Exploring to learn:
Curiosity, breadth and depth of exploration, and recall in young children

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Abstract

Curiosity relates to learning and recent work shows robust associations between curiosity and recall of information in adults and children over age 10. The current study tested a similar association in younger children and explored children's information-seeking behaviors. Children (*n*=90, 4-10-year-olds) played a free-exploration game in which they clicked shapes to learn different facts about different topics. They then recalled what they remembered learning on the task (recall) and asked questions about what they were curious to know more about (curiosity). We observed a positive association between children's curiosity and recall of information, even when controlling for amount of information seeking and children's age. This association was seen for recall with and without memory cues. There was no association between children's curiosity and information seeking behavior, and children showed a strong tendency of breadth exploration over exploring in depth with indication of an association between exploring more depth with age.

Keywords: curiosity; children; cognitive development; memory; exploration; information seeking

Curiosity and Learning

Curiosity is often described as an intellectual virtue (Baehr, 2017) that can support learning (Jirout, 2020) and is associated with academic behavior and performance in both children and adults (Kashdan & Silvia, 2009; Kashdan & Steger, 2007; Shah, 2018; von Stumm et al., 2011). The broad literature defines curiosity as seeking information in response to a knowledge gap (e.g., Loewenstien, 1994; Gruber & Ranganath, 2019). Curiosity can be considered both as a state, in which one becomes motivated to seek out information to resolve a knowledge gap in-the-moment, or as a stable individual characteristic in terms of the general propensity to become curious across various situations based on one's approach to uncertainty (Jirout et al., 2023). Research has explored associations between both trait and state curiosity and learning, typically as a result of information seeking and subsequent information gain, and also through enhanced cognitive processes (Jirout, 2020). Specifically, some findings suggest that curiosity motivates information-seeking behavior, leading to more information gained through exploration, and by promoting more connection-making during curious learning than non-curious learning by activating prior knowledge (e.g., learning because one wants to know something based on recognizing a specific gap in prior knowledge; Jirout, 2020).

Thus, curiosity can influence information seeking in two ways: by promoting *more* information seeking and also promoting *more effective* information seeking, which aligns with the PACE framework (Gruber & Ranganath, 2019). Developed using neurological evidence of the theorized pathways, Gruber and colleagues (2019) suggest that curiosity results from an individual's recognition of an information gap or prediction error. This recognition leads the individual to appraise the missing information, such as its usefulness, or leads to a more general positive expectation of information to be gained. Curiosity (i.e., a desire to address the information gap) then leads to enhanced attention and information seeking, and subsequent enhanced encoding of the information as indicated by better memory (Gruber & Ranganath, 2019). Consistent with this framework, empirical research shows that information-seeking while curious can enhance participants' memory for what they were curious about, and participants with greater curiosity often show higher incidental memory of unrelated information presented (e.g., Gruber et al., 2014; Kang et al., 2009).

This prior work suggests that the value of information gained through curiosity-driven information-seeking is important for reinforcing curiosity; the interaction between initial curiosity or expectations and the appraisal of information gained through it is an important consideration when understanding how curiosity leads to information seeking and subsequent curiosity (e.g., Gruber & Ranganath, 2019; Dubey & Griffiths, 2020). However, much of this prior work involved adolescents and adults; few studies have tested for similar patterns occur in children. In one study including children ages 10-12 years, children's curiosity-related cognitive processes appeared to differ from adolescents and adults, though findings still showed curiosity-related memory benefits for children (Fandakova & Gruber, 2019). The current study aimed to test whether similar memory benefits would be observed in even younger children.

