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Varieties of social learning in children: Characterizing the development of imitation, goal emulation and affordance learning within subjects and tasks

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ABSTRACT

Children's social learning (SL) is characterized by significant variation. Explaining when and why children excel in some SL problems but not others is an unappreciated but significant problem in the developmental sciences. Here, two studies explore different forms of SL in preschoolers (3–6 years) using two tablet-based tasks, Cognitive and Spatial. These tasks involve sequencing items by their identity (e.g., Apple→Boy→Cat) or spatial location (e.g., Top→Bottom→Right). Experiment 1 (n = **189**) explored children's ability to learn different sequences by individual—trial-and-error—learning (baseline), recalling these individually learned sequences after a brief delay (recall), copying a novel sequence following a demonstration (novel imitation), and copying a familiar sequence that had been previously learned by trial and error (familiar imitation). Experiment 2 (n = **99**) measured novel imitation and individual recall in addition to children's ability to learn different sequences from a model's mistake (goal emulation) and from physical/symbolic feedback provided automatically by a tablet (i.e., ghost condition). Results showed that familiar imitation and goal emulation developed early across tasks. Whereas novel imitation and ghost (affordance) learning developed late. An exploration of the dimensionality of these skills showed that imitation (Exp. 1), whether familiar or novel, was domain-specific. In contrast, emulation (Exp. 2) was multi-dimensional in the Spatial Task but unidimensional in the Cognitive Task. These results highlight the mosaic nature of children's SL development. Results provide a model for explaining some of the observed variation in children's performance across task and research paradigms. This information can be used to better predict when and why children are likely to succeed (or fail) in SL tasks.

1. Introduction

Like other primates (Bard, 2007; Ferrari et al., 2006; Myowa-Yamakoshi et al., 2004),[1] humans are precocious social learners (Meltzoff et al., 2018). However, in contrast to other primates, human social learning (SL) evidences significant quantitative (i.e., fidelity of copying) and qualitative (i.e., breadth of problems) developmental changes during the preschool years—between 3 and 6 years of age—(Speidel et al., 2021; Subiaul et al., 2016; Vanvuchelen et al., 2011a, 2011b; Yu & Kushnir, 2020). Similar developmental changes have not been observed in other great apes (Tomasello & Carpenter, 2005), including those who have received human

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[1] Evidence includes neonatal imitation in rhesus monkeys (Ferrari et al., 2006) and chimpanzees (e.g., Bard, 2007).

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enculturation (Subiaul, 2016).

A hallmark of human SL is its robustness and flexibility (Tomasello, 2016). Depending on the problem, children can faithfully imitate observed actions, infer an intended response from a model's error (i.e., goal emulation), along with the affordances of objects (i.e., affordance learning) or their end-states ("end-state emulation"), among other indirect learning skills (Tomasello, 2016). In fact, our species' ability to flexibly alternate between faithful copying and inferential SL (emulation) are believed to underly another uniquely human trait, cumulative cultural evolution (Legare & Nielsen, 2015; Subiaul & Stanton, 2020). Table 1 summarizes various SL and asocial learning terms as well as relevant domains.

An open set of questions in the developmental sciences is, *what explains developmental changes in SL?* And *are such changes mediated by different SL skills that are uni- or multi-dimensional?*

Existing evidence suggests that early in development (between 12 and 24 months), the copying of vocalizations (e.g., eh-eh), familiar intransitive gestures (e.g., waving bye-bye), and simple, transitive actions on objects (e.g., shaking a rattle), develop continuously with other sensory-motor skills (Jones, 2007; Young et al., 2011). Such results imply a single unidimensional, domain-general, SL mechanism. However, after the second birthday, SL skills begin to diversify and evidence domain- and content-specificity (Piaget, 1951; Subiaul et al., 2012; Subiaul et al., 2015; Uzgiris & Hunt, 1987; Vanvuchelen et al., 2011b; Vanvuchelen et al., 2011; Yu & Kushnir, 2020). For example, Vanvuchelen and colleagues (2011a, 2011b; 2011) tested a large sample (n = 498) of young children (12–59 months) on a battery of imitation tasks, the *Preschool Imitation and Praxis Scales* (PIPS). Tasks in the PIPS included different gestural responses (e.g., bye-bye; pretend to comb hair) as well as instrumental forms of imitation (e.g., manipulating objects), each varying in complexity (e.g., uni- vs. bi-manual actions), cognitive load (single vs. serial responses), and reinforcement type (e.g., type of feedback). A principal components analysis produced four distinct imitation domains: (1) single bodily imitation (e.g., tapping head), (2) goal-directed procedural imitation (e.g., opening a bottle), (3) sequential bodily imitation (e.g., copying head-shoulders-knees actions) and (4) non-goal-directed procedural imitation (e.g., copying novel, arbitrary acts such as a password). As expected, there were robust correlations with age and developmental level. Older children excelled in all four imitation domains, whereas the youngest children performed well only in the single bodily imitation and goal-directed procedural imitation domains. These results indicate that during the preschool years, SL—and imitation, specifically—is multi-dimensional with distinct developmental trajectories.

Consistent with this conclusion are results from a study that explored individual differences in children's SL using a variety of procedural, instrumental and language tasks (Yu & Kushnir, 2020). Among these were variations of the Horner and Whiten (2005) puzzle box (Brugger et al., 2007; Lyons et al., 2011; Nielsen et al., 2012; Yu & Kushnir, 2014) as well as a task developed by Carpenter et al. (2005)—"Puppet Show"—to assess action (and vocal) imitation versus goal emulation in infants (12–18 month olds). The battery also included a version of a word learning task originally developed by Tomasello and Barton (Henderson & Graham, 2005; Tomasello & Barton, 1994). Besides SL, Yu and Kushnir (2020) also evaluated children's causal knowledge, theory of mind, prosociality, as well as temperament and language skills, among others. Results produced two distinct constructs—faithful imitation and goal emulation—that together explained over 50% of the variance in children's SL performance. Besides age, prosociality, and temperament, few other skills (e.g., language, causal learning, executive functions) significantly predicted imitation or goal emulation performance.

Although significant, these results raise several questions. For instance, out of the three sets of puzzle boxes used by Yu and Kushnir (2020), two correlated (Brugger et al., 2007; Nielsen et al., 2012; Yu & Kushnir, 2014) but the third set (Horner & Whiten, 2005; Lyons et al., 2011) did not.[2] Why? Yu and Kushnir (2020) suggest that the third group of puzzle boxes were more causally complex. But neither causal learning nor working memory correlated with overall imitation or goal emulation scores in their study. Besides possible differences in the number of causal representations child had to make in each task, the puzzle boxes used also differed in size and the number of responses children observed. Moreover, demonstrations and required responses likely varied in familiarity and motor complexity. Thus, variation in these tasks may be explained by differences in spatial cognition (Vasilyeva & Lourenco, 2012), sensory-motor representations (Adolph & Hoch, 2019), cognitive load (Barr et al., 2016; Burch et al., 2010; Harnick, 1978; Subiaul & Schilder, 2014; Wiebe et al., 2010), the number of familiar "enabling relations" (or familiar causal elements) involved in each task (Bauer, 1992), the goal structure of multiple responses (Loucks & Meltzoff, 2013; Loucks et al., 2017), among others known to affect whether children imitate or emulate (Speidel et al., 2021; Subiaul & Schilder, 2014). In other words, to fully appreciate individual differences in SL, one must deconstruct these complex tasks into more basic, elemental components, concepts, and representations (Subiaul et al., 2016).

Unfortunately, most tasks commonly used in SL research, while high in ecological validity, are low in stimulus control. They are simply too complex to isolate which representations or concepts are guiding children's SL. A response to this has been to develop tablet-based tasks that afford greater stimulus control. Though rarely used in cognitive development research, there is evidence that measuring social and asocial learning using tablets can be very successful with young children (Chetcuti et al., 2019; Gerhardstein & Rovee-Collier, 2002; Moser et al., 2015; Renner et al., 2021; Subiaul & Schilder, 2014; Zack et al., 2009). Another benefit of these tasks is that they are linguistically and culturally-neutral as well as based on an intrinsically rewarding rapid learning mechanism (Herodotou, 2018). These task features make them highly efficacious for assessing learning in young children (Herodotou, 2018). A

[2] Yu and Kushnir (2020) are not the first to encounter this problem. Various studies that have developed puzzle boxes have found that imitation in one does not always predict imitation in other analogous puzzle boxes that are equivalent in size, cognitive load and action types Lyons, D. E., Young, A. G., & Keil, F. C. (2007). The hidden structure of overimitation. *Proc Natl Acad Sci U S A*, *104*(50), 19751–19756. https://doi.org/10.1073/pnas.0704452104. The fact that tasks that we expect to correlate do not, tell us we do not fully understand the tasks or factors controlling performance in them.

