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Brief Report

The man and the machine: Do children learn from and transmit tool-use knowledge acquired from a robot in ways that are comparable to a human model?

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A B S T R A C T

Robots are an increasingly prevalent presence in children's lives. However, little is known about the ways in which children learn from robots and whether they do so in the same way as they learn from humans. To investigate this, we adapted a previously established imitation paradigm centered on inefficient tool use. Children (3- to 6-year-olds; N = 121) were measured on their acquisition and transmission of normative knowledge modeled by a human or a robot. Children were more likely to adopt use of a normative tool and to transmit this knowledge to another when shown how to do so by the human than when shown how to do so by the robot. Older children (5- and 6-year-olds) were less likely than younger children (3- and 4-year-olds) to select the normative tool. Our findings suggest that preschool children are capable of copying and transmitting normative techniques from both human and robot models, albeit at different rates and dependent on age.

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Introduction

Preschool children are especially attuned to, and highly motivated to act in accordance with, group norms (Rakoczy & Schmidt, 2013). Similarly, with age, children become more inclined to persist in copying object-directed actions shown to them even when those actions are obviously causally redundant (Hoehl et al., 2019). That is, social motivations to connect with in-group members and to adhere to group norms override the desire for functionality, driving children to adopt less efficient means for completing a goal even when simpler alternatives are available (Over, 2020).

However, preschoolers do not always conform to ingroup preferences or imitate a socially preferred method, especially when they prioritize instrumental factors (e.g., task efficiency) over social motivations (Carpenter & Call, 2009). When the socially modeled approach appears to be erroneous, children will typically follow their own intuitions of method efficacy. For example, in one study preschool children were presented with a tangible goal (e.g., crushing a cookie) before observing a model intentionally reject an optimal tool (e.g., a rigid object) in favor of an obviously suboptimal alternative (e.g., a cluster of pompoms attached to a handle) (DiYanni & Kelemen, 2008). When subsequently given the opportunity to complete the task, the majority of children eschewed the model's choice and instead selected the optimal tool, with few children actually selecting the suboptimal tool. A follow-up experiment found that emphasizing the suboptimal tool through claims about its design (i.e., "This tool here is *made for* crushing cookies") enhanced 3-year-olds choice of the suboptimal tool but did not have the same impact on 2- or 4-year-olds, where the imitative decision of 3-year-olds appeared to be malleable.

It is important to note that cues to tool design and model intention might not yield the same effect as verbal cues that emphasize group norms. There is currently no published research documenting whether coupling the "cookie-crushing" task with simple normative language motivates children to adopt the suboptimal tool to achieve the goal. In Clegg and Legare (2016), children were significantly more likely to replicate irrelevant actions when making a bead necklace (e.g., touching each bead to the forehead before stringing it on the necklace) when the task was coupled with normative framing (i.e., "Everybody always does it this way") than when it was framed instrumentally (i.e., "I am going to make a necklace"). This effect was not apparent with 3-year-olds but was found to become stronger across age groups of 4- to 7-year-olds. Children's decisions about whether to prioritize conventions or task efficiency appear to be governed, at least in part, by linguistic cues that motivate them to attend to normative information. In a similar light, regardless of the impact of cultural or environmental factors on the expectations surrounding normative behavior (Legare & Harris, 2016), social learning is fundamentally driven by human-specific pedagogical relationships—an active teaching and learning communicative system where human individuals are naturally motivated to pass on and learn information to and from conspecifics (Gergely & Csibra, 2006).

But to what extent are these processes framed by the agent delivering the information? This question is particularly relevant in an environment where humanoid robots are becoming increasingly common (Meltzoff, Kuhl, Movellan, & Sejnowski, 2009; Tanaka, Cicourel, & Movellan, 2007). Indeed, there is growing interest in examining the roles of interactive robots in child development. Children have been observed to treat a humanoid robot as a social being (e.g., a friend, someone who can offer comfort) that possesses human-like mental states (e.g., intelligence, feelings) (Kahn et al., 2012) and should not be physically harmed (Sommer et al., 2019). Children also appear to conform to the false judgments of robots (Vollmer, Read, Trippas, & Belpaeme, 2018) but are, in contrast, less likely to imitate ritual-like actions they model (Sommer et al., 2020). Further clarity around the extent to which children will conform to actions framed normatively when demonstrated by robots is required in order to better understand how children process learning scenarios in general.

