair (Pair 1: cat and snowman; Pair 2: dog and scarecrow), and active toy (cat or dog active; snowman or scarecrow active) were counterbalanced across children.

Test

Immediately following experimenter teaching, one of two trained assistants, who was not present for caregiver or experimenter teaching, tested children on their target action performance. Toddlers were tested on the caregiver-taught toy (see supplementary material), then the two generalization toys, and finally the two taught toys. Children's action performance on the toys they were taught during experimenter teaching reflected their learning from instruction. Performance on the matched, untaught generalization toys reflected children's action transfer skills. Children were tested on each toy individually for up to 2 min or until children refused to continue performing actions. The assistant remained neutral during test and assisted only when necessary to help children complete actions. See supplementary material for additional details.

Cognitive maturity assessment

To test children's cognitive maturity, the experimenter administered the Cognitive subscale of the Bayley Scales of Infant and Toddler Development–Third Edition (hereafter the Bayley; Bayley, 2006) following standardized testing procedures. This subscale requires similar skills as those needed to perform target actions in the study (e.g., assembling simple puzzles, putting pegs into a pegboard).

Memory task

One year after participating in the lab, families were invited to meet with a researcher over Zoom for the virtual memory task, which tested children's long-term visual recognition memory for information they had been taught in the lab. Caregivers set up their computer screens so that children could see only the images that the assistant shared via screen sharing on Zoom. Caregivers hid the view of their own video to minimize distraction and were told not to intervene. The assistant administered two practice trials (orange circle and blue circle: "Can you point to the blue circle?"; yellow star and green heart: "What shape is this?") to encourage children to respond either by naming the item or by pointing. Then, the assistant showed children the pictures from their original lab visit to remind them about the previous session (e.g., "A long time ago, you played with toys with your mom and some friends! Here you are playing with your mom!"). Children then saw the warm-up trial and the caregiver-taught toy trial as additional practice (e.g., "Did you make a tower or did you make a castle?").

Next, children saw the four *test trials:* fox and cat, scarecrow and cowboy, dog and panda, and clown and snowman. On each trial, children were asked which toy they remembered playing with (e.g., "Did you make a fox or did you make a cat?"). When each toy was named, it expanded slightly on the screen for emphasis and then returned to its original size. Children responded by pointing to or labeling one of the two toys. Test trials corresponded with toys that children had been previously taught: *active taught toy, active generalization toy, observed taught toy,* and *observed generalization toy* (toy assignment was counterbalanced across participants during the lab visit) (Fig. 1). An additional four trials were presented to make the game more engaging: clown and scarecrow, fox and dog, snowman and cowboy, and cat and panda. However, children's memory for those additional trials could have been contaminated by their responses to the four test trials; thus, only responses to the four test trials were analyzed.

Coding

Coding was performed to answer three research questions. First, did active or observed instruction differentially support action learning or generalization? To assess action learning differences, Test sessions were coded for children's ability to perform taught actions, generating *test scores* for each toy. Second, did individual differences in children's cognitive maturity relate to learning? Specifically, we examined children's cognitive maturity as measured by the Bayley. Third, did active or observed instruction differentially support children's long-term visual recognition memory for taught information? To measure memory differences, children's responses to the memory task items were coded.

Additional control measures were included from the lab visit to test whether session- or child-level individual differences were related to learning. *Session factors* included the amount of time children spent in each teaching session (active, observed, and caregiver teaching). *Child factors* included children's *age* and *MCDI score.* We also coded children's engagement with active and observed instructions to ensure that children performed actions accurately in active instruction and were visually attentive to observed instruction. In addition, we coded the assistance that the experimenter provided to children during active instruction. See Table 1 for all measures. Prior to conducting final coding, coders were trained with manuals and practice. One coder coded caregiver teaching and test sessions and was blind to the toys taught in experimenter teaching. A second coder coded experimenter teaching and was blind to children's performance at test. All coding was performed in Interact (Mangold, 1998).

Table 1
Measures.

