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Integrating lines of research on children's curiosity-driven learning

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ABSTRACT

Epistemic curiosity is considered indispensable in children's learning, but previous empirical research on children's curiosity-driven learning has been fragmented; separate research lines tend to focus on single learning outcomes. Therefore, this study aimed at integrating different research lines by adapting an existing paradigm to investigate not only the relation between children's state curiosity and their memory performance but also their desire to explore. In addition, this study examined a possible mechanism through which curiosity affects recall: increased attentional processes. Last, this study investigated the role of intelligence and perceived prior knowledge in the relation between curiosity and recall. We applied a within-participants design in which the Trivia task (N = 32) and Raven's Standard Progressive Matrices were administered to 10- to 12-year-olds. In the Trivia task, participants learn answers to trivia questions for which they have high and low curiosity, and subsequently recall is tested. Main findings include that children memorized trivia facts better when they were in a high-curious state rather than a low-curious state, and this positive relation may increase with intelligence. Importantly, the relation between curiosity and recall still held when taking into account perceived prior knowledge. Curiosity was positively related not only to recall but also to children's desire to further explore the concerning topic. Given that in some educational contexts promoting curiosity is not considered a priority and children express little school-related curiosity, an important value of this study for educational practice lies in the reinforcement of the notion of curiosity being a main driver of children's learning.

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Introduction

Epistemic curiosity is considered an important driver of children's learning (e.g., Peterson, 2020). Different definitions of epistemic curiosity exist, but a broadly accepted definition is based on Loewenstein's (1994) information gap theory, which sees curiosity as the desire for new knowledge or experiences to resolve a knowledge gap (e.g., Grossnickle, 2016; Jirout & Klahr, 2012; Loewenstein, 1994). The awareness of a knowledge gap leads an individual to experience uncertainty, which, if individuals believe in their ability to resolve the gap, motivates curiosity and information seeking behaviors that potentially lead to learning (Gruber & Ranganath, 2019; Murayama et al., 2019; Peterson & Cohen, 2019). This is illustrated by studies demonstrating positive relations between children's curiosity and their academic achievement (e.g., Alberti & Witryol, 1994; Shah et al., 2018).

Even though epistemic curiosity is considered to drive children's learning, empirical support for this claim is fragmented (Peterson, 2020). Children's curiosity-driven learning has been studied in different scientific disciplines, rendering separate lines of research applying different paradigms and focusing on different learning outcomes. For example, some lines of research focus on how children's curiosity relates to their information seeking (e.g., Bonawitz et al., 2012; Cook et al., 2011; Jirout & Klahr, 2020; Luce & Hsi, 2015; Schulz & Bonawitz, 2007; Van Schijndel et al., 2015), whereas other lines of research focus on how children's curiosity relates to their learning as measured by knowledge acquisition and transfer (e.g., Arnone et al., 1994; Lamnina & Chase, 2019, 2021), and memory performance (e.g., Fandakova & Gruber, 2021; Jirout & Evans, 2023; Walin et al., 2016).

Looking more closely at children's information seeking, several studies have examined how curiosity relates to question asking (Jirout & Klahr, 2020; Luce & Hsi, 2015). For example, Jirout and Klahr (2020) found 4- to 7-year-olds' trait curiosity to be positively related to their abilities to recognize effective questions and generate questions for learning, but not to their ability to generate questions for problem solving. Besides asking questions to others, one can also seek information by engaging in exploration oneself. A line of research in the field of developmental psychology has shown that provoking preschoolers' state curiosity by raising their awareness of a knowledge gap leads them to engage in a higher quantity and quality of exploration (Bonawitz et al., 2012; Cook et al., 2011; Schulz & Bonawitz, 2007; Van Schijndel et al., 2015). For example, Bonawitz et al. (2012) confronted 6- and 7-year-olds with evidence conflicting with their prior knowledge on balance (an asymmetrical toy balancing on its geometrical center) and found that this group explored balancing materials longer as opposed to a novel toy, whereas this was not the case for a group that was confronted with evidence confirming their prior knowledge.