Curiosity in Children

Curiosity is often measured in adults using self-report, but this type of measure can present challenges in research with younger children, so behavioral indicators of curiosity are often preferred (Jirout & Klahr, 2012). For example, one study used an exploration measure of uncertainty preference (i.e., how much uncertainty children preferred to explore) as

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a measure of curiosity, and then observed children's exploration and learning with a museum science exhibit (van Schijndel et al., 2018). Consistent with prior research, children's curiosity was associated with their learning about properties of different objects through exploration, and there were differences in information seeking relating to different levels of curiosity, though perhaps not in the direction expected (van Schijndel et al., 2018). Although some research would suggest that curiosity should be related to more exploration (e.g., Murayama et al. 2022), van Schijndel et al. (2018) found that children who were higher in curiosity explored for less time overall compared to children lower in curiosity, but they showed higher learning about the explored objects. While this may seem counterintuitive, it is possible that the more curious children had enhanced cognition as suggested in the PACE framework (Fandakova & Gruber, 2019), and more efficiently learned from their exploration and satisfied their curiosity, in which case they would have little reason to continue exploring. Another study of online exploration of causal relations showed similar findings of more efficient exploration with higher learning outcomes for more curious children using the same uncertainty preference task (Evans, 2022). Specifically, the study showed that although children's exploration was similar across levels of curiosity, greater curiosity (not exploration) was positively associated with learning. Supporting this idea of efficient learning, children with higher curiosity on the uncertainty preference task were found to be better able to categorize information as helpful or not helpful for solving a mystery problem than children with lower curiosity, while still showing more information-seeking in the form of question asking about a topic when prompted to ask about things they wanted to know (Jirout & Klahr, 2020).

These studies of curiosity provide support for associations with information seeking and learning when curiosity was measured as a stable, individual difference in the preference to explore under conditions of higher uncertainty, but prior work with adults suggests that there is still important variability in state curiosity (e.g., Jach et al., 2022). For potential interventions to support learning, it is likely easier to influence state curiosity than to impact trait curiosity.

Studies of curiosity as a state often use information seeking (e.g., exploration behavior or question asking) as a measure of curiosity in-the-moment. For example, Schulz and Bonawitz (2007) tested whether children would prefer to explore a toy they had already seen demonstrated over a novel causal toy, finding that children preferred to explore the toy they had already seen if the demonstration showed ambiguous information about the toy (e.g., they had uncertainty about how it worked), but preferring the new toy if the demonstration showed how the toy worked (no uncertainty). Similar preference was observed for children's preference to explore when information violated their prior beliefs (Bonawitz et al., 2012).

These studies and related findings suggest that creating uncertainty, such as through ambiguity, knowledge gaps, and violations of prior knowledge, can be a way to promote state curiosity that leads to information seeking and exploration. Along with the research showing that stable curiosity relates to more (or at least more efficient) learning, there is also some evidence that children's state curiosity relates to learning. Walin et al. (2016) had seven- and eight-year-old children rank-order questions based on how curious they were to know the answer. Results showed an association between children's rankings and their memory for the answers for the eight-year-olds, with better recall for questions ranked as inducing more curiosity. The same association was not observed for seven-year-olds, but there were only nine participants in that group.

Taken together, prior research shows that children often explore most when there is uncertainty and knowledge gaps, and that curiosity – both an individual difference and as a state – is related to more efficient cognition and learning. Yet, curiosity does not seem to lead to more information seeking in general, which is one of the proposed mechanisms through which it supports learning. One potential reason for this in past studies is that the information seeking tends to be related to learning specific things or solving specific problems (e.g., figuring out a causal relation, finding the answer to a trivia question, identifying a mystery animal). Real-world exploration is often more spontaneous; in a less constrained exploration task, children explored in meaningfully different ways from adults – with more exploration overall and also more creativity, but with less efficiency (Hart et al., 2022). The current study explored whether we could observe associations among children's curiosity, information seeking, and memory by measuring children's own intrinsic curiosity. That is, rather than assuming information seeking was a result of curiosity, we directly asked children what they were curious to know as a measure of curiosity. We wanted to test whether this naturalistic, open-ended curiosity related to their information seeking and memory for information gained through exploration, and to explore patterns of exploration.