Study phase	Measure	Description of measure
Experimenter teaching	Observed attention	Visual attention (proportional): (observed time – look-away time) / observed time
	Active instruction: Child best performance score	Children's accuracy in attempting target actions during active instruction
	Active instruction: Experimenter assistance	Number of instances of experimenter assistance during active instruction: repeating instructions or pointing, finishing an action, adjusting a placement, or briefly demonstrating an action
Test	Active taught test score	Active learning: Accuracy in target action performance on toy taught in active instruction
	Observed taught test score	Observational learning: Accuracy in target action performance on toy taught in observed instruction
	Active generalization test score	Active generalization: Accuracy in target action performance on toy matched to toy taught in active instruction
	Observed generalization test score	Observational generalization: Accuracy in target action performance on toy matched to toy taught in observed instruction
Cognitive maturity assessment	Bayley	Cognitive maturity; age-normed score on Cognitive subscale of Bayley
Session factors	Active time	Amount of time active instruction lasted
	observed time	Amount of time observed instruction lasted
	Caregiver teaching time	Amount of time caregiver spent teaching; maximum 5 min
Child factors	MCDI	Productive vocabulary
	Age	Child's age at date of test
	Active taught memory score	1/0 score reflecting recognition memory for the toy taught in active instruction during the lab visit
Memory task	Observed taught memory score	1/0 score reflecting recognition memory for the toy taught in observed instruction during the lab visit
	Active generalization memory score	1/0 score reflecting recognition memory for the toy matched to the toy taught in active instruction during the lab visit (generalization toy; experienced during test)
	Observed generalization memory score	1/0 score reflecting recognition memory for the toy matched to the toy taught in observed instruction during the lab visit (generalization toy; experienced during test)

Note. Measures and descriptions of measures coded during the lab visit (experimenter teaching, test, and cognitive maturity assessment; Bayley, Bayley Scales of Infant and Toddler Development–Third Edition), measures included as session and child factors (including MCDI; MacArthur–Bates Communicative Development Inventory, Level II, short form), and measures coded during the virtual memory follow-up task are shown.

The researcher who administered the memory task sessions coded children's responses from the videos.

Action learning: Test

Children's target action performance was coded during test to examine whether toddlers learned and generalized differently from active and observed instructions. Children's action attempts on each toy were coded by *action type* (e.g., cat: eye 1, eye 2, ear 1, ear 2, nose, mouth) and assigned a numerical score reflecting accuracy (maximum score per action = 1, range = 0–1), which allowed children to receive partial credit for performing actions imperfectly (Fig. 3). Because children often attempted actions more than once, children's highest scoring action attempt per action type was used to calculate test scores. For example, if a child placed a cat ear in the upper right corner of the base, that attempt would receive 1 full point. However, if the child then placed the ear near the bottom of the base, the attempt would receive a lower score (.2). The highest scoring attempt of each action type (e.g., the score of 1 rather than .2 for the cat ear) was averaged to generate a test score for each toy (maximum score = 1). Children's *active taught test score* and *observed taught test score* reflected learning from experimenter teaching. Children's scores on the generalization toys reflected their ability to transfer actions learned in experimenter teaching to matched toys: *active generalization test score* and *observed generalization test score.*

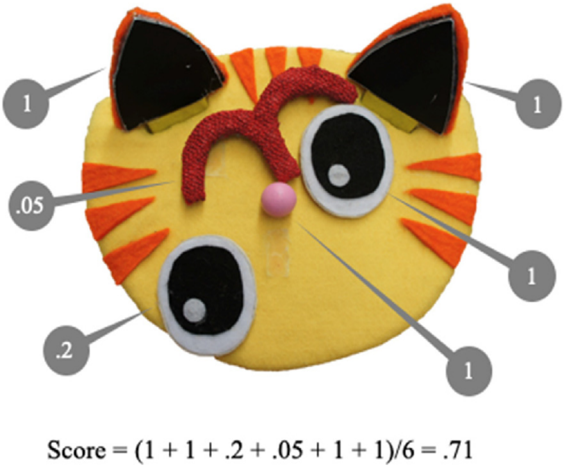

Fig. 3. Example of scoring target action attempts. Example of scoring actions on the cat toy is shown. Target action attempts were coded by action type (e.g., ear 1, ear 2, eye 1, eye 2, nose, mouth) and scored for accuracy (range = 0–1) during experimenter teaching (active instruction: child best performance score) and test for all toys. The score from the best attempt of each action type was averaged to calculate final scores out of 1. If an action was not performed, it would receive a score of 0; for example, if ear 1 was never placed, the score would be calculated as (0 + 1 + .2 + .05 + 1 + 1)/6 = .54. Scoring levels were based on Brezack et al. (2021) and were further developed during piloting to ensure that scores represented children's overall accuracy in constructing each toy.