Looking more closely at children's learning, several studies have applied inquiry-based paradigms to examine how curiosity relates to knowledge acquisition and transfer of knowledge (Arnone et al., 1994; Lamnina & Chase 2019, 2021; Van Schijndel et al., 2018). For both 6- to 8-year-olds in a computer-based learning environment (Arnone et al., 1994) and 7- to 9-year-olds in a hands-on learning environment (Van Schijndel et al., 2018), it was found that high-curious children acquired more knowledge from inquiry than low-curious children. In studying the curiosity-driven learning of a somewhat older age group, 10- to 12-year-olds, Lamnina and Chase (2019, 2021) took into account not only children's learning but also their transfer of knowledge. The authors provoked children's state curiosity by exposing them to an uncertain form of instruction ("invention activities") in which children learned about ratio structures in physics. The authors manipulated uncertainty by providing children with expectations of feeling uncertain (Lamnina & Chase, 2019) or withholding them from task-relevant information about the problem-solving process (Lamnina & Chase, 2021). In both studies, the uncertainty manipulations predicted children's transfer of knowledge, that is, their ability to apply and adapt ratio structures in novel contexts. However, surprisingly, the uncertainty manipulations did not predict children's initial learning, that is, their understanding of ratio structures in the taught context. And even though the uncertainty manipulations in both studies positively affected children's state curiosity, curiosity predicted transfer in only one of the two studies (Lamnina & Chase, 2019).

In addition, a line of neuroscientific research has investigated how children's curiosity relates to their memory for factual information using different versions of the Trivia paradigm, which was first applied in studies with adults (e.g., Gruber et al., 2014; Kang et al., 2009). In this task, participants learn answers to trivia questions for which they have high and low curiosity. Just before presenting the answers, unrelated incidental information is presented. Fandakova and Gruber (2021) applied the task to children (10- to 12-year-olds), and adolescents (13- and 14-year-olds). Memory was shown to be better for high-curiosity trivia facts as compared with low-curiosity trivia facts in both children and adolescents. These results were in line with those that Walin et al. (2016) previously found for 8-year-olds, but not for 7-year-olds, in a study with a very small sample. However, in contrast to adults (e.g., Gruber et al., 2014), children and adolescents in the Fandakova and Gruber (2021) study did not recall incidental information better when it was paired with high-curiosity versus low-curiosity trivia facts. Recently, Jirout and Evans (2023) also found a positive association between curiosity and recall in 4- to 10-year-olds using a different paradigm.

A limited set of studies on children's curiosity-driven learning has taken into account both information seeking and learning (Arnone et al., 1994; Bonawitz et al., 2012; Jirout & Evans, 2023; Lamnina & Chase 2021; Van Schijndel et al., 2015, 2018). For example, Van Schijndel et al. (2018) showed that 7- to 9-year-old children's curiosity was positively related to their knowledge acquisition from inquiry, and this relation was in part explained by the duration of children's exploration; high-curious children explored shorter and learned more. High- and low-curious children did not differ in the quality of their exploration, that is, the number of performed unique informative experiments.

Besides fragmentation arising from separate lines of curiosity-driven learning research focusing on different learning outcomes, another challenge the field faces is the identification of the mechanism(s) through which curiosity affects information seeking and learning. A proposed mechanism centers around the role of reward processing in curiosity (e.g., Gruber et al., 2014; Jepma et al., 2012; Kang et al., 2009; Murayama et al., 2019). After having experienced a knowledge gap and having engaged in information seeking, the acquisition of knowledge is considered a rewarding experience, which is hypothesized to positively affect the reward value of new information (e.g., Murayama et al., 2019). In line with this hypothesis, imaging studies have shown curiosity to go together with increased activity in memory- and reward-related brain regions (e.g., Gruber et al., 2014; Jepma et al., 2012; Kang et al., 2009), and behavioral results have shown curiosity to correlate with a willingness to spend scarce resources to acquire information (Kang et al., 2009). The PACE (prediction, appraisal, curiosity, and exploration) framework (Gruber & Ranganath, 2019) focusing on the neural mechanisms of curiosity and memory assumes, however, that a curious state cannot be compared one to one with a state associated with reward motivation. Besides describing prediction errors as triggers of curiosity and an appraisal process determining one's actions and subjective experiences, the framework emphasizes the role of attention and predicts that if curiosity is provoked, not only is learning enhanced through increased exploration and memory performance (encoding and consolidation), but also increased attentional processes play an important role herein. That is, during information seeking an attentional bias leads one to focus on stimuli associated with rewards, which positively affects memory performance. In line with this assumption, curiosity elicited by trivia questions has been shown to go together with increased pupil dilation during answer anticipation (Kang et al., 2009) and earlier anticipatory gaze orientation toward the expected answer location (Baranes et al., 2015). In addition, trait curiosity has been shown to predict the visual exploration of natural scenes (Risko et al., 2012).