Table 1
SL concepts and domains. Note SL concepts are content-independent and apply to different sensory and cognitive domains.

SL Concepts	Description	Source
Social Learning (SL)	Learning based on direct or indirect interactions with individuals or artifacts.	(Nielsen et al., 2012; Zentall & Galef, 1988)
Asocial Learning	Learning resulting from happenstance, trial-and-error, or inferences derived from either; learning from oneself; individual learning (Kendal et al., 2018).	(Heyes, 2012; Lombrozo, 2019; Kendal et al., 2018)
Novel Imitation	Faithfully copying an unfamiliar, novel response, or new sequence of familiar acts.	(Subiaul et al., 2012)
Familiar Imitation and Automatic Imitation	Reproducing a familiar (previously learned) response(s); sometimes without awareness (i.e., "automatic").	(Rumiati & Tessari, 2002; Subiaul et al., 2012), Heyes, 2011)
Goal Emulation (Behavioral Re-Enactment)	Reproducing a model's intended (but unobserved) response to achieve a goal; "copying goals"; (c.f., *intentional* stance).	(Meltzoff, 1995; Carpenter et al., 1998a,1998b, 1998c; Dennett, 1987; Whiten et al., 2004a)
End-State Emulation (Reverse Engineering)	Inferring the actions necessary to reproduce an observed outcome; "copying results" (c.f., *design* stance).	(Dennett, 1987; Huang & Charman, 2005)
Affordance Learning (Ghost Control/Condition)	Identifying and reproducing functional properties of artifacts; "Copying effects" (c.f., *design* or *physical* stance, respectively).	(Hopper, 2010; Dennett, 1987; Huang & Charman, 2005)

SL Domains		
Cognitive	Abstract (symbolic) content or functions including ordinal, categorial, hierarchical and sortal rules.	(Byrne & Russon, 1998; Subiaul, 2010; Williamson et al., 2010)
Motor/ Spatial	Transitive responses directed toward objects and/or locations in space	(Subiaul, 2010; Subiaul et al., 2015)
Gestural	Intransitive acts with a defined topography and spatial-temporal features (can vary in communicative meaning).	(Rumiati et al., 2009; Rumiati & Tessari, 2002)
Vocal	Words or vocalizations with or without linguistic content or identifiable meaning (communicative)	(Belyk et al., 2016; Subiaul et al., 2016)

growing body of research shows that tablet SL tasks predicts SL on "real-world" 3D tasks (Rusnak, 2020; Subiaul et al., 2016). Additionally, children with autism who often have motor imitation deficits when tested 3D—object-based—tasks have similar deficits in 2D tablet-based tasks that involve copying simple gestures (e.g., slide) or movement trajectories (Chetcuti et al., 2019; Stewart et al., 2013).

A few labs have used touchscreen or tablet-based SL tasks to isolate social and asocial learning within-subjects among preschoolers (Moser et al., 2015; Renner et al., 2021; Subiaul et al., 2012). For instance, Subiaul and colleagues, across different studies, have presented children with various serial learning problems (Spatial, location-specific representations, Fig. 1A: Up→Down→Right; Cognitive, item-specific representations: Fig. 1B: Apple→Boy→Cat). Each tap into basic representations present in most real-world SL problems (Rachwani et al., 2021; Rachwani et al., 2020; Vasilyeva & Lourenco, 2012). Specifically, these tasks isolate item-specific—"what" —representations (i.e., identifying different objects or their parts) and location-specific— "where"—representations (i.e., where in space to launch actions) as well as temporal/causal-specific—"when"—representations (i.e., what objects to respond to, where, and when). The cognitive (item-specific) and spatial (location-specific) tasks are now well-characterized. These tasks have been used widely in comparative (Renner et al., 2020; Subiaul et al., 2004; Terrace, 2005), developmental (Rusnak, 2020; Subiaul et al., 2012; Subiaul et al., 2015) and cognitive neuroscience (Renner et al., 2018) studies.

Subiaul and colleagues have shown that children can learn different sequences in each task tasks using SL and asocial learning skills. For instance, in the baseline learning condition, children discover sequences entirely by trial and error. During individual recall, children must retrieve from memory the serial rule learned previously in Baseline following a brief delay. Of course, children can also learn new sequences indirectly via imitation, where a model demonstrates the target sequence; by goal emulation, where the model responds correctly to the first item in the sequence (i.e., Apple) and then skips the second item (i.e., Boy) and touches the last item (i.e., Cat), resulting in an error (Apple→Cat); or, by inferring the affordances of a tool based on physical/symbolic cues (Ghost Control). See table Table 1 for more information.

Results across different studies have showed age-related effects that vary depending on domain and learning type (Renner et al., 2020; Subiaul et al., 2015). For instance, multiple studies have shown that 3-year-olds can successfully copy novel "what-when" *item* sequences, but not novel "where-when" *spatial* sequences demonstrated by either a live (human) model or the computer; "ghost control" (Renner et al., 2020; Subiaul et al., 2012; Exp. 1; Subiaul et al., 2015). Yet, the same 3-year-olds, have no difficulty recalling newly learned spatial rules (Renner et al., 2020; Subiaul et al., 2012; Exp. 2; Subiaul et al., 2015), nor imitating meaningful spatial sequences that follow a linear sequence of right to left(Subiaul et al., 2012; Exp. 4). 3-year-olds can also produce a novel spatial sequence in a goal emulation condition, where they had to infer rather than replicate the demonstrated response (Subiaul et al., 2012; Exp. 3).

But despite these categorical distinctions between imitation, goal emulation and ghost (affordance) learning, some have hypothesized that varieties of SL lie along a continuum of copying fidelity or selectivity (Whiten et al., 2004b; Whiten et al., 2009). According to this view, all forms of SL share a common set of cognitive processes that are universal and domain-general (c.f., Heyes, 2012). For example, although Whiten & Ham, (1992, 2004b) reject that SL is mediated by associative processes and devoid of mental-state reasoning, they, nonetheless "interpret some of the varieties of what has been called emulation as overlapping with imitation in important ways, rather than as offering a neat dichotomy" (Whiten et al., 2004b: p. 38). To our knowledge, this assumption that varieties of emulation overlap with imitation has not been empirically tested within-subjects.

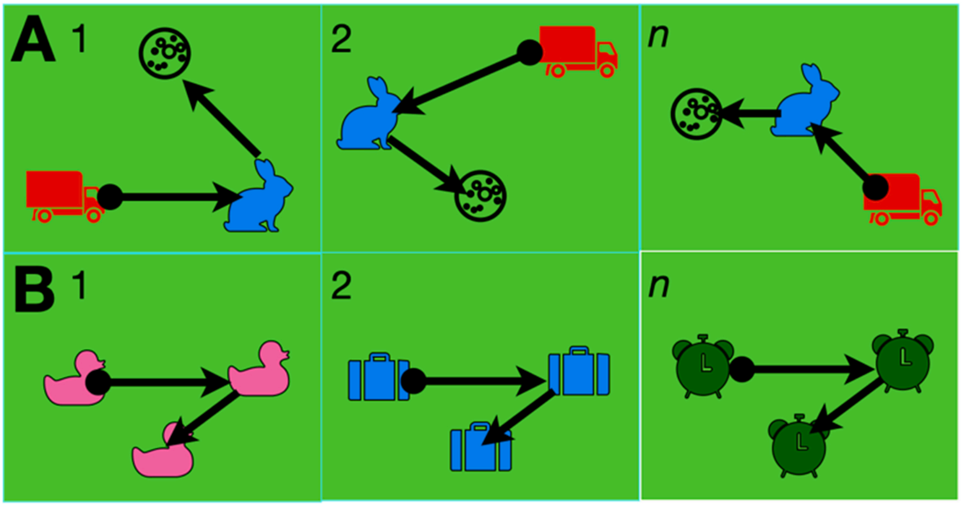

Fig. 1. Tablet-Based Serial Learning Tasks: (A) Cognitive (Item) Task, children must sequence different items that change spatial location from trial to trial. The goal in the Cognitive Task is to learn an item-specific "what-when" rule. (B) Spatial Task, children must sequence identical items that do not change spatial location from trial to trial. The goal in the Spatial Task is to learn a location-specific "where-when" rule.