Cognitive maturity assessment: Bayley

Children's cognitive maturity was measured by scoring children's performance on the Cognitive subscale of the Bayley. Children's performance on the Bayley Cognitive subscale was scored following standardized scoring guidelines to generate an age-normed Bayley score for each child.

Engagement during experimenter teaching: Active and observed

Children's visual attention was coded to ensure that children watched the Observed sessions for at least 80% of the demonstration. To measure visual attention, we first coded the total time that active and observed instructions lasted. *Active time* and *observed time* (included as session factors) were coded from the onset of experimenter speech about the toy until the toy was taken away. Then, durations of time toddlers were looking away from the demonstration (experimenter and toy) were coded. *Observed attention* was calculated as the proportion of time children were watching the instruction out of 1 (observed time – look-away time) / observed time).

Children's actions were coded analogously to their actions during test, but actions performed during active instruction reflected children's practice with taught information, whereas test performance reflected learning. Analogous to test scores, each action was coded by action type and accuracy with a maximum of 1 point per action. The highest scoring attempt of each action type was averaged to yield a measure of *active instruction: child best performance score* out of 1. Actions were coded to ensure that children reached a score of at least .8, as preregistered. Each instance of experimenter assistance necessary for children to perform taught actions was coded, including repeating instructions or pointing gestures, assisting in finishing children's actions, adjusting placements during or after children performed an action, hovering pieces over their correct locations, and briefly demonstrating actions. The total number of times the experimenter assisted children was counted per child for a measure of *active instruction: experimenter assistance.*

Session and Child Factors

In addition to active time and observed time, *caregiver teaching time* was coded as a session factor. Time was coded from the onset of caregivers' speech about or first touch of the toy, whichever occurred first, until the toy was taken away. This measure included only the time that caregivers were on-task and teaching their toddlers. Child factors were calculated to control for child-level individual differences that might relate to learning, including children's age in months and the number of words caregivers reported children said on the MCDI (a measure of productive vocabulary).

Memory task

The memory task sessions were coded for children's forced-choice response to each item (correct: selected the target toy; incorrect: selected the foil image) based on children's verbal label, pointing, or both. Therefore, each trial received a *memory score* of 1 or 0: *active taught memory score, active generalization memory score, observed taught memory score,* and *observed generalization memory score.*

Reliability coding

Videos of 10 children (21.7%) from the lab visit were coded by a second coder. Each measure was calculated for each child separately per coder and compared between coders to calculate reliability (e.g., taught test scores on each toy for each child were compared; see supplementary material). Across all measures, reliability was high: test scores: average intra-class correlation coefficient (ICC) = .899, all *ps* < .001; experimenter teaching: average ICC = .873, all *ps* < .013; session factors: average ICC = .989, all *ps* < .001. Reliability could not be calculated for active instruction: child best performance score because within the subset of videos coded for reliability children performed all actions perfectly (i.e., all children in the reliability sample received scores of 1). Videos of 6 children (23.1%) from the memory task were double-coded by another coder. Reliability was high (23 of 24 judgments were identical; 95.8% agreement).

Analysis

Inclusion criteria

As preregistered, children included in the analyses performed actions with at least .8 accuracy during active instruction (active instruction: child best performance score) and visually attended for at least 80% of the observed time (observed attention). All children were included based on active instruction: child best performance score. Data from 2 children were excluded for insufficient observed attention (.58, .75), leaving 46 children for the analyses. Three toddlers did not complete the Bayley and were not included in the analyses of the Bayley. For the memory task, as preregistered, children needed to respond to at least two of the four test trials to be included; all children did so. An additional 6 children demonstrated a side bias on the four test trials (i.e., children selected the image on the right side of the screen on all four trials) and were excluded from the analyses as preregistered for a final sample of 26 children.

