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Preschool-Aged Children Jointly Consider Others' Emotional Expressions and Prior Knowledge to Decide When to Explore

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Emotional expressions are abundant in children's lives. What role do they play in children's causal inference and exploration? This study investigates whether preschool-aged children use others' emotional expressions to infer the presence of unknown causal functions and guide their exploration accordingly. Children (age: 3.0–4.9; N = 112, the United States) learned about one salient causal function of a novel toy and then saw an adult play with it. Children explored the toy more when the adult expressed surprise than when she expressed happiness (Experiment 1), but only when the adult already knew about the toy's salient function (Experiment 2). These results suggest that children consider others' knowledge and selectively interpret others' surprise as *vicarious prediction error* to guide their own exploration.

Parents, caregivers, and educators display a wide range of emotions around young children; they might express joy when the child smiles, or sadness when the child is hurt. While such expressions may reflect the emoter's internal feelings, they are often exaggerated, or even feigned, in interactions with children. For instance, adults might look surprised when demonstrating a novel effect even when they do not *feel* surprised, or make a sad face when they discover that a toy is broken. What role do these expressions play in children's lives? Are they mere attention-grabbers that adults use to attract children's attention, or do they play a more significant role in what children think and how they learn? The current work investigates the possibility that emotional expressions are a rich source of information that guides children's exploratory play, providing valuable opportunities for learning.

Prior work suggests that sensitivity to others' emotional expressions emerges early in life. Even infants refer to the valence of others' emotional expressions to guide their own behaviors; they are more likely to approach, rather than avoid, an ambiguous situation when others' expressions are positive than when those expressions are negative (i.e., social referencing; Klinnert, Emde, Butterfield, & Campos, 1986; Moses, Baldwin, Rosicky, & Tidball, 2001; Sorce, Emde, Campos, & Klinnert, 1985; see Clément & Dukes, 2017; Walle, Reschke, & Knothe, 2017 for review). Beyond distinguishing positive from negative emotions, infants can also discriminate a wide range of within-valence emotional vocalizations and infer probable causes of these expressions (e.g., inferring something adorable from "Aww!" and something delicious from "Mmm!", Wu, Muentener, & Schulz, 2017; see Reschke, Walle, Flom, & Guenther, 2017; Ruba, Meltzoff, & Repacholi, 2019 for negative emotions). Infants also consider an individual's object-directed emotional expressions in communicative contexts as indicative of shared, generalizable attitudes across individuals (Egyed, Király, & Gergely, 2013; Gergely, Egyed, & Király, 2007).

Children's understanding of others' emotions becomes more sophisticated as they begin to appreciate that others' emotional reactions to observed events are also modulated by others' unobservable mental states, such as their prior perceptions, goals, desires, and beliefs. By 14 months, infants understand that an expression of excitement or surprise indicates an experience that is novel to the emoter, even though it is not novel to the infants themselves (Moll, Carpenter, & Tomasello, 2007; Moll, Koring, Carpenter, & Tomasello, 2006; Tomasello & Haberl, 2003). Infants also expect the valence of

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another agent's emotional expressions to be congruent with the agent's goal outcomes (Phillips, Wellman, & Spelke, 2002; Skerry & Spelke, 2014). By late preschool and early school years, children flexibly draw both forward inferences (i.e., using others' mental states and event outcomes to predict how others might feel; e.g., Asaba, Ong, & Gweon, 2019; Doan, Friedman, & Denison, 2018, 2020; Lagattuta, Wellman, & Flavell, 1997; Lara, Lagattuta, & Kramer, 2019; Pons, Harris, & de Rosnay, 2004) and inverse inferences (i.e., using others' emotional expressions to recover their underlying mental states or event outcomes; Repacholi & Gopnik, 1997; Wu, Haque, & Schulz, 2018; Wu & Schulz, 2018, 2020) in ways that are consistent with formal models of emotion understanding (Ong, Zaki, & Goodman, 2015; Saxe & Houlihan, 2017; Wu, Baker, Tenenbaum, & Schulz, 2018). Collectively, these results suggest that an abstract, theory-like understanding of emotion develops throughout early childhood, allowing children to use others' mental states to predict how others might feel and infer the latent causes of others' emotional expressions.