To fill this gap, Experiment 1 explored the relationship between two different forms of imitation—familiar and novel imitation—a distinction first made by Piaget (1951). For many, in the comparative and developmental sciences, imitation corresponds to *new* learning (i.e., relative to a baseline, control condition). However, in the neurosciences, many paradigms involve copying common responses such as lifting an index finger, relative to other fingers (Iacoboni et al., 1999) or opening and closing one's hand (Heyes et al., 2005). These latter instances involve no new learning. Experiment 1 directly contrasted these two forms of imitation within subjects. Experiment 2 took a similar approach for two different forms of emulation that are rarely contrasted in experimental studies in the cognitive sciences[3]: goal emulation or behavioral 're-enactment' of an intended response/goal (Carpenter et al., 1998a,1998b,1998c; Meltzoff, 1995) and affordance learning as measured by a ghost control (Renner et al., 2020; Subiaul et al., 2004). Although rarely explored together in young children, the available evidence indicates significant variation in both (Huang & Charman, 2005; Huang et al., 2002).

These two studies sought to test first and foremost the hypothesis that *SL performance across social conditions co-vary* (Hypothesis 1, Exp. 1 & 2). Additionally, based on prior work by our group, it was hypothesized that *familiar imitation develops before novel imitation across tasks* (Hypothesis 2, Exp. 1). However, *only novel—not familiar—imitation performance is domain/task-specific* (Hypothesis 3, Exp. 1); It was also hypothesized that *goal emulation develops before ghost—affordance—learning* (Hypothesis 4, Exp. 2) and that *learning in the ghost condition evidences the same type of domain-specificity observed for novel imitation.*

2. Experiment 1

2.1. Methods & procedures

2.1.1. Participants

189 racially and ethnically diverse children (White =58%, Black = 6%, Asian = 12%, Native American = 0.05%, Hispanic = 6%, Mixed = 13%, Other = 2%, N/R = 4%) ranging in age from 3 to 6 years of age (M = 52.97 months, SD = 9.77, Females = 95) participated in the study while visiting the National Building Museum in Washington, DC. Prior to testing, parents were approached by undergraduate research assistants (RAs) trained by the PI (Subiaul) and approved by GWU IRB as they and their child visited the museum. RAs introduced themselves and briefly described the study, including the population of interest (children between ages 3 and 5). They then asked the parent if their child could participate. If they agreed, both parent and child were directed to a corner where another RA was set up for testing. For assent, RAs asked the child if they wanted to play with them. If the child refused after 2 additional requests, RAs played with them (i.e., giving them stickers and encouraging them to put it on their "sticker page"; 7.5'' X 11'' white paper) and then told the parents testing was complete. The same was done for children who refused to continue after testing

[3] An exception are the elegant studies by Huang and colleagues (2002; 2005). Huang, C. T., & Charman, T. (2005). Gradations of emulation learning in infants' imitation of actions on objects. *Journal of Experimental Child Psychology*, *92*, 276–302., Huang, C. T., Heyes, C., & Charman, T. (2002). Infants' behavioral reenactment of "failed attempts": exploring the roles of emulation learning, stimulus enhancement, and understanding of intentions. *Dev Psychol*, *38*(5), 840–855. https://www.ncbi.nlm.nih.gov/pubmed/12220059

started (i.e., withdrew assent).[4] All 189 children completed at least two conditions and included in at least some analyses (e.g., correlations, PCA). Of these, 136 completed all testing condition in both tasks (included in repeated measures ANOVA). An additional 17 children were enrolled but not tested for the following reason: failed to complete more than 1 condition = 6, child refused to participate = 10; parental interference = **1.**

2.1.2. *Experimental tasks*

Children were presented with two different computer tasks: cognitive and spatial (Fig. 1). In both tasks, 3 pictures are displayed simultaneously throughout each trial (Fig. 1) on a Macintosh desktop computer with a 54.61-cm Magic Touch (Keytech; Garland, TX) detachable screen. In the cognitive task, the identity of the 3 pictures on the screen is different and their spatial arrangement is varied randomly from trial to trial (Fig. 1A). This task assesses children's ability to learn an item-based "what-when" (henceforth, "what") rule. In the motor–spatial task, the identity of the 3 pictures on the screen is the same and their position on the screen remains constant. However, from trial to trial the picture changes (Fig. 1B). This task assesses children's ability to learn a location-based "where-when" (henceforth, "where") rule. For both tasks there are 3 pictures on the screen. In the case of the cognitive task, the pictures appear in a unique spatial arrangement every trial. In the case of the spatial task, the pictures change identity but remain in a fixed position for every trial during a session. Reinforcement is dependent upon touching the target item in the correct order. In both tasks, when children respond to all 3 pictures in the correct order, a 5 s video clip of a man doing a backward somersault—" jumping man" —accompanied by music or clapping plays in the middle of the screen. An analogy would be going to an Automated Teller Machine (ATM) with just three buttons. The buttons on the "Cognitive" ATM are labelled 1, 2, 3. To retrieve money, buttons must be touched in a specific order: 1–2–3 (as in a typical ATM). However, unlike typical ATMs, every time you go to the Cognitive ATM, the buttons/ numbers are in a *different* spatial location. Yet, the password is the same: 1–2–3. In contrast, the buttons in the "Spatial" ATM always have the *same* number (e.g., 1–1–1), appear in the same location and must be touched in a fixed sequence (Top→Bottom→Left). Every time you go to the Spatial ATM, the number on the buttons change (e.g., 2–2–2 or 3–3–3) but their location and sequence remain the same (Top→Bottom→Left).

One of the unique benefits of this task is that it allows for the manipulation of different forms of learning (social, asocial) within subjects and tasks without carry-over or practice effects. Consequently, differences in performance cannot be explained by differences in affordances or underlying constructs.

2.1.3. *Training & testing*

To control for experience with the task, approximately half of the children (n = 104) were trained on each task prior to testing.[5] Briefly, training procedures mirrored those described below for Baseline. During training children were encouraged to touch all pictures on the screen in the target order. When they touched a picture out of sequence, the RA provided the child with social feedback (Whoops!) and encouragement (e.g., Let's try again. What do you think is Picture #1?). Correct responses were followed by social praise, (e.g., "That's right. What's next?" after touching pictures 1 and 2). When they touched all 3 pictures, the RA would say "Yay! You found Jumping Man!" The remaining children were tested without any prior exposure to the tasks.

Testing consisted of one session per child. Using a repeated measures design, children completed a total of 8 sequences (4 on the cognitive task and 4 on spatial task) blocked by task and presented in counterbalanced order with half starting with Cognitive Task. This procedure was used to avoid confusion or interference between tasks. The order of learning conditions within those tasks was also counterbalanced. The one exception to this counterbalancing scheme was that the Baseline condition was always followed by the Recall condition or the Familiar Imitation condition. This was done because participants needed to learn the 'what' or 'where' rule before recalling or imitating it.

The two asocial learning conditions were baseline and recall:

2.1.4. *Baseline (trial & error learning)*

Children were encouraged to discover the correct sequence entirely by trial-and-error. Upon touching all pictures correctly and the Jumping Man video finished, the computer was turned away from the child for 10 s, and the child's attention was diverted to placing a sticker and/or stamp on an 11 × 17 sheet of white printing paper.

2.1.5. *Recall*

Ten-seconds after the completion of Baseline, the computer was turned back around and the child was told, "Okay, it's your turn . Can you find jumping man again? Remember, start with picture number 1." The same sequence from the Baseline condition was used in the Recall condition to assess the child's ability to encode and recall a previously learned rule.

The two SL conditions were novel imitation and familiar imitation:

2.1.6. *Novel imitation*

The experimenter faced the child and said, "Watch me!" and then proceeded to touch pictures in the target sequence (e.g., A→B→C) three consecutive times. Immediately after the third and final demonstration, the experimenter faced the child and exclaimed, "Yay! I

[4] Parents who insisted or pleaded with their child to participate were told about the importance of child assent and participation without any type of coercion.

[5] Refer to Subiaul et al. (2012) for details concerning training procedures.

found Jumping Man! Ok, now it's your turn. Can you find Jumping Man? Remember, start with picture number 1."

2.1.7. *Familiar imitation*

Immediately following the completion Baseline, the experimenter faced the child and said, "Watch me!" In contrast to the novel imitation condition described above, where the model responded to novel items on the screen, in this condition, the model responded to the *same* items the child had just discovered on their own in Baseline. Hence, responding to a familiar sequence.

The Baseline list learned prior to the Recall condition was different to that learned prior to the familiar imitation condition. In effect, children learned two different baseline lists, one for Recall and another for Familiar Imitation.

Because both tasks used these same conditions, we will refer to each by first identifying the task and then the condition (e.g., cognitive novel imitation, spatial recall).

Learning conditions are summarized in Fig. 2.