Analysis strategy

The analyses were run to test whether active experience during instruction or cognitive maturity was related to children's action learning from active and observed instructions. The analyses were run as linear mixed-effects models with participants as random effects (intercept) and the outcome as test score on the four experimenter-taught items (active taught test score, active generalization test score, observed taught test score, observed generalization test score) using the lme4 package in R (Bates et al., 2015). Across measures, values more than 3 standard deviations from the mean were excluded (although the results did not differ if the outliers were included in the analyses): active time (1 value), observed attention (1 value), and active instruction: experimenter assistance (1 value).

Additional preregistered analyses were run to test whether children's memory scores differed by active or observed instruction. The analyses were run as logistic mixed-effects models with participants as random effects (intercept) and the outcome of binary memory score for the four toys using the lme4 package in R (generalized linear mixed model [GLMM]; Bates et al., 2015). Deviations from preregistered analyses are noted. See supplementary material for additional descriptive statistics.

Results

Action learning from active and observed instructions

Prior to testing whether learning differed by active and observed instructions, we checked for effects of the items within each type of toy (animal faces and stacking figures; scores did not differ, all *ps* > .109). We next tested whether session factors (active time: M = 95.7 s, SD = 17.0, range = 66.1–156.9; observed time: M = 74.3 s, SD = 6.1, range = 61.8–86.7; caregiver teaching time: M = 3.0 min, SD = 1.4, range = 0.95–5.88; instruction order: active or observed first; taught toy pair: cat and snowman or dog and scarecrow; active toy: cat or dog active, snowman or scarecrow active) or child factors (age and MCDI: M = 40, SD = 17.9, range = 5–77) were related to test scores, combining two preregistered models. As preregistered, we included children's cognitive maturity (Bayley score; M = 61.5, SD = 5.9, range = 48–74) in this model.

Bayley score was significantly related to test score (β = 0.015, SE = 0.007, p = .045); no other session factors or child factors were related to learning (all *ps* > .18). Individual differences in children's cognitive maturity were related to learning; more advanced children performed better at test. In addition, we did not see evidence that the assistance the experimenter provided to children during active instruction was related to children's active test scores (exploratory analysis controlling for Bayley: β = $-$0.003, SE = 0.007, p = .671). The main preregistered analysis examined whether children learned differently from active or observed instruction beyond variations in children's cognitive maturity. A model was run with test scores as the outcome, predicted by instruction experience (active or observed), test type (taught or generalization), and the interaction between instruction experience and test type, controlling for Bayley. Surprisingly, the main effects and interaction did not reach significance (all βs < .060, all *ps* > .156; intercept: β = $-$.634, p = .028) (Fig. 4A); children learned similarly from active and observed instructions and performed similarly on taught and generalization items. Only Bayley scores were significantly related to learning (β = 0.019, SE = 0.005, p < .001).

We exploratorily tested whether learning from active and observed instructions differed by performance on the Bayley. A model with test score predicted by instruction experience (active or observed), Bayley score, and their interaction revealed a marginal interaction between instruction experience and Bayley score (β = 0.009, SE = 0.005, p = .083) (Fig. 4B) such that toddlers with higher Bayley scores learned marginally more from observed instruction than from active instruction. In sum, children's cognitive maturity, not the opportunity to act during instruction, supported children's immediate action learning and generalization.

Memory test

As preregistered, control analyses were run to test whether memory scores differed by session factors or child factors. Age during the lab visit, the time difference between the lab visit and the memory task, and gender were tested as predictors of memory score; no predictors reached significance (all *ps* > .219). Toy type (cat, dog, snowman, or scarecrow) also was not significantly related to memory (all *ps* > .316), and a chi-square test did not show a significant difference in the distribution of toys previously taught in the active or observed condition, $\chi^2(3)$ = 1.539, p = .673. Therefore, analyses were collapsed across session and child factors. Within this subsample, the main preregistered analysis showed similar results as that of the full sample; only Bayley score predicted children's test scores (β = 0.023, SE = 0.008, p = .007); instruction experience, test type, and their interaction did not reach significance (other βs < .085, other *ps* > .131).