Information Seeking: Breadth and Depth of Exploration

Children are effective explorers: when exploring, they recognize when there is something unknown to seek information about, and they choose effective means of exploring to get desired information (e.g., Cook et al., 2011; Ruggeri et al., 2019). In research on children's information seeking through questioning, studies show that there is somewhat equal frequency of children's questions about new topics vs. follow-up questions about the same topic, requesting more depth of information (e.g., Chouinard et al., 2007). In this study, we explored patterns of exploratory information seeking, testing whether children choose to explore different topics or to learn more about the same topic. Past theories of curiosity suggest varying dimensions and types of curiosity, one of which is breadth and/vs. depth. Simply put, these theories posit that one can be curious about many things related to the same topic (depth, sometimes considered general curiosity or close investigation of a specific topic or object), or many things each related to many different topics (breadth, sometimes considered a preference for variety, e.g., Ainley, 1987; Byman 1993).

There is some debate over whether breadth and depth are both dimensions of curiosity, with the suggestion that breadth curiosity is a meaningfully different behavior of seeking out stimulation or alleviating boredom (Loewenstein, 1994), whereas others suggest that the seeking of information more broadly might be indicative of a trait-type of curiosity while seeking information in more depth is the state of being curious, or that the different factors might be simply a result of measurement differences (e.g., Langevin, 1971; Boyle, 1989). Yet, when observing information seeking, there are clear differences in seeking information about multiple things (breadth) versus seeking additional information about the same thing (depth) (Henderson & Moore, 1979). Because little is known about children's preferences for exploring breadth and depth, this study examined patterns of exploration across age and how these patterns relate to curiosity.

Research Questions

This study addressed three primary research questions. First, we tested whether an association between children's state curiosity and their information seeking behavior and exploration patterns exists. Second, we tested whether state curiosity related to children's recall of information explored during the task. We further explored whether this association was present specifically for recall of information without any memory cues. Third, we explored whether children's information seeking showed stronger patterns of breadth vs. depth (i.e., whether children were more likely to explore across different topics vs. within the same topic), and we further explored whether this was different for younger and older children. Data were collected as part of a related study with the primary goal of testing the task and conducting measurement development work, but we included the prompts for recall and curiosity specifically to test these research questions; analyses related to the effects of cues, age differences, and patterns of breadth and depth of information seeking were all considered exploratory. Based on the prior work by Gruber et al. (2014) and Kang et al. (2009), we expected to see an association between children's curiosity and recall but did not have specific hypotheses about the effect of recall cues.

Methods

Participants

Participants included 90 children ages 4-10 (48-118 months; M = 83.4; SD = 19.8), with slightly more girls (59%) than boys (41%). Families were recruited for online participation using ChildrenHelpingScience.org, a participation signup list from members of the Cognitive Development Society, and Twitter posts with a link to a lab website. These methods limited the sample to children from predominately highly educated parents (i.e., at least one parent had a graduate degree in 84% of families who answered this question, n = 87). Most parents answered an open-ended question asking for race (n = 87), and participants reported their child's race as White (62%), two or more races (18%), Asian (14.5%), Black (1.2%) and Hispanic (1.2%).

Measures and Procedures

All children participated in data collection online over Zoom. These data were collected as part of a project to develop new measures of children's curiosity, creativity, and creative problem solving, but we focus on only one of the measures here. The measure was called "Explore and Learn", designed to measure children's free exploration to learn about different topics (see Figure 1). Children had the opportunity to explore and hear 27 facts total, three each for nine shapes. One prior study using a similar methodology found that about 75% of children clicked unusual animals a second time to hear more information (Mills et al., 2019), so we added a third click option to try to ensure variability in children's information search behavior.