In the current study, we adapted the cookie-crushing paradigm (Corriveau et al., 2017; DiYanni, Corriveau, Kurkul, Nasrini, & Nini, 2015; DiYanni & Kelemen, 2008) to evaluate whether children would differ in their tendency to adopt the normative, but suboptimal, actions of a robot and a human. We chose this task because it presents a simple goal-directed task designed to test inefficient tool-use learning. Critically, we amplified the social value of the suboptimal option by using explicit normative framing (e.g., "Everybody uses this") while making the goal apparent.

Children (3- to6-year-olds) were shown video demonstrations of a human or robot depicting how to crush a cookieby using either a suboptimal but normative tool or an optimal but non-normative alternative.Participants were given the opportunity to complete the task (learning) and show a puppet how to do it (teaching) using either of the tools. In line with previous studies (Corriveau et al., 2017; Sommer et al., 2020), we expected that children would conform at higher rates when demonstrated by a human than when demonstrated by a robot across learning and teaching tasks. Children were initially asked which tool they *intended* to use and *why* in order to gain insight into their behavioral responses, and they were prompted to identify which tool was the *best* after their attempts at task completion. The combination of these different measures enabled us to document potential variability or similarity of children's social learning from human versus robot agents across different contexts as well as replicating aspects of prior research.

Method

Preregistration

An initial design was preregistered on the Open Science Framework on May 17, 2017 (https://osf.io/zrwkf/?view_only=31a3de75961946278629e545a8dd33de).

Participants

A total of 125 children were recruited and tested. Four of these children were excluded due to technical issues. Thus, the final sample comprised 121 children (63 boys and 58 girls) aged 3–6 years[2] (M = 4.87 years, SD = 1.22, range = 2.95–6.88). Children were recruited and tested in either a museum (n = 95) or a university lab (n = 26). Children's cultural heritage was identified as Australian (n = 89), Asian (n = 11), European (n = 10), North American (n = 3), African (n = 2), South American (n = 1), or undisclosed (n = 5), all with middle to high socioeconomic status.

Test environment and materials

This study required children to crush a cookie using one of two available tools and to subsequently show a puppet[3] (which was absent during demonstration) how to complete the same task. The first tool was a "pom-pom" made up of multicolored wool balls with a handle on the top (9.5 × 9 cm). The second tool was a "hammer" made up of a rectangular wooden block (6.5 × 3.5 × 3.5 cm) and a dowel (8 × 2 cm). The pom-pom tool was a suboptimal tool for the task and was labeled as the normative option (henceforth referred to as the suboptimal tool), whereas the hammer tool was the optimal tool for the task and was labeled as the non-normative option (henceforth referred to as the optimal tool).

Counterbalance

The order of presentation of each tool and the side of presentation of each tool were counterbalanced across all participants. There were a total of four counterbalances: (1) suboptimal tool presented first on the left side, (2) suboptimal tool presented first on the right side, (3) optimal tool presented first on the left side, and (4) optimal tool presented first on the right side.

[2] The initial preregistered experiment stipulated an age range of 4 to 6 years. However, the nature of data collection in the museum necessitated that all children interested in participating in the experiment were to be included. As such, we also collected a convenience sample of 3-year-old children.

[3] In light of previous research (e.g., Corriveau et al., 2017), a puppet was chosen to represent a naïve third party, whereas children served in a teacher role. Using the same agent type as the learning task would likely bias children's decision toward the modeled option. In addition, using an adult model would not resemble the same "student–teacher" relationship. Logistical constraints prevented us from presenting a live robot to children.

Experimental conditions

Children were randomly assigned to either a *human* condition ($n = 61$) or a *robot* condition ($n = 60$). The human model was a woman, aged 23 years at the time of testing, and was of similar cultural background to the majority of the child participants. The robotic platform employed was RUBI-6 (Johnson, Malmir, Forster, Alac, & Movellan, 2012), that is, a humanoid robot capable of making fine motor movements and fluid motion and of producing verbal commands. Practical limitations prevented this study from being conducted live using the robot because it was not able to be transported to, and used safely in, the large public forum in which data collection took place. Thus, all demonstrations were prerecorded and shown on a laptop computer (see Table 1).