To test whether children's long-term visual recognition memory for toys differed by the way the associated actions had been originally instructed, a preregistered model was run with memory score per toy as the outcome predicted by instruction experience (active or observed), test type (taught or generalization), and their interaction, controlling for Bayley score (measured during the lab visit). Children demonstrated significantly better memory for items learned through active instruction than through observed instruction (instruction experience: β = 1.654, SE = 0.695, p = .017; exponentiated coefficients: odds ratio of remembering a toy taught in active instruction vs. observed

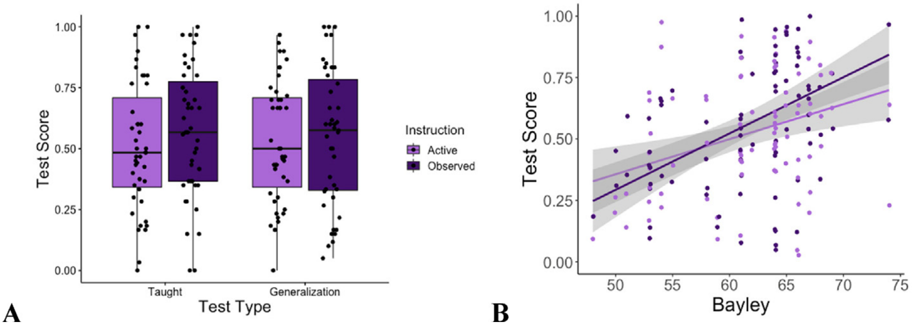

Fig. 4. Test scores from active and observed instructions. (A) Box plot showing average test scores from active and observed instructions separated by taught and generalization test types. (B) Scatterplot showing relation between Bayley score and test scores separated by active and observed instruction. Shaded areas represent 95% confidence intervals.

instruction = 5.23) (Fig. 5). Test type, the interaction between instruction experience and test type, and Bayley score were not significantly related to memory (all *ps* > .131; intercept: $\beta = -4.056$, $p = .256$). Therefore, children showed better memory for actively learned toys than for observationally learned toys. Children's cognitive maturity previously supported their immediate learning; in contrast, children's maturity was not related to their memory. Instead, the ability to be active during instruction supported children's memory.

Discussion

Although young children learn effectively through viewing demonstrations (Bauer, 1996), active experience has been argued to be central for learning (Piaget, 1964). We found that active experience was crucial for memory: Children's long-term memory was enhanced for material the children had learned through active instruction compared with observational instruction. Surprisingly, children learned and generalized actions similarly from instructions that did and did not offer opportunities to act. Still, children showed enhanced long-term memory for the toys that they had learned actively rather than observationally. This was found even though children had initially been taught in both conditions with tightly matched instructions. Instruction that included opportunities for children to act benefitted children's memory after a considerable delay of 1 year.

In addition, the results suggest that children's developmental level plays a substantial role in learning. An independent measure of children's cognitive maturity, the Cognitive subscale of the Bayley, was the most influential predictor of children's immediate action learning and generalization. Children with greater cognitive maturity demonstrated better learning regardless of instruction condition. However, children's maturity was unrelated to their long-term memory. Instead, children's developmental level supported their ability to learn from instruction, whereas active experience played a critical role in supporting children's memory.

In particular, active experience supported children's *visual recognition* memory. During instruction, children were taught two types of information: (a) target actions, which were performed to assemble (b) final toy structures. The immediate learning and generalization test examined children's learning of *actions,* whereas the delayed memory test measured children's visual recall of the *structures.* As such, children engaged in cross-modal object recognition during the memory task; children learned to perform actions on three-dimensional objects but were asked to recall the objects they had constructed when represented by two-dimensional images. Prior research with adults suggests that active experience may specifically support visual recognition memory. When sensorimotor information and coordinated muscle movements (Pouw et al., 2014) contribute to information encoding, visual representations are activated (Johnson et al., 1989). Physically exploring objects improved adults' object recall after 3 weeks (Novak & Schwan, 2021), specifically when learners were tested in a visual recognition test (Hutmacher & Kuhbandner, 2018). Still, if we had been able to test children's immediate