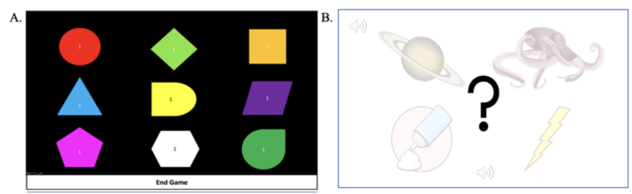

Figure 1. Screenshots from the explore and learn game. (A). Screenshot of game introduction: Children were told that they could explore to hear lots of fun information about different topics by clicking on different shapes. (B). Images from some topics to prompt recall: Once they were done exploring, children were prompted first without pictures to recall what they had learned, and then again with picture cues from some of the topics they may have explored, before being asked what else they were curious to know about.

In the Explore and Learn task, children hear recorded instructions explaining that they will play a game where they can explore to learn new things about different topics. The recording says that "another friend found out some really fun things and wants to share the things they learned with you." They are then shown an array of shapes and told they can click a shape to learn things, and they can click the same shape to hear more about the same topic and click different shapes to learn about different topics. They are told they can click an "I'm done" button when they are finished exploring. When a shape was clicked, the screen showed a full-screen image related to the audio fact that was given, and then the program returned to the main screen.

Topics corresponding to the different shapes included things like lightening, the human body, octopuses, video games, and whipped cream. Although they were about the same topics, independent and complete facts were given within each shape, as prior research finds that information seeking is influenced by children's feelings of having providing explanations that children perceive as being complete or incomplete (Mills et al., 2019). For example, facts given about Saturn included: “A year on Saturn is over 10,000 days” and “Saturn is less dense than water; it could actually float on an ocean of water.”

The shapes had small numbers on them, which began at ‘1’ and changed to ‘2’ and ‘3’ as each shape was clicked to help children keep track of which shapes they had explored, with each shape disappearing after it was clicked the third time. If children clicked the “I’m done” button, a window popped up to ask children if they were done exploring and they could confirm to advance the program.

When children had explored all 27 exploration opportunities or clicked “I’m done”, the screen changed to show text saying, “What did you learn?”. Children were prompted to recall information they remembered hearing during exploration. If the said nothing, they were prompted again to recall any information. The screen then changed to show pictures corresponding to four of the topics they may have explored (see Figure 1b). Children were told “here are some pictures to remind you of things you may have learned about to see if there’s anything else you can remember learning.” They were then asked again to recall anything they had learned. Two versions of the task were used, with half the children seeing one set of four topics represented, and the other seeing a different set (counterbalanced). Finally, children were asked what questions they had about the things they learned or about or any other topics. They were also told, “If you tell us what you are curious to know, we can find the answers to add to our game! What are you curious about?” The number of curiosity questions asked provided a measure of children’s state curiosity.

Children’s information seeking was measured as the number of explorations that provided information. Breadth of exploration was measured as the total number of explorations in which a different shape was clicked from the one that had previously been selected, and depth of exploration was coded as repeat clicks on the same shape. Recall was measured as the number of things children had recalled after the task, using the total number of things combined with and without the prompt. Curiosity was measured as the number of questions children articulated that they were curious to know.

Results

Across the task, children’s information seeking was skewed, with more than half of the sample exploring at ceiling. On average, children explored 19.9 facts (SD = 8.8), with 57% exploring all 27 opportunities. Because of the non-normal distribution, we used Kendall’s Tau-b to explore associations with exploration, except when we partial out age. Children’s total recall was 4.9 items (SD = 2.8), with 2.9 (SD = 2.1) given before the memory cues and 2.0 (SD = 1.5) additional facts given after the picture cues were shown. When asked what else they were curious to know, children asked an average of 1.6 curiosity questions (SD = 1.4). Age was associated with the number of facts recalled (τ b = .307, $p <$ .001) and the number of curiosity questions (τ b = .217, $p =$ .007), but not total number of explorations (τ b =.112, p=.166.

Our first research question asked whether we would observe an association between children’s state curiosity, as measured by number of curiosity questions asked, and their information seeking behavior. Surprisingly, we did not observe an association between children’s curiosity questions and their information seeking (τ b = .051, p = .567; controlling for age p = .854).