Human. At the beginning of the prerecorded video clip, the demonstrator (different from those running the experiment) appeared seated at a table with a cookie between two tools placed on it. The demonstrator touched the side of the suboptimal tool and the optimal tool one after the other. She then touched the top of each tool, appearing to examine and subsequently choose which one to use. While picking up the suboptimal tool, the demonstrator said, "You can use this, everybody here uses this," and then demonstrated how to use the tool. Following this, she picked up the optimal tool and said, "Or you can use this, nobody here uses this," and then demonstrated how to use the tool. As the demonstrator demonstrated the use of both tools, the cookie was never crushed. In both instances, the cookie was tapped and some crumbs fell from the cookie, following the methodology documented in DiYanni and Kelemen (2008).

Robot. The robot condition was identical to the human condition except that the actions were modeled by the RUBI-6 robot. The actions of the human were matched closely to those of the robot; however, the robot's mouth did not move when it spoke and its voice sounded slightly synthetic.

Procedures

Learning task

The experimenter presented children with a cookie and said, "I need your help to crush this cookie, but first let's watch a video showing how you can do this." At this point, the video clip was played twice. To measure *intended tool choice,* the experimenter asked, "Which of these tools are you going to use?" To measure children's *explicit reasoning* for their preference, children were then asked, "Why did you choose that tool?" They were prompted until a clear answer was given. For example, if a child answered "I don't know" or "I like it," the experimenter would ask, "What made you choose it?" or "Why did you like it?" To measure children's *actual tool choice,* children were then offered a turn to select a tool and crush the cookie. Finally, to measure perceptions of *tool quality,* after children's attempt, the experimenter asked, "Which tool do you think is the best?".

Teaching task

Children were then introduced to a puppet. To measure *intended tool choice* in a pedagogical context, children were asked which tool they would use to "teach Tommy how to crush the cookie." Children were subsequently prompted for a reason for their intended tool choice (*explicit reasoning*) and then were offered a turn to select a tool to teach the puppet how to crush the cookie (*actual tool choice*).

Coding and reliability

Children's intended and actual tool choices were coded dichotomously for all questions and tasks across the two experimental trials. Responses for explicit reasoning in both tasks were coded categorically as instrumental (reasons related to the physical or causal properties of either tool; e.g., "Because it's hard"), social (e.g., "Because everyone uses it"), or uninformative (e.g., "I don't know").

To measure inter-rater reliability for explicit reasoning, a random 20% of the sample was coded by a second coder who was blind to condition and the study aims. There was high agreement between the two coders (learning task: Cohen's kappa = .95, $p < .001$; teaching task: Cohen's kappa = .89, $p < .001$). Any disagreement was resolved after discussion.

Table 1
Screenshots of human and robot demonstrations.

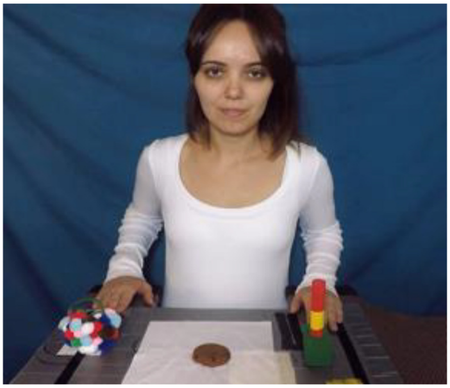
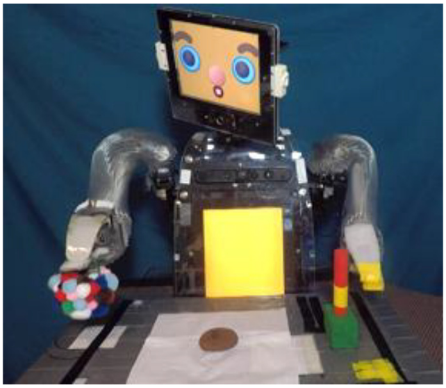
Human	Robot
	

Table 2
Proportion scores in the learning and teaching tasks.