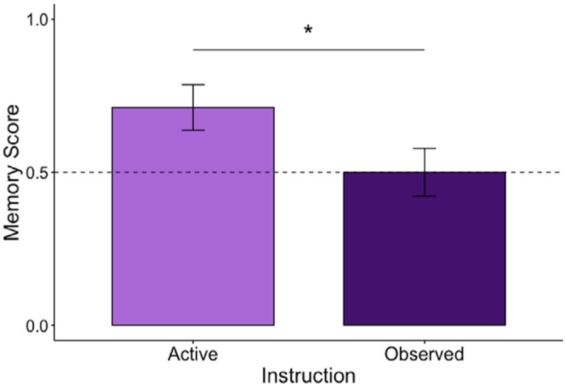

Fig. 5. Memory for active and observed toys. Bar graph of memory score for active and observed toys is shown. There was no effect of taught or generalization item on memory score; the graph collapses across taught and generalization items. Chance is .5. Error bars indicate ±1 standard error. $^*p < .05$.

learning of items and long-term memory for actions, it is possible that active experience could have also supported item learning and action memory.

It is possible that physical activity during instruction supported children's long-term visual recognition memory by enhancing encoding. Active experience involves the integration of sensorimotor (i.e., visual and manual) and proprioceptive cues about body positions in space (Knoblich & Sebanz, 2006), which contribute to rich multimodal representations of information (Rochat, 1989). Encoding multiple cues during learning could provide stronger episodic representations of performed actions compared with observed actions, which would be more likely to be stored in and retrieved from memory than information learned without sensorimotor integration (Hutmacher & Kuhbandner 2018; Markant et al., 2016). In addition, acting involves planning and executing motor commands (Barrett et al., 2008), which could have similarly deepened mental representations of learned information (Trewartha et al., 2015). The "motor-induced encoding effect" suggests that the degree to which motor information is processed, including preparing to act and executing actions, improves information encoding (Kinder & Buss, 2021).

In addition, physical activity could have guided children's attention to relevant information, focusing their attention on the actions they performed (Boudreau & Bushnell, 2000), similarly enhancing encoding. Although children were visually attentive to both active and observed instructions, during active instruction children could have targeted their attention toward the specific toy pieces they were manipulating and the actions they were performing. Focused attention supports learning (e.g., label learning; Pereira et al., 2009) and both short- and long-term memory (Amso & Scerif, 2015). Therefore, physical activity may have targeted children's attention toward self-performed actions, supporting their encoding of taught information (Markant et al., 2016).

Specifically, physical activity *during instruction* could have contributed to the memory difference between actively and observationally taught toys. Although active instruction took longer than observational instruction and included experimenter scaffolding, neither the assistance provided nor the time spent in active instruction was related to children's learning. Physical activity alone also cannot explain these findings. Children had the same amount of physical contact with the active generalization item and both observational items during the test phase, although they showed better memory for the generalization item paired with the actively taught toy compared with the observationally taught toy.

Interestingly, children's long-term visual recognition memory was enhanced for both the active taught and generalization items compared with the observational taught and generalization items. Even though children were not taught to perform actions on the active generalization item and only experienced that toy during the test phase, children's memory for the active generalization toys did not differ from their memory for the active taught toy. This may have occurred because children's enhanced physical engagement with the active taught toy transferred to their subsequent engagement with the matched active generalization toy during the test phase. This seems likely given toddlers' limited representational flexibility (Herbert & Hayne, 2000). It is possible that the memory advantage was due to this experience at test, which occurred post-encoding; assembling the active generalization items at test could have allowed children to store richer representations of the highly similar active toys, which in turn improved their long-term memory for the toy they had constructed actively during instruction as well as the matched generalization toy. If more dissimilar taught and generalization items had been used, children might not have transferred what they had learned as readily to the generalization toy.

It is possible that this physical activity during instruction, which may have transferred to the highly similar generalization item experienced post-encoding, supported children's long-term visual recognition memory. However, it is also possible that memory was enhanced after the test phase, perhaps facilitated by sleep (e.g., Seehagen et al., 2019; Stickgold & Walker, 2013), by integrating the newly encoded memories. From this study alone, we cannot know exactly how the memory benefit occurred, although we theorize that it was in part due to greater physical activity during instruction.