For all conditions, once a child successfully responded to all items on the screen and found Jumping Man, the condition was terminated, and the next condition began until testing was complete. In all conditions, except Baseline, the child was allowed to skip to the next trial if, for example, the child excessively perseverated on a picture or spatial location or was otherwise unable to discover the correct sequence within 5 trials (the total number of trials given to discover the target sequence). For all children, testing lasted approximately 10–15 min.

2.1.8. *Measure of learning*

A learning ratio measure was calculated for each condition. The ratio was calculated as the total number of correct responses (i.e., touching an item in the target order) divided by the total number of trials it took to discover the target sequence. For example, if a child responded correctly to all the items on the screen on trial 3 but had pressed 5 items correctly in previous trials (e.g., correct responses on trial 1 = 1, trial 2 = 1, trial 3 = 3), the ratio would be 5/3 = 1.67. The learning ratio significantly correlated with first trial accuracy (Exp. 1 and 2, all rs >.88 [range.89 −.98], all ps <.001).

While children were tested, parents completed the *Behavior Rating Inventory of Executive Function OR BRIEF-P (*Gioia et al., 2003*)* a standardized rating scale for children aged 2–5 years that evaluates common behaviors that have been linked to particular executive functioning domains. However, in this study we did not evaluate these results.

These procedures were reviewed and approved by the George Washington University's Institution Review Board (IRB#051134). All data can be found in the OSF website: https://osf.io/3bmt9/.

3. Results

Preliminary data analysis explored effects of sex, testing order, and training on performance. None were significant predictors of performance. Consequently, they were excluded from further analysis. To evaluate task, condition, and age-effects, a repeated measures ANOVA was used. The ANOVA included 2 Tasks (Cognitive, Spatial) X 4 Condition (Baseline, Recall, Familiar Imitation, Novel Imitation) as repeated measures and Age Group (3-, 4-, 5-year-olds) as a between-subjects factor. The sphericity assumptions were met (Condition: Mauchly's W =.977, $p = .69$, Task X Condition: Mauchly's W, $p = .70$), so no correction procedures were used.

There was a main effect for Task, F(1,8) = 10.02, $p < .01$ (Cognitive > Spatial), Condition, F(3,8) = 56.24, p < .01 (Baseline < Novel Imitation < (Familiar Imitation = Recall)) and Age-Group, F(2,8) = 23.76, $p < .01$ (3- < 4- < 5-year-olds). There were also significant interactions between Task X Condition (F(2133) = 4.51, $p < .01$), Condition X Age-Group (F(6399) = 3.09, $p < 01$) and Task X Condition X Age Group (F(6399) = 2.40, $p = .03$). Results are summarized in Table 2.

To better understand the 3-way interaction, two different ANOVA were run, one for each task.

3.1. *Cognitive task*

Sphericity assumptions were met (Mauchly's W =.99, $p = .88$), so there was no need for correction procedures. There was a main effect for condition (F(3,6) = 21.85, p < .01, $\eta^2 = .13$) and age group (F(2151) = 17.69, p < . 01, $\eta^2 = .06$). However, the condition X age group interaction was not significant (F(6453) = 1.12, p = .35, $\eta^2 = .01$). Pairwise comparisons showed that all age groups' performance in the various learning conditions was generally better than baseline (all $ps < .01$) except for 3-year-olds' ($p = 1.0$). Groups did not differ in recall performance (all $ps > .50$). Although, 3-year-olds performed poorly on novel imitation relative to both 4- ($p = .04$) and 5-year-olds (p < .01). 3-year-olds also performed worse than 5-year-olds on familiar imitation ($p = .03$). However, no other contrast was statistically significant. Results are summarized in Fig. 3.

3.2. *Spatial Task*

Sphericity assumptions were met (Mauchly's W =.98, $p = .55$), so no correction procedure was used. There was a main effect for condition (F(3,6) = 53.02, p < .01, $\eta^2 = .18$) and age group (F(2160) = 14.90, p < . 01, $\eta^2 = .04$) as well as a significant condition X age group interaction (F(6480) = 6.50, p < .01, $\eta^2 = .04$). This interaction was driven by the fact that 3-year-olds performed significantly worse than older children (4- and 5-year-olds) in novel imitation, relative to other learning conditions (c.f., Fig. 3). Pairwise comparisons showed that all age groups' performance in the learning conditions was generally better than baseline (all $ps < .01$) except for 3- and 4-year-olds' performance in novel imitation ($p = 1.0$). Groups did not differ on recall or familiar Imitation (all $ps > .10$). All age groups differed on novel imitation (all $ps < .01$). Results are summarized in Fig. 3.

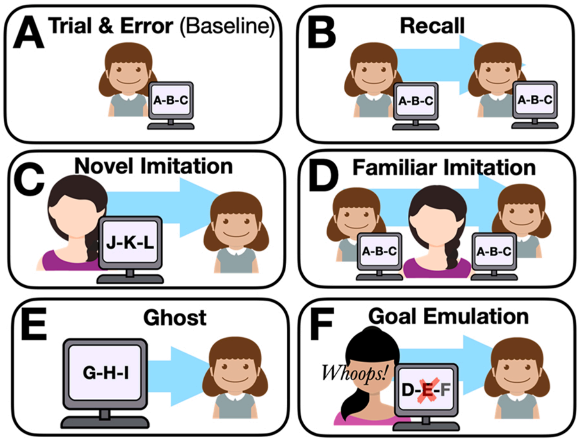

Fig. 2. Learning Conditions in Experiment 1 and 2. Sequences in the different serial learning tasks can be learned in a variety of ways. (A) Trial-and-error learning (Baseline): Children discover sequences independently; (B) Recall: Upon discovering the sequence by trial and error, the child is asked to recall the same sequence; (C) Novel Imitation: Model demonstrates a new sequence prior to the child responding; (D) Familiar imitation: Model demonstrates a familiar sequence that the child had previously discovered on their own; (E) Ghost (Affordance Emulation): Measure of affordance learning where the computer highlights the pictures on the screen in the target sequence; (F) Goal Emulation: model responds to the first and then the last item in the sequence, making an error that allows the child to infer which is the correct sequence. Experiment 1 included conditions A-D. Experiment 2 included conditions A, B, E and F.

Table 2
Exp. 1 Summary Results for Repeated Measures ANOVA.

A. Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
Task	7.05	1	7.05	10.02	< .01	0.07
Task X Age Group	0.74	2	0.37	0.53	0.59	0.01
Residuals	93.63	133	0.70			
Conditions	108.50	3	36.17	56.24	< .01	0.30
Conditions X Age Group	18.56	6	3.09	4.81	< .01	0.07
Residuals	256.56	399	0.64			
Task X Conditions	8.00	3	2.67	4.51	< .01	0.03
Task X Conditions X Age Group	8.49	6	1.42	2.40	0.03	0.04
Residuals	235.56	399	0.59			

B. Between Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
Age Group	47.570	2	23.76	34.82	< .01	0.34
Residuals	90.861	133	0.683			

Note. Type III Sum of Squares

While highlighting differences in performance, none of these results tell us whether these social (imitation) and asocial forms of learning (recall) co-vary and are uni- or multi-dimensional.

Using the promax rotation method because some variables were correlated (c.f., Table 3) and excluding missing cases listwise, the PCA produced three 3 components with Eigen values of 1 or greater (Table 4). The component correlations between factors were low (0.17 – 0.24). Specifically, there were two domain-specific components, corresponding to distinct imitation domains: cognitive imitation (RC1) and spatial imitation (RC2). The third component was domain-general, encompassing individual recall in both the cognitive and spatial task (RC3). Each component accounted for approximately 20% of the variance (cumulative = 62%). Correlations are summarized in Table 3. PCA results are summarized in Tables 4 and 5.