Question	Human				Robot			
	3-year-olds	4-year-olds	5-year-olds	6-year-olds	3-year-olds	4-year-olds	5-year-olds	6-year-olds
Learning								
Intended	8/21	4/8	6/19	3/13	6/21	3/12	2/12	2/15
Actual	6/21	4/8	6/19	3/13	4/21	2/12	1/12	2/15
Quality	12/20	4/8	7/19	3/13	12/21	1/12	1/12	3/15
Teaching								
Intended	13/21	4/8	4/19	2/13	10/21	6/12	1/12	4/15
Actual	12/21	4/8	5/19	2/13	7/21	5/12	1/12	5/15

Note. Proportion score reflects the number of children who selected the normative (suboptimal) tool over the total number of children in each age group and condition. *one participant had missing data for this question

Results

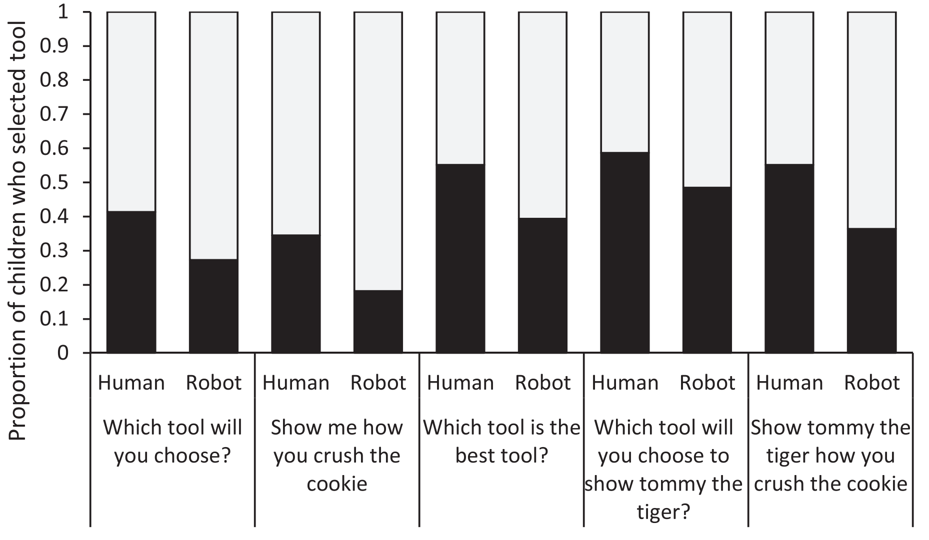
Children's tool choice was analyzed using generalized linear mixed models with a binomial distribution using the GLIMMIX procedure in SAS 9.3 (Stroup, 2016). The proportions of children who selected the normative and optimal tools across age groups and conditions are shown in Table 2 and Fig. 1. Model results are summarized in Table 3.[4] The initial model included three fixed effects of interest—task (five levels: learning intended tool choice, learning actual tool choice, learning tool quality, teaching intended tool choice, or teaching actual tool choice), agent (human vs. robot), and age (continuous)—as well as control variables of sex (male vs. female), testing location (lab vs. museum), and counterbalancing order (1, 2, 3, or 4). All models also included a random intercept to account for individual participant differences.

The initial model (i.e., Model 1; see Table 3) revealed a significant effect of agent, indicating that children were more likely to select the normative tool in the human condition than in the robot condition, $b = 0.60$, $SE = 0.28$, $t = 2.15$, $p = .032$. There was also a significant continuous effect of

[4] The original preregistration specified a different analytic approach; however, following advice, we altered our analytic approach to reduce the testwise error rate. GLMM (generalized linear mixed model) is a form of regression that can estimate the variance related to each factor, with continuous and categorical independent variables within a single model, and thus was deemed more appropriate for handling the specific research questions outlined in this study over other analytic methods.

age, $b = 0.50$, $SE = 0.12$, $t = -4.15$, $p < .001$. To conduct follow-up tests, children were divided into four age groups based on their age in months (e.g., 48- to 59-month-olds would fall under the age group of 4). Post hoc comparisons indicated similar levels of normative tendencies within 3- and 4-year-olds as well as within 5- and 6-year-olds (see Table 4). Collapsing across age groups with equivalent normative scores, a further analysis revealed that 3- and 4-year-olds were much more likely to select the normative tool than 5- and 6-year-olds, $b = 2.56$, $SE = 0.62$, $t = 4.16$, $p < .001$.