In contrast to the abundant literature on children's understanding of others' emotional expressions, relatively less is known about how such understanding influences children's learning and exploration. While recent efforts have begun to recognize the role of emotion in the social transmission of shared value (e.g., Dukes & Clément, 2019 on affective social learning; see also Gergely & Király, 2019), studies that directly measure children's inferences and exploration about the physical world is scarce. Instead, research on social learning has focused mostly on how children use adults' speech (e.g., "Look, it's a blicket!") or demonstrations (e.g., pressing a button to play music) to draw causal inferences (e.g., Bonawitz et al., 2011; Buchsbaum, Gopnik, Griffiths, & Shafto, 2011; Buchsbaum, Griffiths, Plunkett, Gopnik, & Baldwin, 2015; Butler & Markman, 2012; Gweon & Schulz, 2011) and inductive generalizations about the physical world (e.g., Csibra & Gergely, 2009; Csibra & Shamsudheen, 2015; Gweon, Tenenbaum, & Schulz, 2010). Building on these findings, a recent proposal has raised the possibility that in addition to others' utterances and demonstrations, young learners might also use others' emotional expressions as input to such inferences (Wu, Schulz, Frank, & Gweon, in press).

Among various emotions, surprise is particularly relevant to learning. The idea that learning is driven by *prediction error* (i.e., a discrepancy between an expected and actual outcome) has been extensively studied in both animal models and human adults (see Schultz, 2016 for review). Infants and young children also selectively explore when they observe events that violate their expectations (Sim & Xu, 2017; Stahl & Feigenson, 2015; van Schijndel, Visser, van Bers, & Raijmakers, 2015), suggesting that surprise is linked to exploration and modification of future behaviors.

However, such work has focused on how learners' own surprise affects learning, rather than how observing *others' expressions of surprise* influences learning. An important prerequisite for learning from one's own surprise is that the learner already knows enough to form a prediction in the first place; a learner with insufficient knowledge may fail to detect surprising events and miss out on important opportunities for learning. Yet, if children can capitalize on others' surprise as an indicator of *vicarious prediction error*, they can maximize opportunities for learning even when they lack the relevant knowledge to learn from their own surprise. For instance, upon seeing an adult expressing surprise while interacting with a causal toy, would a child infer that the toy has an unknown causal function and explore the toy to discover how it works?

Here we ask whether children can use others' expressions of surprise and unsurprised happiness (i.e., a baseline emotion at play) to decide when to explore to acquire new information and when to exploit their own existing knowledge. Note that such facial configurations may genuinely reflect the emoters' internal feelings or they can be deliberately displayed especially in child-directed communications; we are agnostic as to how these facial configurations are generated or how children map them onto underlying emotional states (but see Barrett, Adolphs, Marsella, Martinez, & Pollak, 2019; Cowen, Sauter, Tracy, & Keltner, 2019 for reviews and perspectives). Instead, our primary focus is to study how children use these expressions to guide their inferences about the *physical world* and their *exploratory play*. Following prior work on the influence of social contexts on preschoolers' exploratory play (Bonawitz et al., 2011; Butler & Markman, 2012; Gweon, Pelton, Konopka, & Schulz, 2014, but see Shneidman, Gweon, Schulz, & Woodward, 2016), we targeted 3- and 4-year-olds.

Experiment 1

Method

Participants

Our sample size and inclusion criteria were determined a priori based on Gweon et al. (2014;

Experiment 2), which used a similar free-play paradigm to measure children's exploration of a novel causal toy. We recruited 56 children (required sample size for 80% power: $n = 28$ per condition; $M_{age} = 4.1$ years [range: 3.0–4.9]; 32 girls). Three children were replaced due to failing to meet the inclusion criteria (< 5 s of playtime). Parents identified these children as Caucasian (34%), Asian (20%), Hispanic (7%), African American (2%), or multiracial (27%), or did not specify (11%). All children (in both experiments) were recruited from a university-affiliated preschool in the United States (Bing Nursery School, Stanford, CA) between October 2018 and June 2019.