4. Discussion

There was a remarkable degree of variation in children's SL performance across tasks and learning conditions as evidence by the 3-way interaction between task, condition, and age. Observed main effects and interactions had moderate (.07) to large (.34) effect sizes. 5-year-olds consistently performed better than 3- and 4-year-olds on novel imitation. Yet, across tasks, age groups did not differ in terms of individual recall. Though, perhaps tellingly, on the Spatial Task, 3- and 5-year-olds performed better in familiar imitation than individual Recall (c.f., Fig. 3). These results are consistent with Hypothesis 2, whereby performance in familiar imitation is more robust

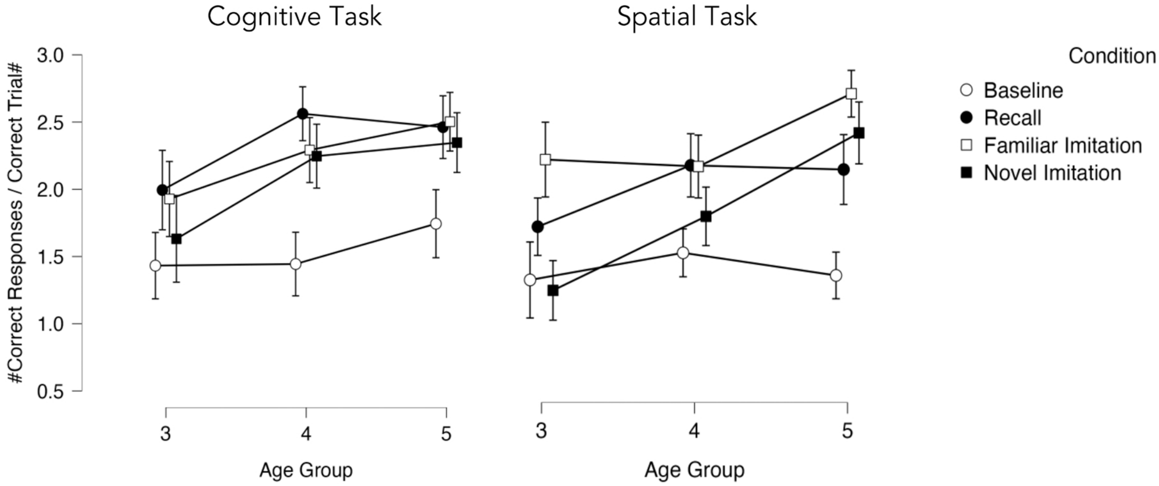

Fig. 3. Experiment 1: Mean Learning Ratio Across Tasks, Conditions and Age-Groups. Note: Error bars correspond to 95% CI.

Table 3
Pearson's correlation of all experimental condition.

			A. COGNITIVE			B. SPATIAL		
		Age (months)	Recall	Familiar Imitation	Novel Imitation	Recall	Familiar Imitation	Novel Imitation
A. COGNITIVE								
Recall	**n**	**169**	—					
	r	**0.229**	—					
	p-value	**0.003** * *	—					
Familiar Imitation	**n**	**169**	**160**	—				
	r	**0.274**	**0.156**	**—**				
	p-value	**< .001** * **	**0.049** *	**—**				
Novel Imitation	**n**	**170**	**161**	**162**	—			
	r	**0.319**	**0.163**	**0.253**	—			
	p-value	**< .001** * **	**0.039** *	**< .001** * **	—			
B. SPATIAL								
Recall	n	180	161	161	162	—		
	r	0.071	*0.149*	0.082	0.105	—		
	p-value	0.344	0.058ˆ	0.303	0.184	—		
Familiar Imitation	**n**	**174**	157	158	158	169	—	
	r	**0.205**	0.060	0.054	0.066	0.066	—	
	p-value	**0.007** * *	0.459	0.497	0.410	0.397	—	
Novel Imitation	**n**	**179**	159	159	**161**	173	168	—
	r	**0.472**	0.130	0.079	**0.207**	*0.148*	*0.143*	—
	p-value	**< .001** * **	0.102	0.322	**0.008** * *	0.052ˆ	0.064ˆ	—

ˆp < 0.10, *p < 0.05, **p < 0.01, *** p < 0.001.

Table 4
Component Loadings.

	RC1	RC2	RC3	Uniqueness
COG-Novel Imitation	0.798			0.366
COG-Familiar Imitation	0.776			0.403
SPA-Familiar Imitation		0.882		0.271
SPA-Novel Imitation		0.628		0.427
COG-Recall			0.825	0.353
SPA-Recall			0.708	0.472

Note. Applied rotation method is promax. COG = Cognitive Task, SPA = Spatial Task.

than, and developmentally predates, novel imitation. Children, generally, did not differ in terms of familiar imitation, performing similarly in both the Spatial and Cognitive Tasks. However, their novel imitation skills differed markedly in the Spatial and Cognitive tasks, consistent with Hypothesis 3. Finally, the correlations and PCA results showing significant associations between novel and familiar imitation are consistent with Hypothesis 1, with the important caveat that associations were within and not between task

Table 5
Component characteristics for rotated and unrotated solutions.

	Unrotated solution			Rotated solution		
	Eigenvalue	Proportion var.	Cumulative	SumSq. Loadings	Proportion var.	Cumulative
Comp. 1	1.647	0.275	0.275	1.299	0.216	0.216
Comp. 2	1.061	0.177	0.451	1.209	0.201	0.418
Comp. 3	1.000	0.167	0.618	1.202	0.200	0.618

domains.

This pattern of results may help explain why children excel in some imitation tasks but not others. Specifically, it shows how minimal direct experience with a task can optimize imitation learning. In conjunction with results from adults (Badets et al., 2018; Boutin et al., 2010), the present study with young children further challenges the argument that there is no difference between early and late imitative responses (Heyes, 2016; Heyes & Foster, 2002). Given these results, tasks should consider the loading of familiar and novel elements for each domain or representation type (what vs when). The more familiar elements a task has, the more those elements will scaffold imitation performance. Bauer (1992) has referred to such elements as "enabling relations." The presence of familiar features and few novel spatial features may explain why children younger than 3 evidence imitation learning in puzzle boxes (Nielsen, 2006) or even superficially complex tasks (i.e., involving more steps) such as building a rattle (Herbert & Hayne, 2000).

The results of the PCA adds support to the claim that underlying imitation performance are abstract "elemental" representations or concepts guiding imitation learning. Those concepts appear to differ from those guiding individual learning *on the same task*. It is important to highlight that last point. While RC1 and RC2 were task-specific imitation (SL) components, the third component included both tasks and was, instead, specific to individual (asocial) learning. This add further support to the claim that imitation is not unidimensional but, rather, multi-dimensional, at least during the preschool years. It remains an open question, whether the dimensionality of imitation changes later in development or in adulthood.

One possible limitation is how this study operationalized familiar imitation. Here, familiar imitation was operationalized as the replication of a formerly executed response, which involved copying either a serial item-specific "what" or location-based "where" rule. That's quite different from what has been done in the neurosciences which has focused mostly on very simple, familiar, and singular gestural or manual responses (Heyes et al., 2005; Iacoboni et al., 1999).[6] Perhaps a better operationalization of familiar imitation using the tablet tasks would be a tapping response. In fact, one study with preschoolers demonstrated that children copy the tapping of pictures multiple times, even when instructed not to do so (Subiaul & Schilder, 2014). While such a paradigm would be more like those used previously in automatic imitation studies, it is unclear how (or why) they would produce results different from those reported here.

Still, despite the differences between familiar and novel imitation, the present study suggests that they are task-dependent, but otherwise unidimensional constructs within tasks. That begs the question, is the same true for other forms of SL? Experiment 2 sought to answer that very question. Specifically, it sought to clarify the relationship between goal emulation or copying of a model's intent and ghost (affordance) emulation.

5. Experiment 2

5.1. Methods & procedures

5.1.1. Participants

99 racially and ethnically diverse children (White = 74%, Black = 6%, Asian = 3%, Native American = 0%, Mixed = 7%, Hispanic = 10%) ranging in age from 3 to 5 years of age (M = 53 months, SD = 9.89, Females = 53) participated in the study while visiting the National Building Museum in Washington, DC. 16 additional children were excluded from the final analysis for the following reasons: parental interference = 1; experimenter/tablet error = 2). All 99 children completed at least 2 conditions were included in some of the analyses (e.g., correlations, PCA). Of these, 80 completed all testing conditions within tasks (ANOVA: Cognitive = 39, Spatial = 41).

5.1.2. Experimental tasks

Same as in Experiment 1 (c.f., Fig. 1).

5.1.3. Training & testing

Same as in Experiment 1 except that children were tested in only one of the two Tasks (Cognitive, Spatial) and trained on that task prior to testing. Children were tested in two asocial learning conditions, Baseline and Recall, which followed the same procedures described in Experiment 1 in addition to Novel Imitation (same as in Experiment 1) and two emulation conditions, Goal Emulation and Ghost or affordance learning (c.f,. Table 1 and Fig. 2).

[6] But see Cook et al. Cook, R., Bird, G., Lunser, G., Huck, S., & Heyes, C. (2012). Automatic imitation in a strategic context: players of rock-paper-scissors imitate opponents' gestures. *Proc Biol Sci*, *279*(1729), 780–786. https://doi.org/10.1098/rspb.2011.1024 which used a more complex game—Rocks-Papers-Scissors—that involves a multi-hand, multi-action sequence.