Our second research question asked whether we would observe an association between curiosity and recall. We tested the relation between children’s curiosity (number of curiosity questions asked by the child) and the total number of items recalled from the task using a Kendall’s Tau-b test, which showed a significant positive but moderate correlation (τ b = .298; p < .001). Because children may have had different opportunities to recall facts based on how many facts they explored and exploration itself related to recall (τ b = .275, p = .001), we ran a partial correlation test to control for the total number of facts explored, and observed a similar correlation (r_p = .314, p = .003). Because age was associated with total recall and curiosity, we ran the association again controlling for both the total number of facts explored and age, and the association remained significant (r_p = .255, p = .019). Children’s curiosity questions fell almost evenly into giving none (25.3%), one (25.3%), two (25.6%) or three or more (23%) total questions, so we plot the total number of facts recalled by curiosity level in Figure 2 to show the association, using estimated means controlling for age and total facts explored.

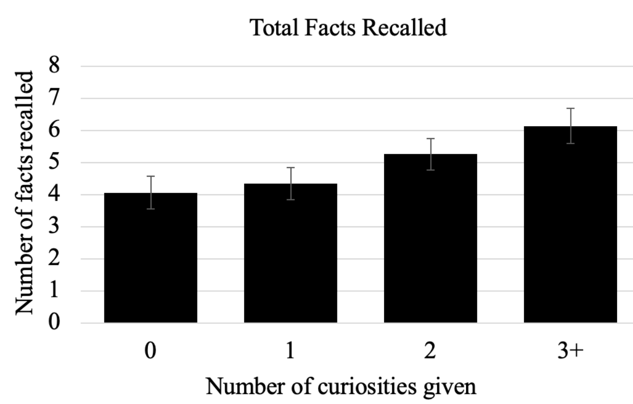

Figure 2. Estimated mean recall (and SE) by curiosity level.

We tested whether this association was specific to items recalled without cues by repeating the correlation controlling for age and total explorations with recall before the cue prompt, and observed a similar association (r_p=.220, p=.045).

To further explore the effects of the prompt, we tested whether children’s recall was significantly higher after the prompting, finding that it was (F = 175.32, p < .001; η^2 = .68), with a significant interaction with age, using a median split (F = 6.35, p = .014; η^2 = .07, see Figure 3). However, there was no difference in facts recalled after the prompt between those cued and not cued (i.e., (p = .509).

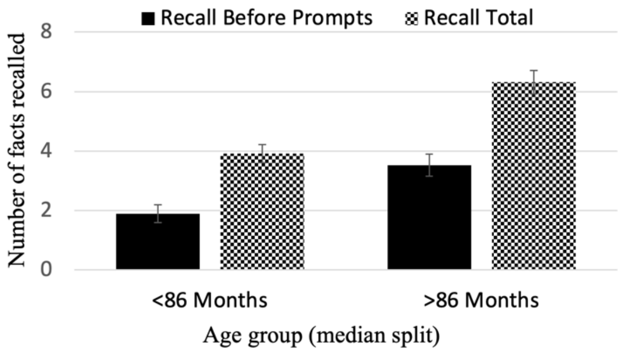

Figure 3. Estimated mean recall before prompting and combined before and after (total) by age group.

Our third research question asked whether children show patterns of exploring for breadth of information over depth of information. This was assessed using exploration of different shapes consecutively as indicating depth and exploring the same shape multiple times as indicating breadth. Because our data only provided the total number of clicks, we coded the exploration patterns from video of children's sessions for subsequent clicks on the same shape (note that this would be possible up to 18 times, because shapes disappeared after being clicked the third time). With an overall average of 21.10 explorations (SD = 8.25), children click the same shape twice in a row 4.26 times (SD = 5.68). Children were more likely to click the same shape twice in a row on their second time clicking it ($M = 2.42$) than their first time ($M = 1.84$; $p = .039$). Curiosity as measured by the question responses was not related to children's overall number of breadth explorations ($\tau_b = -.093$, $p = .245$) or depth explorations ($\tau_b = .036$, $p = .673$). To explore potential changes across age, we calculated the proportion of total number of explorations that were depth explorations, which indicated that age is slightly but positively associated with a higher proportion of depth exploration to overall exploration ($\tau_b = .166$, $p = .033$).