Materials

We created a novel toy featuring a large yellow button which generated visually salient effects (spinning LEDs in a large plastic globe on top of the toy, see Figure 1). We also installed five smaller buttons and one peephole to make it plausible that the toy has additional functions. A box-shaped occluder with an opening in the front was used to enhance the effect of LEDs and to allow the experimenter to act on the toy without revealing the toy or her actions to the child. For a video demo of the toy and the occluder, see https://tinyurl.com/y4qxj34c.

Procedure

Each child was tested in a private room inside the preschool. The experimenter first introduced the toy to the child and expressed ignorance about how it works. In front of the child, she rotated the toy around and then pressed the top yellow button, apparently discovering that pressing the button activates the spinning light globe. She placed the toy inside the occluder box, generated the effects again, and turned the box around to show the child how the lights looked inside the box. The experimenter then invited the child to press the yellow button and activate the lights. She then turned the occluder box toward herself (such that the child could no longer see what she was doing) and said: "Now it's my turn again!"

A confederate then entered the room and reminded the experimenter of some paperwork they had to do. The experimenter suggested: "Maybe you could start the paperwork and I'll join you soon after I finish up playing with the toy."

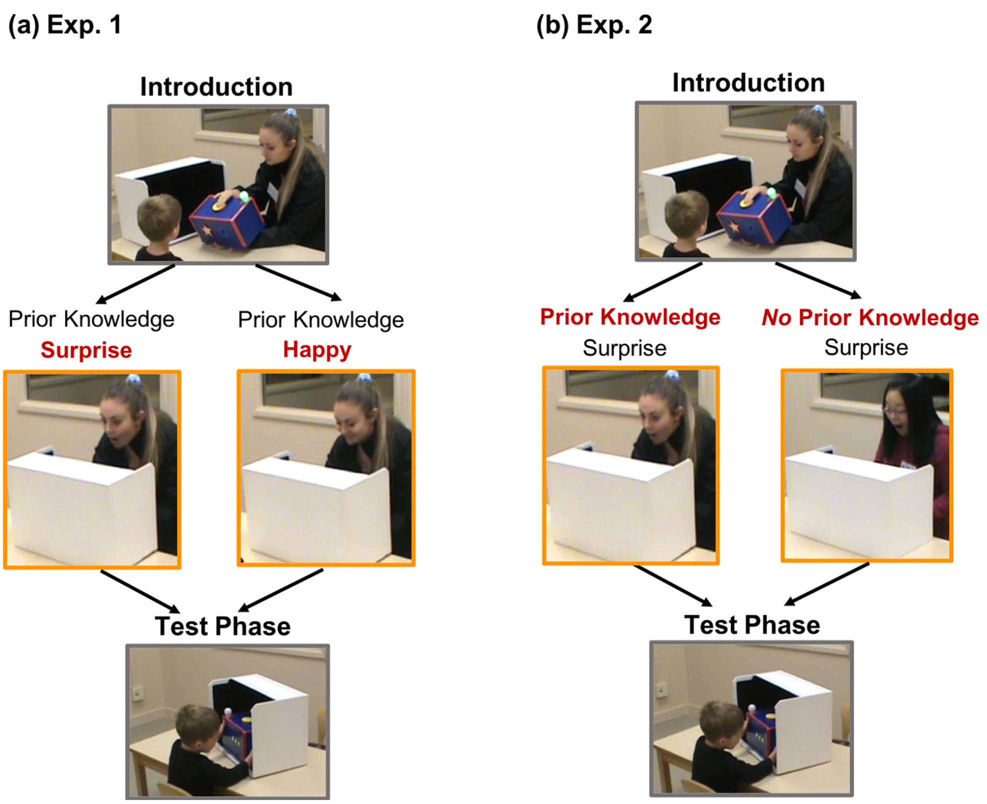

Figure 1. Design and procedure of Exp. 1 (a) and Exp. 2 (b). [Color figure can be viewed at wileyonlinelibrary.com]