Follow-up models examined whether children's tool choice varied as a function of Task × Agent, Agent × Age Group, or Age Group × Task interactions. This was accomplished by adding these two-way interaction terms into the main-effects model one at a time. None of the interactions was significant.



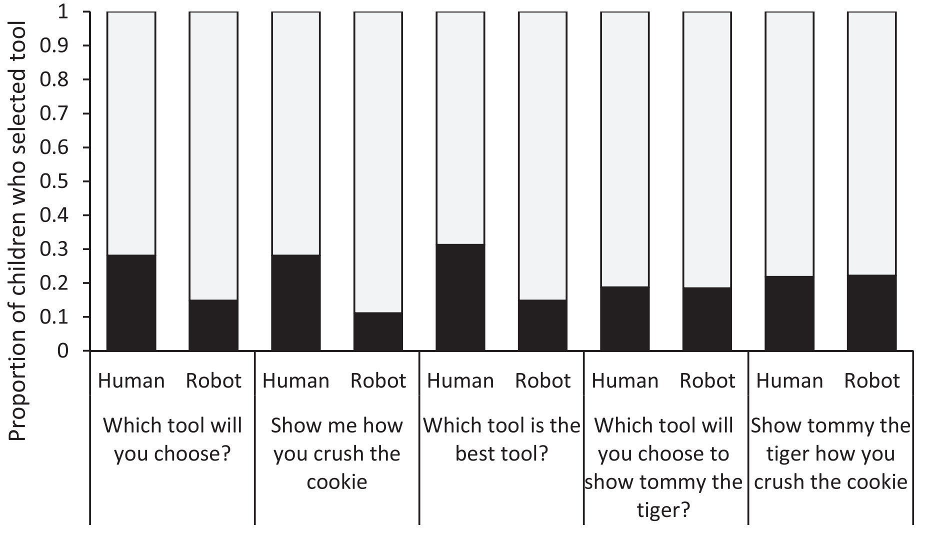


Fig. 1. The 3- and 4-year-old (top) and 5- and 6-year-old (bottom) tool selection preferences for the normative tool (black bars) and optimal tool (gray bars) for each question across the learning and teaching tasks.

Table 3
Fixed and random effects for children's tool choice.

	Main effects only			Additional interactions		
Variable	*b*	*SE*	*p*	*b*	*SE*	*p*
Fixed effects						
Intercept	−0.43	0.41	.292			
Sex (control)	−0.29	0.28	.305			
Location (control)	−0.17	0.34	.609			
Counterbalance (control)	*F* = 1.03		.377			
Task	*F* = 2.27		.061			
Agent	0.60	0.28	.032			
Age (continuous)	−0.50	0.12	<.001			
Agent × Age				−0.09	0.23	.693
Agent × Task				*F* = 0.69		.596
Age × Task				*F* = 1.24		.293
Random effects						
Intercept	1.03	0.38	.003			

Note. This table models the likelihood that children will select the normative tool. Interactions were added one at a time to the main-effects model. *F* scores are listed for variables with more than two levels, such that it was not possible to summarize the effect with a single *b* value. Negative values on sex indicate that girls on average had a slightly higher likelihood of selecting the normative tool than boys. Negative values on location indicate that children tested in the museum had a slightly higher likelihood of selecting the normative tool than girls. Positive values on agent indicate that children in the human condition had a higher likelihood of selecting the normative tool than children in the robot condition. Negative values on age indicate that as children aged, their likelihood of selecting the normative tool decreased.

Table 4
Main-effects pairwise comparisons for age group preference of the normative tool.