Finally, we looked at whether breadth might be indicated not only by sequential clicks, but by exhausting the facts that could be learned for a shape (i.e., considering breadth as clicking all three times at any point, even if not sequentially). This is a somewhat limited way of considering breadth because of the ceiling effects of 57% of children clicking all shapes all three times throughout the task. Interestingly, though, of the remaining children who did not reach ceiling, most (68%) did not explore *any* shapes all three times (29% of the overall sample). Of these children who did not explore any shapes all three times, half (13/26) explored all nine shapes at least once; of children who explored two to seven shapes all three times (n=12), only three did not explore all nine shapes at least once, further demonstrating a strong pattern of breadth over depth exploration.

Discussion

The results of this study show that children's curiosity, as measured by number of curiosity questions asked, relates to recall of information explored in an open-ended information seeking task, even when controlling for overall amount of information seeking and children's age. This association was seen for free recall specifically, with no difference in results with memory cues, though the added prompting led to additional recalled facts more generally. Although we did not see an association between children's curiosity and their information seeking behavior and exploration patterns, children showed a strong tendency of breadth exploration over exploring in depth, with some indication of children beginning to explore in depth more with age, though breadth exploration was still much more frequent across ages.

Based on prior theory that information seeking may explain the link between curiosity and learning (e.g., Fandakova & Gruber, 2021; Jirout, 2020), it was surprising to find that curiosity did not relate to information seeking in this task, even though similar recall effects were observed. While this could suggest incidental memory effects of curiosity, there are several other possible explanations for this as well. First, it is possible that curiosity does not motivate information seeking, but this is unlikely. Many past theories and studies of curiosity defined it as a motivation that leads to information seeking; so, it is more appropriate to say that the specific measure of curiosity used here is either not assessing curiosity in a way similar to prior research, or that it is meaningfully different or incomplete from prior measures. For example, by asking children to articulate something they are curious about in the moment, it is possible that the context of curiosity assessed is unrelated to what children were exploring and learning during their information seeking, and so might not make sense to expect an association with what they chose to explore. It is also possible that being curious *after the task* does not indicate curiosity experienced *during the exploration*, but that would not explain why we observed the expected association between curiosity (after the task) and recall (of information from exploring during the task). This association would make sense if the number of curiosity questions asked as a measure was indicating a more general curiosity or stable individual difference in curiosity, rather than curiosity as a state, which is also a possibility. This kind of curiosity, often thought of as trait curiosity, relates to state curiosity and other personality factors in exploration tasks (e.g., Jach et al., 2022). In this case, it is possible that curiosity expressed in the curiosity questions was indicating a different type of curiosity than that expressed by the information seeking itself, which is consistent with both relating to recall, but is still unexpected that they would not relate to each other, as general trait curiosity does relate to state curiosity and exploration in adults (Jach et al., 2022).

It is also possible that this lack of association, whether or not the exploration and curiosity questions are measuring trait or state curiosity, could be a result of limitations to the task used. Specifically, there may have been inadequate variability in information seeking to detect an association, since the majority of children's exploration was at ceiling. However, even when we look only at the children who did not explore at ceiling, there is no indication of an association between curiosity questions asked and information seeking.

Another possibility is that children have different motivations for information seeking. Some may be exploring to hear the different information because they are curious, but some may be doing something more systematic, such as clicking all of the shapes in order, or clicking them all to get them to disappear and clear the board, etc. In follow-up work with this measure, we have adapted shapes to have many more facts, to not disappear at the end, and not indicate how many times it has been clicked. Early data collection suggest that many fewer children explore all possible opportunities. We are also collecting children's explanations of how they decide whether to continue clicking and which shape to click on, but these data are not currently available to analyze as data collection is ongoing. We expect that information seeking, even when done in open-ended tasks without explicit goals, vary in terms of children's explanations for decision making with curiosity only being one such explanation. There are likely additional possible explanations for this lack of association, and this is a very interesting topic for future research to explore. It is also possible that these explanations might explain differences in exploration patterns.