The confederate agreed and started the paperwork at a different table in the room, facing away from the child. The experimenter continued to play with the toy behind the occluder box such that the child could see her face but not her actions or the toy. After a few seconds, the experimenter said: "I think I really like this toy! . . . I really like playing with it!" Then she made a surprised (Surprise Condition) or happy (Happy Condition) facial expression toward the hidden toy (see Figure 1a). The experimenter was trained to use a prototypical expression of surprise or happiness (Ekman & Friesen, 1971). While maintaining this expression, she looked at the child for 1 s and then looked back at the toy. Then, in both conditions, she said: "That's so cool!" If the child didn't pay attention to the experimenter's expression, the experimenter called the child's name and repeated the procedure, starting from "I think I really like this toy!"

The experimenter then asked the child: "Would you like a turn to play?" and rotated the opening of the occluder box toward the child. She said: "Let me know when you are done playing!" and joined the confederate to do the paperwork, facing away from the child. This marked the beginning of the *Test* Phase, which ended when the child said that she was done playing, or when the child had played for 2 min, whichever came first. If the child attempted to communicate with the experimenter (e.g., asking "What was so cool?" or "which button did you press?"), the experimenter either did not respond or gave an uninformative response (e.g., "We are doing our paperwork. Let me know when you are done playing!"). The full script for both experiments can be found here: https://tinyurl.com/7b7r4yer.

Results and Discussion

Children's behaviors at test were coded frame-by-frame as Exploitation (i.e., playing with the known function), Exploration (i.e., exploring other parts of the toy), or Disengagement (i.e., being disengaged from the toy) by two blind coders (intercoder reliability: $\kappa = .82$). See Supporting Information Section 1 for additional details on coding. Our key dependent measure was the percentage of time children spent exploring the toy over the duration of their play, calculated as follows: Percent Exploration (%) = Exploration (s)/Total Playtime (Exploration (s) + Exploitation (s)) $\times$ 100. Including Disengagement in Total Playtime did not affect our conclusion in both experiments (see Supporting Information Section 2).

Children's total playtime did not differ between conditions (Surprise: $M = 78.9$ s, $SD = 40.3$; Happy: $M = 64.0$ s, SD=38.9; $t(53.9) = 1.41$, $p = .164$, 95% CI [−6.28, 36.14], Welch Two Sample t-test). As predicted, however, children spent a larger proportion of time exploring the toy in the Surprise condition than in the Happy condition (Surprise: $M = 58.7\%$, $SD = 24.0$; Happy: $M = 41.1\%$, $SD = 29.3$; $t(52.0) = 2.45$, $p = .017$, 95% CI [3.21, 31.94]; see Figure 2a). Following Gweon et al. (2014), we also looked at the first 30 s of the test phase, during which most children played, and found a similar pattern (Surprise: $M = 59.1\%$, $SD = 29.5$; Happy: $M = 38.5\%$, $SD = 34.5$; $t(52.7) = 2.40$, $p = .020$, 95% CI [3.35, 37.74]). See Supporting Information Section 3 for Supporting Figures and Sections 4 and 5 for exploratory analyses on the effect of age and children's first actions at test. All data, analysis