Age	*b*	*SE*	*t*	*p*
3 years vs. 4 years	0.21	0.40	0.53	>.999
3 years vs. 5 years	1.45	0.39	3.71	.001*
3 years vs. 6 years	1.32	0.38	3.45	.004*
4 years vs. 5 years	1.24	0.47	2.67	.047*
4 years vs. 6 years	1.11	0.45	2.45	.088
5 years vs. 6 years	−0.13	0.43	−0.31	>.999

Note. Positive values indicate that the age listed first was more likely to select the normative tool than the age listed second. Negative values indicate that the age listed second was more likely to select the normative tool than the age listed first. The *p* values are Bonferroni corrected for six familywise tests.

Binomial logistic regressions were conducted to explore the relationship between children's explicit reasoning and their actual tool choice across agents on the learning and teaching tasks, respectively. For each task, children's explanations were coded as either social or instrumental (binary dependent variable) and were modeled as a function of agent (human vs. robot) and tool choice (normative vs. optimal). In line with previous research (DiYanni et al., 2015), we excluded uninformative explanations (see Table S1 in the online supplementary material). There was no main effect of agent for learning, *b* = 0.90, *SE* = 0.86, *p* = .291, odds ratio = 0.41, or teaching, *b* = − 0.28, *SE* = 0.84, *p* = .739, odds ratio = 0.76. There was, however, a significant main effect of tool choice for learning, *b* = 3.02, *SE* = 0.89, *p* = .001, odds ratio = 20.52, and teaching, *b* = 2.07, *SE* = 0.89, *p* = .019, odds ratio = 7.93. This effect indicated that children were more likely to use a social explanation (e.g., "Because the person/robot used it," "Because everybody uses it") if they chose the normative tool and were more likely to use an instrumental explanation (e.g., "Because it's hard," "Because it can crush things") if they chose the optimal tool. However, this result should be interpreted with caution due to the small sample size (following exclusion of uninformative explanations) given the risk of Type II error.

Discussion

We adapted an imitation test of inefficient tool use to investigate potential variation in children's normative proclivities on the basis of a model's identity as either human or robot. As predicted, in line with recent evidence that children overimitate robots with less fidelity than they overimitate humans (Sommer et al., 2020), the children we tested were more likely to reenact the model's suboptimal tool preference on the basis of a stated normative convention and to pass this on to a new agent when it was shown by a human than when it was shown by a robot. This highlights how children process social information in the context of who is providing it and the normative valence that accompanies this information. It also adds to a growing body of literature documenting that children do not consider detail provided by a humanoid robot identically to detail provided by a human.

Although children appear to prioritize normative information received by a human model over a robot model, what currently remains unclear is the underlying reason for this selective learning and teaching. There are several explanations that may account for the variation in adherence to norms between human and robot models. Children's tendency to overimitate has been attributed to their social drive to affiliate with others (Hoehl et al., 2019; Over, 2020). Children may know (and in some cases acknowledge or are explicitly told) that the actions employed are not the most efficient, but children nevertheless imitate the redundant actions to align themselves with the model in order to be "like them" or included in the ingroup. Children might not perceive or wish to align themselves with a robotic model in this way, thereby leading lower uptake of the suboptimal, yet normative, tool in this study. Conversely, imitating obviously inefficient actions requires children to allocate some level of trust toward the model. Children are more likely to trust native-accented speakers than foreign-accented speakers and will selectively learn from native-accented speakers (Kinzler, Corriveau, & Harris, 2011), and children who assign higher trust in media characters are more likely to learn from those characters (Schlesinger, Flynn, & Richert, 2016). Children report that they can trust robots with secrets (Kahn et al., 2012), but young children trend toward trusting humans more than robots (Di Dio et al., 2020). The variation in trust between humans and robots may lead to lower imitation of suboptimal behavior irrespective of normativity. Future research should investigate whether children's adherence to norms varies between human and robot models when there is no difference in the two options with respect to optimality.

The finding that children are less likely to adopt the conventional behavior of a robot than that of a human contrasts somewhat with recent evidence that children will conform to the false judgments of robots (Vollmer et al., 2018). However, Vollmer et al. (2018) did not directly compare children's conformity to humans versus robots; thus, it is possible that conformity would have been higher following human false judgments. In the current study, some children did follow the robot's behavior; however, the proportion of children who did so was significantly less than the proportion of those who conformed to the human. Research is now needed to clarify in what contexts robots are treated as a teacher from whom novel knowledge is to be acquired or as a peer with whom to play and learn in ways that are comparable to a human agent.