The current study aimed to contribute to filling the above-described gaps in the research on children's curiosity-driven learning. That is, we aimed to integrate separate lines of research on children's curiosity-driven learning by investigating both exploration and memory. We investigated a possible mechanism through which curiosity affects memory (attention) and included two relevant control variables: intelligence and (perceived) prior knowledge. We used the Trivia task (Fandakova & Gruber, 2021; Gruber et al., 2014; Kang et al., 2009), in which participants learn answers to trivia questions for which they have high- and low-state curiosity. Given that the task originally focused on children's memory for factual information, we first investigated whether 10- to 12-year-olds' curiosity for trivia facts is related to better recall for these facts (Research Question 1) and better recognition for incidental information that was paired with these facts (Research Question 2). Based on prior results in a comparable age group (Fandakova & Gruber, 2021), we expected to find curiosity to go together with better trivia recall but not with better recognition for incidental information.

Moreover, in line with our aim to further integrate the lines of curiosity-driven learning research that focus on different learning outcomes, in the current study we added an assessment for children's willingness to explore to the Trivia task. In this exploration phase participants indicated, for trivia questions for which they had high and low curiosity, whether they wanted to further explore these questions in the future. Specifically, we investigated whether children's curiosity for trivia facts was related to their desire to further explore the questions' topics (Research Question 3). Given that curiosity is considered to drive or manifest through information seeking (Gruber & Ranganath, 2019; Jirout & Klahr, 2012; Peterson & Cohen, 2019), and previous empirical studies have shown positive relations between children's curiosity and their exploratory behaviors (Bonawitz et al., 2012; Cook et al., 2011; Schulz & Bonawitz, 2007; Van Schijndel et al., 2015), we expected to replicate this positive relation with the Trivia paradigm.

In addition, we investigated, in an exploratory manner, a possible mechanism through which curiosity affects learning: increased attentional processes (e.g., Baranes et al., 2015; Gruber & Ranganath, 2019; Kang et al., 2009; Risko et al., 2012). For this purpose, we added an attention assessment to the study phase of the Trivia task. That is, in the study phase the answers to questions were presented and attention was measured in between the presentation of the questions and their answers (see Method for further details). Specifically, we investigated whether the relation between children's curiosity and their recall of trivia facts is mediated by attention (Research Question 4).

Last, we included, in an exploratory manner, two relevant control variables in the current study. Given that both curiosity (e.g., Von Stumm et al., 2011) and memory performance (e.g., Zelinski et al., 1993) have been shown to relate to intelligence, we assessed children's intelligence (with Raven's [1965] Standard Progressive Matrices) and investigated the role of intelligence in the relation between state curiosity and recall of trivia facts (Research Question 5). A second control variable we included concerns (perceived) prior knowledge. In the Trivia task, questions were used from different categories or domains such as art, history, and science. If children would be more curious to know the answers to questions from a particular domain, they could possibly also possess, or believe to possess, a higher prior knowledge level in that domain. In this scenario, the hypothesized better recall of trivia facts (Research Question 1) could be explained not only by the higher curiosity level but also by the higher prior knowledge level facilitating memory encoding. Therefore, we investigated, using existing perceived prior knowledge ratings in the screening phase of the Trivia task (see Method for further details), whether the hypothesized curiosity effect on trivia recall still held when taking into account perceived prior knowledge of trivia facts (Research Question 6).

Method

Participants

Data from 12 children were excluded because of technical issues (n = 2), not finishing the Trivia task (n = 6), or not having sufficient questions in the high- and low-curiosity pools (n = 4) (see "Trivia task" section below and see "Descriptives" section in Results). The final sample (for the within-participants design) consisted of 32 children (M_{age} = 11 years 7 months [age was unavailable for 1 child]; 15 girls and 17 boys from two Dutch primary schools). Raven's Standard Progressive Matrices (RSPM) data were available only for the second school (n = 22). For all participating children, written consent from a parent or legal guardian was obtained. The study, including the consent procedures, was approved by the ethics committee of the Department of Psychology at the University of Amsterdam.