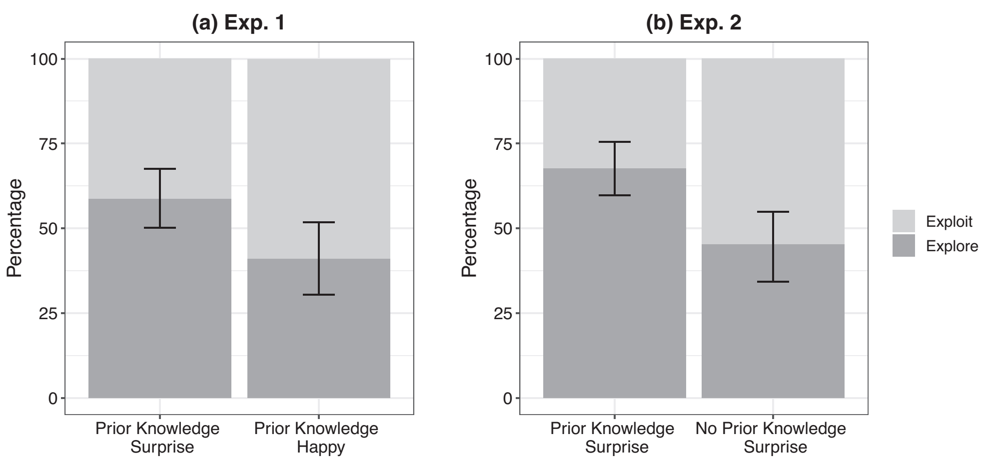

Figure 2. Results of Exp. 1 (a) and Exp. 2 (b). Error bars indicate 95% confidence intervals.

scripts, and results for both experiments can be found here: https://tinyurl.com/y2j9upwf.

These findings suggest that children were more likely to infer the presence of an unknown causal function following the experimenter's surprise than her happiness. One alternative explanation, however, is that children were simply responding to a high-arousal emotional cue or following a simple heuristic to explore whenever they observe a surprised expression. Thus, in Experiment 2, we ask whether children interpret the same expression of surprise differently depending on the emoter's prior knowledge. If children draw different inferences based on the emoter's prior knowledge, children would be less likely to explore the toy when the surprised expression came from a naïve confederate (which may indicate that she activated the salient function—LEDs—for the first time) than when it came from the experimenter who already knew about the LEDs.

Experiment 2

Method

Participants

As in Experiment 1, we recruited 56 children (n = 28 per condition, M_{age} = 4.1 years [range: 3.0–4.9]; 33 girls; 43% Caucasian, 18% Asian, 2% Hispanic, 5% African American, 25% multiracial, and 7% unknown). Six children were replaced due to failing to meet the predetermined inclusion criteria: (a) showing < 5 s of total playtime (n = 1); (b) spontaneously informing the Ignorant agent of the toy's function before the agent expresses surprise (n = 5).

Materials

We used the same materials as Experiment 1.

Procedure

The Prior Knowledge condition was identical to the Surprise condition in Experiment 1. In the No Prior Knowledge condition, the naïve confederate (who came into the room in the middle of the play; see Experiment 1 Procedure), rather than the experimenter, played with the toy and expressed surprise. More specifically, when the naïve confederate came into the room and reminded the experimenter of some paperwork, the experimenter suggested: "Maybe you could play with [the child's name] with this toy, and I'll start the paperwork over there. I don't think you've ever seen this toy before." The confederate agreed and sat at the experimenter's seat facing the child, while the experimenter moved to a different table in the room facing away from the child. The confederate greeted the child: "Hi! My name is [the confederate's name]. I'm a friend of [the experimenter's name]'s." From this point on, the confederate's behavior and emotional expressions were identical to the experimenter in the Prior Knowledge condition: After playing with the toy behind the occluder for a few seconds, the confederate said, "I think I really like this toy! . . . I really like playing with it!" Then she displayed a surprised facial expression toward the toy. While maintaining this expression, she looked at the child for 1 s and then looked back at the toy, saying: "That's so cool!" This ensured that children in both conditions saw an adult play with the toy behind an occluder with the same baseline emotional state and then change their expression to surprise. We also counterbalanced actor identity (experimenter and confederate) across participants. Thus, the only difference between conditions was whether or not the adult already knew about the salient function (see Figure 1b).