5.1.4. Goal emulation[7] (Emulation)

Procedures were identical to those described in Experiment 1 for Novel Imitation, except that the experimenter touched the first picture in the sequence correctly and then incorrectly touched the last picture in the sequence (e.g., A→C), skipping the second picture (e.g., B), resulting in an error. Following this error, the experimenter faced the child and with a sad face said, "Whoops, that's not right. Let me try again. Watch me." The same error (A→C) was repeated 2 more time (total 3 times). Following the last demonstration, the experimenter turned to the child and said, "Whoops, that's not right. I can't find Jumping Man. Can you find Jumping Man? Remember, start with picture number 1." This procedure was equivalent to the non-verbal re-enactment procedure used by Meltzoff (1995) and the "Whoops" paradigm used by Carpenter et al. (1998a,1998b,1998c). For more details of this procedure see Subiaul et al. (2012, Experiment 3).

5.1.5. Ghost (affordance learning)[8]

Procedures were identical to those described in Experiment 1 for Novel Imitation except that the computer rather than an experimenter highlighted the order of the pictures. At the start of the condition, the experimenter said, "Let's watch the computer." At this point, the computer—acting as the model—automatically highlighted each item with a gold star that appeared atop each picture (0.5 s) in the correct serial order without any intervention by the human experimenter. Once all items were highlighted by the computer, Jumping Man played on the screen (5 s). While Jumping Man played, the experimenter clapped looked at the child and said, "Yay, the computer found Jumping Man." The procedure then repeated two more times before testing (total of 3 demonstration trials). In the SL literature this condition is often referred to as the "ghost control" (Hopper, 2010) because the condition and "demonstration" proceeds 'as if' a ghost is making the response. For more details about the Ghost Control see Subiaul et al. (2011). In contrast to imitation and goal emulation condition, ghost controls lack social-affective-communicative cues known to aide SL (Csibra & Gergely, 2011).

5.1.6. Measure of learning

Same as in Experiment 1.

As in Experiment 1. Parents completed the BRIEF-P while children were tested. However, results were not analyzed in the present study and excluded from all analyses.

All data can be found in the OSF website: https://osf.io/3bmt9/.

6. Results

Preliminary data analysis exploring condition order and participant sex effects were not statistically significant results. Consequently, these factors were not explored further. But, as expected, age predicted performance across tasks and conditions (see below).

Differences between task, condition and age group were explored using two repeated measures ANOVA, one for each task (Cognitive, Spatial) that included 5 Conditions (Baseline, Recall, Goal Emulation, Ghost, Novel Imitation) as within-subjects, repeated measures, and Age Group (3-, 4-, 5-year-olds) as a between-subjects factor.

6.1. Cognitive task

Because the Sphericity assumption was marginally significant [Mauchly's W(9) = .61, $X^2 = 17.27$, $p = 0.05$], we evaluated the within-subject effects using the Greenhouse-Geisser Correction. There was a main effect for Condition ($F(3.29,118.26) = 13.09$, $p < 0.01$, $\eta^2 = .18$) and Age-Group ($F(2,36) = 15.38$, $p < .01$, $\eta^2 = .46$). Moreover, the Condition X Age-Group interaction was significant ($F(6.57,118.26)= 2.17$, $p < 0.045$, $\eta_p^2 = 0.11$). 3-year-olds performance significantly differed from that of 5-year-olds in the goal emulation condition ($p_{holm} <.001$) and marginally differed in the ghost condition ($p_{holm} =.07$). Pairwise comparison using the Holm correction procedure showed that 3-year-olds failed to evidence learning at levels significantly higher than Baseline in every condition (all $ps > .50$) except Recall ($p < .05$). The older age-groups evidenced more robust learning in all conditions relative to Baseline, although some of these p-values were not statistically significant after correcting for multiple comparisons ($p_{range} =.001$ to.125). Age groups did not differ in most learning conditions except the two emulation conditions. Specifically, 5-year-olds performed better than 3-year-olds in Goal Emulation ($p < .01$) and marginally better in Ghost conditions ($p = .06$). No other contrast was significant. Results are summarized in Table 6, Fig. 4A.

6.2. Spatial task

Because the Sphericity assumption was not met [Mauchly's W(9) = .54, $X^2 = 22.36$, $p < 0.01$], we evaluated the within-subject effects using the Greenhouse-Geisser Correction. There was a main effect for Condition ($F (2.94,111.81) = 18.08$, $p < 0.01$, $\eta^2 = 0.26$) but neither Age-Group ($F(2,38) = 1.48$, $p = .24$, $\eta^2 = .01$) nor the Condition by Age-Group interaction were significant ($F (5.89, 111.81 = 1.08$, $p = 37$, $\eta^2 =0.03$). Pairwise comparisons using the Holm correction procedure showed children did better in all learning conditions relative to Baseline (all $ps <.01$), except Ghost ($p = .43$). Recall performance was also better than Ghost (all

[7] For a video demonstration of Goal Emulation see: www.youtube.com/watch?v=Fx-pXL0Ui08

[8] For a video demonstration of the Ghost Condition (Affordance Emulation) see: www.youtube.com/watch?v=_kLOg8iY4tM

Table 6
Exp. 2 Summary Results of Repeated Measures ANOVA for the Cognitive Task. (A) Within-Subject Effects, (B) Between-subjects effects.

A. Within Subjects Effects

Cases	Sphericity Correction	Sum of Squares	df	Mean Square	F	p	η^2_p
Condition	Greenhouse-Geisser	31.341a	3.285a	9.541a	13.091a	< .001a	0.267a
Condition ✻ Age Group	Greenhouse-Geisser	10.399a	6.57a	1.583a	2.172a	0.045a	0.108a
Residuals	Greenhouse-Geisser	86.189	118.26	0.729			

B. Between Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
Age Group	20.986	2	10.493	15.379	< .001	0.461
Residuals	24.562	36	0.682			

Note. Type III Sum of Squares
[a]Mauchly's test of sphericity indicates that the assumption of sphericity is violated (p < .05).

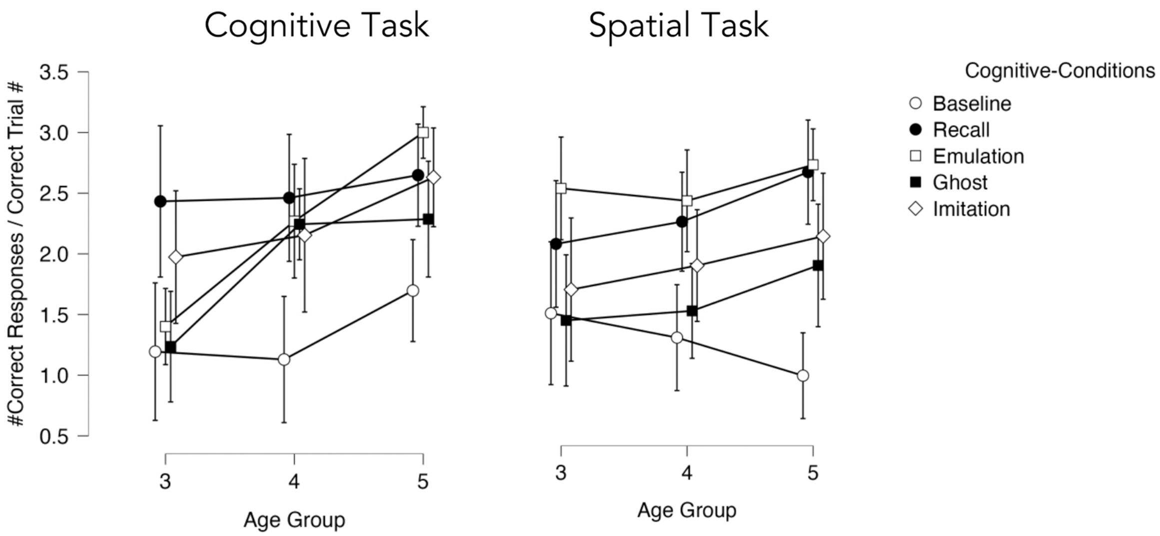

Fig. 4. Experiment 2: Mean Learning Ratio Across Tasks, Conditions and Age-Groups. Note: Error bars correspond to 95% CI. Emulation = Goal Emulation. Ghost = Affordance learning/emulation. Circles correspond to asocial learning condition. Squares correspond to emulation conditions. The diamond corresponds to the imitation condition.

ps = .43). Likewise, performance in Goal Emulation was better than in Ghost and Novel Imitation conditions (all *ps* < .01). No other contrast was significant. Results are summarized in Table 7, Fig. 4B.

As in Experiment 1, we wanted to explore whether different forms of SL (emulation, imitation and affordance learning) are unidimensional as some have suggested (Whiten et al., 2009) or, instead, multidimensional. Because children were tested in only one of the two tasks, we present results for the Cognitive and Spatial Tasks separately.