A secondary aim of the current study was to investigate whether framing enhances children's normative proclivities. Our results suggest that highlighting the normative valence of the suboptimal tool using direct normative framing (i.e., "Everybody here uses this," "Nobody here uses this") did not motivate children to become more likely to adopt the suboptimal tool in comparison with the original works documenting children's performance on this task (DiYanni & Kelemen, 2008, Study 1). This work also supports and extends findings of other studies employing the cookie-crushing paradigm (Corriveau et al., 2017; DiYanni et al., 2015; DiYanni & Kelemen, 2008, Study 2). Potentially, the instrumental cost of not being able to achieve the goal outweighs the power of normative language. This is consistent with Fong, Imuta, Redshaw, and Nielsen's (2021) findings that preschool children preferred a more efficient alternative over a normatively framed suboptimal method in order to complete goal-oriented tasks within a given time frame. Although normative language has been shown to be powerful in enhancing high-fidelity imitation of inefficient approaches (e.g., Clegg & Legare, 2016; Wang, Fong, & Meltzoff, 2021), the current findings extend existing knowledge on imitative flexibility and highlight that the effect of normative language may also be context dependent—in this case, the feasibility of goal attainment.

However, this study did not employ a control condition whereby no normative valence was imposed on either tool, and as such we cannot be certain that normative framing did not motivate children to select the suboptimal tool. We propose that tool selection was not affected by normative framing by comparing our findings with previous literature and by interpreting the very low rates of suboptimal tool selection. To conclude with more certainty that normative framing does not increase suboptimal tool selection, future research should include a non-normative control condition.

Although the manipulation in this study was weaker than intended, we nonetheless uncovered age-related changes in the processing of normative information versus tool affordances across the preschool period. The imitative decisions of 3- and 4-year-olds appear to be more socially malleable than those of 5- and 6-year-olds. Regardless of agent identity, 3- and 4-year-olds were more likely to select the normative tool than 5- and 6-year-olds. This may be because younger preschool children are more inclined to employ simpler heuristic approaches (following socially preferred options) and only with age develop the cognitive capacity for processing the interplay of multiple information simultaneously (e.g., the model's identity, task efficiency) (Hermes, Behne, & Rakoczy, 2018). Future research is needed to explore this possibility.

Taken together, the implication of our findings is that as children grow, they develop the cognitive capacity to differentially weigh verbal statements and physical evidence when making social learning decisions based on contrasting contexts (e.g., when their personal judgment is in conflict with the norm) (Hermes et al., 2018). It is potentially safer for younger children employing a default social approach to "copy when unsure," and it is more advantageous for older children to "only copy if better" to prevent acquisition and transmission of misconceptions or erroneous tool use (Laland, 2004). Reflecting this in our study, younger children may interpret "best" based on normative relevance—as a tool that everyone ought to use—whereas older children may interpret "best" based on instrumental grounds of which tool is optimally suited for task completion. To further understand children's instrumental judgments, future research could include other measures such as "Which is the easiest?" and "Which is made for the task?" (Kelemen, Seston, & Saint Georges, 2012) as well as children's exposure to tools and materials in daily life. Furthermore, individual difference measures, such as parenting style (e.g., authoritarianism) and personality, could also be used to clarify what drives each child's imitative decision under the same testing condition.

This study suggests that preschoolers are capable of encoding the information taught by a robot and redistributing that knowledge, although they do so differently when the modeling agent is a human. Research is now needed to further establish the normative credibility and social relevance of robotic agents compared with humans and whether these will change with increasing exposure. It should be noted that the children we tested were from a WEIRD (Western, Educated, Industrialized, Rich, Democratic) society (cf. Henrich, Heine, & Norenzayan, 2010). Future research is needed to clarify whether the current findings are generalizable to other WEIRD and non-WEIRD societies, documenting possible universality and variation in cultural expectations surrounding conformist behavior and perception of robots. Ongoing investigations across the developmental spectrum and cultures into the research questions broached here will become increasingly critical as robots take on a more prominent presence in our lives and those of our children, and such investigations may afford novel insights into children's development of imitative flexibility in adapting to diverse ecologies.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2021.105148.

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