Results and Discussion

We used the same procedure to code children's free play (intercoder reliability: κ = .79). As in Experiment 1, children's total playtime did not differ between conditions (Prior Knowledge: M = 70.2 s, SD = 33.3; No Prior Knowledge: M = 58.6 s, SD = 35.2; $t(53.8)$ = 1.26, p = .213, 95% CI [−6.82, 29.92]). As predicted, however, children spent a larger proportion of time exploring the toy in the Prior Knowledge condition (M = 67.7%, SD = 22.3) than in the No Prior Knowledge condition (M = 45.3%, SD = 27.7; $t(51.7)$ = 3.32, p = .002, 95% CI [8.83, 35.82]; see Figure 2b). Similar results were found during the first 30 s of the test phase, during which most children played (Prior Knowledge: M = 59.6%, SD = 29.9; No Prior Knowledge: M = 35.6%, SD = 30.6; $t(54.0)$ = 2.97, p = .004, 95% CI [7.80, 40.19]; see Figure S1). These results suggest that although children observed the same surprised expression and spent similar amounts of time with the toy across conditions, they drew different causal inferences and selectively explored depending on the emoter's prior knowledge.

General Discussion

Across two experiments, we found that 3- and 4-year-olds explored a novel causal toy more broadly following an adult's expression of surprise than an expression of happiness (Experiment 1), but only when the surprise indicated the presence of an unknown causal function given the adult's prior knowledge (Experiment 2). These results suggest that preschool-aged children can jointly consider others' emotional expressions and knowledge to guide their causal inference and selective exploration.

Prior work has shown that even infants can identify others' focus of attention based on what is new to others, even though it is not new to themselves (Moll et al., 2006, 2007; Tomasello & Haberl, 2003). While these studies showed that infants can use others' prior experience to resolve ambiguities in referential communication, they did not explicitly test the role of different emotional expressions. On the other hand, despite the growing body of work suggesting that children can differentiate various emotional expressions and infer their latent causes (Repacholi & Gopnik, 1997; Wu, Haque, et al., 2018; Wu & Schulz, 2018, 2020; Wu et al., 2017), the relevance of these inferences in early social learning has remained elusive, especially in contrast to recent advances in understanding the role of learners' own surprise in early learning (Sim & Xu, 2017; Stahl & Feigenson, 2015; van Schijndel et al., 2015).

Grounded in these prior findings, the current work sheds light on how emotion-based inferences can facilitate learning by allowing children to identify novel learning opportunities. Rather than exploring indiscriminately in response to any expression of surprise or to sudden changes in emotional expressions, children in our study considered both the expressions themselves (surprise vs. happiness) and the emoter's prior knowledge to guide their exploration. This suggests that emotional expressions are far more than attention-grabbers or a simple cue to avoid, approach, or explore; preschool-aged children in our sample were able to draw sophisticated causal inferences based on others' observable expressions and unobservable epistemic states, and selectively explored when novel discovery was more likely.

Collectively, these findings advance our understanding of how children learn from others. Building on abundant work that emphasizes the role of others' speech, actions, and demonstrations in guiding early learning (e.g., Bohn & Frank, 2019; Bonawitz et al., 2011; Buchsbaum et al., 2011, 2015; Butler & Markman, 2012; Csibra & Gergely, 2009; Csibra & Shamsudheen, 2015; Gweon & Schulz, 2011; Gweon et al., 2010; Shneidman et al., 2016), a recent proposal has raised the possibility that children treat others' emotional expressions as an important source of information (Wu et al., in press). By synthesizing perspectives from emotion research, social learning, and exploratory play, our work provides empirical support for the idea that young children use others' emotion as information about the world (see also Dukes & Clément, 2019; Gergely & Király, 2019), taking a step toward a more comprehensive account of how we learn from others.