Table 7
Exp. 2 Summary Results of Repeated Measures ANOVA for the Spatial Task. (A) Within-Subject Effects, (B) Between-subjects effects.

A. Within Subjects Effects

Cases	Sphericity Correction	Sum of Squares	df	Mean Square	F	p	η^2_p
Condition	Greenhouse-Geisser	32.15a	2.942a	10.927a	18.078a	< .001a	0.322a
Condition ✻ Age Group	Greenhouse-Geisser	3.845a	5.885a	0.653a	1.081a	0.378a	0.054a
Residuals	Greenhouse-Geisser	67.582	111.808	0.604			

B. Between Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
Age Group	1.506	2	0.753	1.478	0.241	0.072
Residuals	19.358	38	0.509			

Note. Type III Sum of Squares
[a]Mauchly's test of sphericity indicates that the assumption of sphericity is violated (p < .05).

6.3. Cognitive task

Bartlett's Test of Sphericity was significant $X^2(6) = 28.66$, $p < .01$ and the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was low but adequate (MSA_{range}: 0.49 – 0.62). We used the promax rotation method because some measures were correlated (c.f., Table 8) and excluded cases pairwise (given the small sample size). The PCA produced two components that were minimally correlated (0.14): RC1—SL—included all three forms of SL and explained 38% of the observed variance. RC2—Individual Learning—included recall and explained 27% of the variance (cumulative = 65%). Results are summarized in Tables 9A and 10A.

6.4. Spatial task

Bartlett's Test of Sphericity was marginally significant $X^2(6) = 48.94$, $p < .01$. And the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was on the low range for some of the measures ($MSA_{range} = 0.39 – 0.52$). So, these results should be read with some caution. We used the varimax rotation methods because none of the measures were correlated (c.f., Table 8B). We also excluded cases pairwise given the small sample size. The PCA produced two components. RC1—Copying—included novel imitation and learning in the ghost condition (i.e., which in this paradigm involved copying symbolic—computer-generated—cues), accounting for 37% of the variance. RC2—Goal Inference—included goal emulation and recall, accounting for 33% of the variance. This component can best be described as encompassing inferential reasoning and WM (cumulative = 70%). Results are summarized in Tables 9B and 10B.

7. Discussion

As in experiment 1, there was significant variation in children's emulation learning despite there being little difference in the children's individual—recall—performance. Observed main effects and interactions had moderate (.06) to large (.23) effect sizes. Young children performed poorly in goal emulation and ghost (affordance learning) conditions in the cognitive task (Fig. 4A) but not in the spatial task (Fig. 4B). All age-groups excelled in goal emulation, performing close to ceiling. These results replicate those pointing to distinct imitation and emulation dimension (Renner et al., 2020; Subiaul et al., 2016; Subiaul et al., 2015). Results also replicate age-specific differences observed in other studies using these same tasks (Subiaul et al., 2012) as well as in studies using puzzle-boxes (Speidel et al., 2021; Yu & Kushnir, 2020). Like imitation (Vanvuchelen et al., 2011a; Vanvuchelen et al., 2011), the development of different forms of emulation learning appears to be domain-specific. Here, the ability to emulate "where" location goals developed before "what" item-specific goals.

Task-specific differences in emulation were reinforced by PCAs. In the Cognitive Task all forms of SL—imitation, goal emulation and ghost (affordance) learning—formed one dimension. Individual—recall—formed another (c.f., Table 7). However, in the spatial task, goal emulation and recall formed an inferential learning component, while ghost (affordance) learning and imitation formed a second indirect—copying—component (c.f., Table 8). Given the mid to low sampling adequacy in these PCAs, the results should be interpreted cautiously. The relatively poor sampling adequacy may explain these seemingly contradictory results (i.e., unidimensional in the cognitive task but multidimensional in the spatial task). Still, at least one of these results have been independently replicated in another study (Renner et al., 2020). Regardless, the results of Experiment 2 replicate and extend the results reported in prior studies using this paradigm (Renner et al., 2020; Subiaul et al., 2016; Subiaul et al., 2015).

7.1. General discussion

The present study is unique in that it explores different forms of SL (imitation, emulation) in preschoolers within-subjects and across tasks. Specifically, tasks that isolate item- "what" (Cognitive Task: Fig. 1A) and location-specific "where" (Spatial Task, Fig. 1B) representations. These SL skills and representations are essential to understanding and properly using everyday objects (Adolph & Hoch, 2019; Rachwani et al., 2020). Using these tasks, we sought to explain developmental changes in SL as well as the relationship between them. The study evaluated the hypothesis that if all SL skills share common cognitive, motivational, and representational mechanisms, they should correlate (Hypothesis 1, Exp. 1 and 2). Additionally it was hypothesized that familiar forms of imitation—involving previously learned responses—would develop before novel forms of imitation, regardless of task domain (Hypothesis 2, Exp. 1) and that novel—but not familiar imitation—would evidence domain/task-specificity (Hypothesis 3, Exp. 1); Finally, the study evaluated the hypothesis that because goal emulation provides children with multiple social and asocial cues for learning (more than other SL conditions), it would develop before ghost learning, which provides only physical/symbolic cues for learning (Hypothesis, 4, Exp. 2). And, given the parallels between the ghost control and novel imitation, it was hypothesized that both conditions would evidence the same type of domain-specificity; namely, better performance in the cognitive, relative to the spatial task. (Hypothesis 5, Exp. 2).

Experiment 1 explored in preschoolers familiar versus novel imitation. As expected, there were significant differences between age-groups and tasks on novel imitation. Older children consistently out-performed younger children. However, across imitation domains (cognitive, spatial), there were few differences among age-groups for familiar imitation or individual recall. Performance in those conditions often exceeded that of baseline and novel imitation. Given these results, poor novel imitation performance cannot be explained by individual differences in asocial learning or differing motivations within these domains.

Contrary to what was hypothesized, familiar and novel imitation were more alike than expected, even though familiar imitation involved no *new* learning. In the familiar imitation condition, as operationalized here, social input appeared to boost performance relative to individual recall. That result, however, was more evident in the spatial than in the cognitive task; A result that points to a

Table 8
Pearson correlations. (A) Cognitive Task, (B) Spatial Task.

A. Cognitive Task						
Variable		**Age (mo)**	**Recall**	**Emulation**	**Ghost**	**Imitation**
Age (months)	*n*	—				
	r	—				
	p-value	—				
Recall	*n*	46	—			
	r	0.017	—			
	p-value	0.913	—			
Emulation	***n***	**49**	44	—		
	r	**0.639**	0.204	—		
	p-value	**< .001** * **	0.184	—		
Ghost	***n***	**47**	43	45	—	
	r	**0.398**	-0.017	0.269	—	
	p-value	**< .001** * **	0.914	0.073ˆ	—	
Imitation	*n*	*50*	45	48	46	—
	r	*0.246*	0.15	0.204	0.22	—
	p-value	*0.085ˆ*	0.325	0.163	0.141	—

B. Spatial Task						
Variable		**Age (mo)**	**Recall**	**Emulation**	**Ghost**	**Imitation**
Age (months)	*n*	—				
	r	—				
	p-value	—				
Recall	***n***	**47**	—			
	r	**0.392***	—			
	p-value	**0.006**	—			
Emulation	***n***	45	**45**	—		
	r	0.238	**0.316**	—		
	p-value	0.116	**0.034** *	—		
Ghost	*n*	47	46	44	—	
	r	0.174	-0.098	0.010	—	
	p-value	0.242	0.519	0.949	—	
Imitation	***n***	45	44	42	**44**	—
	r	0.228	-0.169	0.195	**0.405** * *	—
	p-value	0.132	0.274	0.215	**0.006**	—

ˆP < .10, [a]p < .05, [b]p < .01, [c]p < .001

Table 9
Component Loadings: (A) Cognitive Task, (B) Spatial Task.

A. Cognitive Task	**RC1**	**RC2**	**Uniqueness**
Ghost	0.753		0.425
Imitation	0.711		0.498
Emulation	0.673		0.399
Recall		0.957	0.093
B. Spatial Task			
Imitation	0.860		0.260
Ghost	0.784		0.380
Emulation		0.837	0.256
Recall		0.782	0.306

Note. Applied rotation method is varimax.

Table 10
Component Characteristics: (A) Cognitive Task, (B) Spatial Task.