Unexpectedly, children did not differ in their immediate learning from active and observational instructions despite the wealth of research on the benefits of active experience for learning (e.g., Piaget, 1964) and generalization (Hmelo-Silver et al., 2007). This may have occurred because both conditions were highly supportive of learning. In this within-participants design, children experienced active and observational instruction on separate toys (with the instruction order counterbalanced). The teaching conditions varied only by whether the child or the experimenter performed the actions to be learned. The instructions were efficient and contained all the information children needed to learn the target actions. Although there was variability in children's action learning, this was due to children's cognitive maturity rather than the instruction style in which the actions were taught. The instructions were also presented in a highly collaborative context, which may have caused children to take an active stance when learning (Knoblich & Sebanz, 2006) even when children were not acting. Indeed, in collaborative environments, children may become confused about who performed actions and may overclaim another person's actions as their own (Sommerville & Hammond, 2007). It is also possible that children learned and generalized the taught actions more effectively from active instruction than from observed instruction, but the immediate learning test did not capture these differences. A more challenging task may have revealed underlying learning and generalization differences between conditions.

It is possible that effects of active experience on immediate learning could have been seen if children had been more active during instruction. In the active condition, the experimenter explained where each piece should be placed, handed children the piece, and guided children to perform each action correctly. Thus, children were physically active, but their actions were constrained by the experimenter. Research with older children and adults has shown that when learners can make decisions during active learning, such as by controlling the flow of information (Gureckis & Markant, 2012), making discoveries (Dean & Kuhn, 2007), and encountering failure (DeCaro & Rittle-Johnson, 2012), learning is enhanced. Here, we manipulated only physical activity to ensure that children had equal access to the actions to be learned, providing a direct comparison of instruction contexts. Young children may learn more effectively when active experience includes opportunities to make decisions.

Importantly, when toddlers were active during learning, they were active in the context of instruction. A teacher guided children to the correct actions by providing prompts, corrections, and demonstrations when children struggled. With the teacher's guidance, nearly all children performed the taught actions with perfect accuracy. Children could not have learned through completely unguided activity because they would not have known which actions were the target actions to be learned. Indeed, children of the same age who learned to assemble similar toys from caregiver instruction in Brezack et al. (2021) were also tested on control toys for which no instruction had been provided. Without guidance, children rarely assembled the control toys correctly (Brezack et al., 2021). Therefore, instruction was necessary for action learning. Although all the relevant action information to be learned could be gained from observing the teacher's actions, in a situation where instruction was necessary for learning, guided active experience supported children's long-term visual recognition memory.

Here, we used novel toys to induce familiar, playful learning environments, but active experience may also be important for children's memory when learning actions on real-world artifacts such as utensils and tools. When caregivers or teachers teach children to use artifacts in everyday contexts, providing children with opportunities to actively engage during learning could similarly benefit their memory. Alternatively, in real-world contexts, children's active experience may be discouraged to avoid costly mistakes (Gaskins & Paradise, 2010). Future studies should address whether active experience during instruction benefits children's memory across more diverse contexts and cultures. In addition, due to the COVID-19 global pandemic, the methods used in the memory follow-up measure were limited and this measure had a relatively small sample size. We also could not re-assess children's cognitive maturity during the follow-up. These limitations could be addressed in future work.

In sum, when children were instructed to perform novel actions by acting rather than observing actions, they had better long-term visual recognition memory for the taught material. Children's cognitive maturity, not the instruction condition, affected their immediate action learning and generalization; children who were more developmentally advanced learned and generalized regardless of whether they had been active during the learning process. Despite the role that children's cognitive development plays in learning, physically active experience during instruction benefitted children's long-term visual recognition memory. This may be due to features of physical activity (enacting motor commands, sensorimotor integration, and focused attention), which may have improved encoding, storage, or retrieval of taught information from memory. Instructions featuring opportunities for children to act seem particularly important for supporting children's long-term memory.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2023.105670.

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