This work also provides insights into how children learn from others' surprise specifically. Complementing prior work on the role of learners' own surprise as an indication of prediction error in learning (Schultz, 2016; Sim & Xu, 2017; Stahl & Feigenson, 2015; van Schijndel et al., 2015), our work suggests that children readily capitalize on *others'* surprise as *vicarious prediction error*. While the role of others' choices, action-outcomes, or social feedback as vicarious prediction error has been an active topic of research in neuroscience (e.g., Apps, Lesage, & Ramnani, 2015; Burke, Tobler, Baddeley, & Schultz, 2010; Collette, Pauli, Bossaerts, & O'Doherty, 2017), our findings further reveal how children's ability to interpret the meaning of others' surprise based on their mental states can support powerful learning.

In this study, children observed a prototypical facial expression of surprise displayed in a positively valenced context (i.e., play) with a reference to "something cool," and children also had already learned about a positively valenced function. Thus, children had strong grounds to assume that the cause of the emoter's expression is also positive, leading them to search for the cause. However, there may be cases in which children interpret others' surprise as vicarious prediction error and draw inferences about the hidden cause, but do not necessarily show an increase in exploration. For instance, if children were placed in ambiguous or even negative contexts (e.g., a haunted house) or if the facial expression itself was negatively valenced (e.g., confusion, shock, freezing; Reisenzein, Bördgen, Holtbernd, & Matz, 2006), children might be less inclined to explore because they infer a hidden cause that is negatively valenced or should be avoided. Other factors may also contribute to children's tendency to explore. For instance, children's own knowledge about the toy might influence their exploration (e.g., if children did not know about the salient function, children might have explored the toy due to its novelty regardless of the emoter's expression or knowledge). Additionally, while we focused on the expression of surprise given its direct relevance to the concept of prediction error and exploration, children may use other emotional expressions or emotional changes as indicators of unexpected or hidden functions. Investigating how children interpret others' emotional expressions in a broader range of situations, and in particular, how these expressions and the broader context interact to modulate children's inferences and exploration, remains an important goal for future work.

Our results also raise questions about the content of children's inferences: *What* kind of hidden cause were children looking for, and what would have satisfied their search? Here we deliberately used a toy that did not have additional functions to avoid spontaneous discoveries, such that our dependent measure (% exploration) would accurately reflect children's strength of belief that the toy has a hidden function. While one might speculate that children might stop exploring upon discovery of a novel function, children might also continue searching if the discovered function is unlikely to have surprised the experimenter (e.g., a button that generates dull white noise; see Wu et al., 2017, experiments 4 and 5 for evidence from infants given diverse positive emotions). Studying the contents of children's inferences will help us better understand the representations that drive children's exploration.

More broadly, the idea that children use others' emotion as information for learning (Wu et al., in press) allows us to ask new questions about how children learn from others. First, while deliberate, exaggerated displays of emotional expressions in child-directed interactions are relatively common in industrialized, westernized societies, their frequency might vary across cultures. The degree to which children use others' emotional expressions for learning across different sociocultural contexts remains an important question for future work. Second, given that children are sensitive to teachers who are unreliable or uninformative (e.g., Gweon et al., 2014; Harris, Koenig, Corriveau, & Jaswal, 2018; Sobel & Kushnir, 2013), one might ask how these abilities might also modulate children's inferences from others' emotional expressions. Although even infants selectively imitate or gaze-follow depending on the past reliability of others' emotional expressions (see Poulin-Dubois & Brosseau-Liard, 2016 for review), the effect of emotional reliability on exploration and learning remains an open question. Finally, our results highlight the educational and clinical significance of emotional expressions. For instance, while autism spectrum disorders are associated with impairments in emotion recognition (see Bayet & Nelson, 2019 for review), their downstream consequences on exploratory play and early learning remain poorly understood. We hope our results will inspire more research into the importance of emotion as information in both typical and atypical development.

What counts as "information" in early learning? Our work extends the scope of social information that children harness for their own learning; beyond using others' actions, demonstrations, and verbal expressions, children also capitalize on others' emotional expressions as information for reasoning about the world, and strategically explore when novel discovery is likely. These findings suggest that the human ability to understand others' emotions not only helps us interact and sympathize with others, but also enables us to harness a wider range of information to learn about the world, supporting "smart" social learning.

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