When exploring patterns of exploration across the task, children's exploration in this study showed very strong patterns of breadth of information seeking over depth, a pattern similar to what is observed in children's exploration of toys (Vandenberg, 1984). Children ages 4-12 tended to briefly explore all toys offered before returning to explore them in more depth, and, similar to the age effect observed here, children were more likely to explore in more depth with age and the authors suggest that older children are more systematic in their exploration (Vandenberg, 1984).

The observed preference for breadth may also relate to the influence of attention in decision making about exploration, which children shifting attention to more novel options after exploring (Blanco and Sloutsky, 2022). In the current task, children may have engaged in more breadth exploration because there were no guiding goals or instructions to focus or direct their exploration, and the information learned through exploration wasn't useful in the moment and had no clear utility value, so other tasks that are more goal directed would perhaps show different patterns of exploration. Further research should continue to explore to understand breadth and depth exploration to inform decisions around providing exploration opportunities in ways that can support learning.

The slight increase in depth exploration choices with age is consistent with the developmental shifts in children's exploration and valuing of information utility (e.g., Nussenbaum & Hartley, 2019), though there was still little indication of depth exploration in this study, and strong patterns of breadth exploration. It is also very possible that exploration might shift to begin showing more depth in information seeking with exploration, and that the current design of the task didn't provide the opportunity to see this kind of shift (i.e., three "levels" of depth to explore may not have been enough). In subsequent studies, we are collecting data with a modified version of the task that includes seven levels per shape, which will allow us to explore this further. In future work, it will also be interesting to further explore potentially related developmental differences in exploration, such as in working memory. For example, older children may better remember shapes and spatial location match with the different topics, and thus be more equipped to direct the information searching towards topics they were most curious about, which could result in more depth search strategies.

Limitations and Future Directions

The conceptualization of curiosity and information seeking as separate constructs in this study could be a limitation, as it is very likely that the information seeking observed was curiosity-driven, at least for some children. That is, we may have underestimated children's curiosity during the information seeking game by only using their verbal questions to what they were curious about in the moment after information seeking was complete. The decision to complete the task in this order was to provide children with some engaging and novel information about topics to spark curiosity – the more information you know about something, the more capable you are to think of additional information you could learn about it to become curious (Wade & Kidd, 2019). In future work, it could be possible to allow children to explore what they wanted to and give all children all additional information they did not get via exploration to test for a similar association between children's information seeking and memory, though this introduces new confounds.

Another limitation to this study was the ceiling effects in information seeking, with more than half of the children exploring all possible options. As discussed above, several modifications to the task have been made for our current data collection, which will allow us to explore several of the questions raised from the findings here in our future work. More generally, it is possible that associations among curiosity, information seeking, and recall could be explained by more general cognitive or intellectual abilities. Prior work including controls for this shows similar associations between curiosity and exploration (Jach et al., 2022) and curiosity and learning (van Schijndel et al., 2018). Future work should still attempt to include this important control when investigating this question with children.

Finally, although we attempted to create an open-ended exploration task without explicit goals, it is still unclear whether information seeking on this task would relate to children's more naturalistic exploration of their world, which is something that could be tested in future research. While the future work will be able to address these limitations and the many questions related to our findings, the current study extends prior research in several ways. The patterns of exploration explored show support for prior research on attention and provide an initial foundation for future work to explore developmental changes in breadth and depth of information seeking. Most importantly, the results here provide further evidence of an association between curiosity and recall, with associations observed in younger children for information from self-directed, open-ended exploration task, demonstrating the robustness of this association.

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