	Unrotated solution			**Rotated solution**		
A. Cognitive	**Eigenvalue**	**Proportion var.**	**Cumulative**	**SumSq. Loadings**	**Proportion var.**	**Cumulative**
Comp. 1	1.564	0.391	0.391	1.523	0.381	0.381
Comp. 2	1.021	0.255	0.646	1.061	0.265	0.646
B. Spatial						
Comp. 1	1.481	0.370	0.370	1.477	0.369	0.369
Comp. 2	1.317	0.329	0.699	1.321	0.330	0.699

distinct role for sensory-motor systems (uniquely engaged in the Spatial Task) and the speed with which they are automatized (Badets et al., 2018; Boutin et al., 2010; Ellenbuerger et al., 2012).[9]

Replicating results of Experiment 1, age-groups in Experiment 2 evidenced individual recall in both tasks (c.f., Fig. 4). Again, there was significant variation in children's learning. The youngest children struggled when emulating (goal and ghost) in the Cognitive (Fig. 4A) but not the Spatial (Fig. 4B) task. Older age-groups, generally, excelled in goal emulation but struggled in the ghost condition (affordance learning), across tasks. This result replicates those reported in other studies that have used a ghost control and highlighted the relative salience of social—agentive—cues in observational/indirect learning contexts (Hopper, 2010; Howard et al., 2020).

Some might take issue with our operationalization of familiar imitation. In the neurosciences, imitation is typically operationalized using simple manual actions such as lifting/lowering a finger or opening and closing a hand (Heyes et al., 2005; Iacoboni et al., 1999). Here, familiar imitation was operationalized as the production of a series of responses that had been previously executed (hence, familiar). This operationalization allowed us to equate familiar imitation with two other learning conditions: individual recall and novel imitation. That is, familiar imitation included a social (i.e., demonstration) component as in novel imitation, but lacked a learning component because the sequence was familiar to the participant as was the case in recall. Perhaps a better familiar imitation manipulation using the tablet tasks would be a tapping response (Subiaul & Schilder, 2014). Such a paradigm would be more like those used in previous automatic imitation studies. But given how quickly and easily serial responses are automatized (Badets et al., 2018), it is an open question whether a different operationalization of familiar imitation will produce results different from those reported here.

Regarding the dimensionality of SL, results of the PCAs provides additional support for the claim that underlying imitation performance are abstract "elemental" representations or concepts guiding imitation learning (Subiaul, 2010; Subiaul et al., 2016; Vanvuchelen et al., 2011a, 2011b). Those concepts appear to differ from those guiding individual learning on the *same* task (Subiaul et al., 2012; Subiaul et al., 2016; Subiaul et al., 2015; Subiaul et al., 2019). Those results support the claim that imitation is not unidimensional but, rather, multi-dimensional (Subiaul et al., 2015; Vanvuchelen et al., 2011).

The picture that emerged for emulation (goal and ghost) across tasks was less clear. In contrast to imitation, emulation evidenced both uni- and multi-dimensional features. Emulating item-specific— "what"—representations in the Cognitive Task were unidimensional (c.f., Table 7). Whereas, emulating location-specific— "where" —representations in the Spatial Task were multi-dimensional. Specifically, in the Cognitive Task, goal emulation and individual recall formed one inferential/asocial learning construct. Novel imitation and ghost (affordance) learning formed a second—general copying construct (c.f., Table 8), replicating results previously reported by Renner et al. (2020). Given the mid to low sampling adequacy for some of the measures in the PCA, these results require greater empirical validation and warrant additional study with different tasks and larger sample sizes. Ideally future studies will replicate and extend some of these SL conditions using different touch-screen or tablet-based tasks, including those that evaluate motor-spatial responses (Chetcuti et al., 2019) and information use (Renner et al., 2021).

8. Conclusion

The current study provides a model for SL research. It highlights how using 2D tablet-based tasks can reproduce results of studies using more complex and experimentally opaque 3D tasks. Specifically, results reported here show that performance varies dramatically when children are pressed to imitate or emulate novel item- "what" (Cognitive Task) or location-specific "where" (Spatial Task) problems. Regardless of task type, preschoolers' (3–5-years of age) individual (asocial) learning does not significantly differ. Consequently, observed individual differences in SL (e.g., novel imitation and emulation learning) cannot simply be explained by differences in the ability to attend to, encode and recall "what" or "where" information inherent in everyday tasks (Adolph & Hoch, 2019; Del Giudice et al., 2000; Subiaul et al., 2016; Vasilyeva & Lourenco, 2012). Given the ubiquity of "what" and "where" representations in SL studies, difficulties learning these basic representations are likely to explain more (or at least as much) variance in performance than opaque concepts like causality or social motivation.

Data availability

OSF link with dataset has been included in manuscript.

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[9] Because responses are random in the Cognitive Task, as the target pictures change location each trial, sensory-motor responses cannot be automatized.

Appendix

Experiment 1. Descriptive Statistics for ANOVA: (A) Cognitive, (B) Spatial (n = 154)

A. Cognitive Task (n = 154)						
Condition	**Age Group**	**N**	**Mean**	**SD**	**SE**	**Coefficient of Variation**
Baseline	3	45	1.345	0.758	0.113	0.564
	4	54	1.417	0.684	0.093	0.482
	5	55	1.697	0.886	0.119	0.522
Recall	3	45	1.991	0.902	0.134	0.453
	4	54	2.502	0.75	0.102	0.3
	5	55	2.491	0.842	0.114	0.338
Familiar	3	45	1.936	0.884	0.132	0.457
	4	54	2.25	0.865	0.118	0.385
	5	55	2.512	0.782	0.105	0.311
Novel	3	45	1.667	0.939	0.14	0.563
	4	54	2.222	0.899	0.122	0.405
	5	55	2.383	0.833	0.112	0.349
B. Spatial Task (n = 163)						
Condition	**Age Group**	**N**	**Mean**	**SD**	**SE**	**Coefficient of Variation**
Baseline	3	48	1.275	0.627	0.091	0.492
	4	55	1.478	0.625	0.084	0.423
	5	60	1.318	0.542	0.07	0.412
Recall	3	48	1.871	0.792	0.114	0.423
	4	55	2.157	0.859	0.116	0.398
	5	60	2.082	0.957	0.124	0.46
Familiar	3	36	2.209	0.826	0.138	0.374
	4	48	2.157	0.831	0.12	0.385
	5	52	2.706	0.582	0.081	0.215
Novel	3	36	1.222	0.707	0.118	0.578
	4	48	1.781	0.787	0.114	0.442
	5	52	2.41	0.82	0.114	0.34

Experiment 2. Descriptive Statistics for ANOVA: (A) Cognitive, (B) Spatial Tasks

A. Cognitive Task (n = 39)						
Conditions	**Age Group**	**N**	**Mean**	**SD**	**SE**	**Coefficient of Variation**
Baseline	3	12	1.194	0.765	0.221	0.641
	4	13	1.129	0.694	0.193	0.615
	5	14	1.697	0.741	0.198	0.436
Recall	3	12	2.433	0.853	0.246	0.351
	4	13	2.462	1.025	0.284	0.417
	5	14	2.649	0.74	0.198	0.279
Emulation	3	12	1.401	0.634	0.183	0.453
	4	13	2.269	0.887	0.246	0.391
	5	14	3	0	0	0
Ghost	3	12	1.236	0.639	0.184	0.517
	4	13	2.244	0.744	0.206	0.332
	5	14	2.286	0.892	0.238	0.39
Imitation	3	12	1.973	0.948	0.274	0.48
	4	13	2.154	0.971	0.269	0.451
	5	14	2.631	0.741	0.198	0.282
B. Spatial Task (n = 41)						
Conditions	**Age Group**	**N**	**Mean**	**SD**	**SE**	**Coefficient of Variation**
Baseline	3	12	1.806	0.807	0.233	0.447
	4	16	1.635	0.633	0.158	0.387
	5	13	1.368	0.419	0.116	0.306
Recall	3	12	2.292	0.66	0.19	0.288
	4	16	2.447	0.68	0.17	0.278
	5	13	2.795	0.52	0.144	0.186
Emulation	3	12	2.681	0.504	0.146	0.188
	4	16	2.594	0.758	0.189	0.292
	5	13	2.846	0.376	0.104	0.132
Ghost	3	12	1.756	0.812	0.234	0.462
	4	16	1.823	0.668	0.167	0.367
	5	13	2.141	0.761	0.211	0.355

(*continued on next page*)

(*continued*)

A. Cognitive Task (n = 39)						
Conditions	**Age Group**	**N**	**Mean**	**SD**	**SE**	**Coefficient of Variation**
Imitation	3	12	1.972	0.829	0.239	0.42
	4	16	2.14	0.735	0.184	0.343
	5	13	2.345	0.766	0.213	0.327

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