Procedure

The data were collected in December 2021 (first school) and May 2022 (second school). The study was performed in separate classrooms at the schools that at the time of the study were used purely for this purpose. Both the Trivia task and the RSPM were performed individually, but the administration took place in small groups. For the second school, the Trivia task and RSPM were administered on 2 consecutive days. The first two phases of the Trivia task (screening and study phase; see "Trivia task" section) took an average of 40 min, after which a break of minimally 20 min followed. At the first school, children played outside during the break; at the second school, during the break a questionnaire was administered that is beyond the scope of this article, after which children played with coloring pages or word search puzzles. The remaining phases of the Trivia task (recognition test for incidental information, recall test for trivia answers, and exploration phase; see "Trivia task" section) also took around 40 min. Last, the RSPM took around 20 min.

Materials

Trivia task

We modeled our version of the Trivia task (Fandakova & Gruber, 2021; Gruber et al., 2014; Kang et al., 2009) after Fandakova and Gruber's (2021) version. The task was administered on a computer and consisted of four phases: a screening phase, a study phase, a recognition test for incidental information phase, and a recall test for trivia answers phase. The main changes we made to the task were that we added an attention assessment to the study phase as well as a fifth phase: an exploration phase. We did not include Fandakova and Gruber's post-answer interest rating in the study phase. Last, in the recall test for trivia answers phase, participants typed in the answers instead of saying them to the researcher as in Fandakova and Gruber's version. We made use of brief phase introductions, practice trials, and rating scale explanations, and we presented stimuli in the center of the computer screen on a light gray background. The five phases are further described below.

Screening phase. In this phase, participants were presented with trivia questions that were drawn randomly from a database (see Fig. 1). The database consisted of 200 questions equally divided over the following categories: art & music, food, geography, history, languages & books, media, science–animals, science–general, sports, and general knowledge. The database was based on Fandakova and Gruber's (2021) questions (see https://osf.io/5tp8j). We only selected questions from Fandakova and Gruber's set that were relevant for the Dutch context, and we translated all questions into Dutch. Questions that were not suited for Dutch children were replaced. Importantly, as in Fandakova and Gruber's version, the database contained questions for which the majority of participants would not know the answer. The questions were presented on the screen one by one for 5 s, and participants were subsequently asked on a next screen whether they knew the answer to the question (perceived prior knowledge rating: 1 = *no*, 2 = *I don't think so*, 3 = *I think so*, 4 = *yes*) and to what extent they wanted to know the answer to the question (curiosity rating: 1 = *not at all*, 2 = *not so much*, 3 = *kind of*, 4 = *very much;* self-paced), after which the next question followed. If participants did not indicate that they knew the answer to the question (all ratings except a rating of 4), questions for which participants indicated that they wanted to know the answer (ratings 3 and 4) were assigned to the

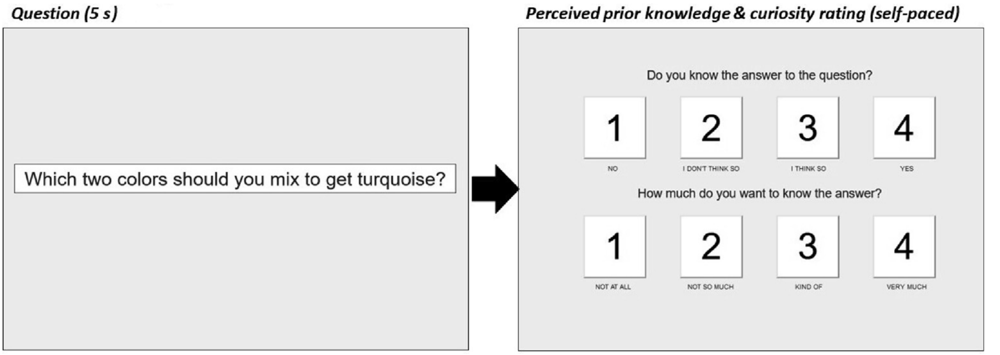

Fig. 1. Screening phase of the Trivia task.

high-curiosity pool, and questions for which participants indicated that they did not want to know the answer (ratings 1 and 2) were assigned to the low-curiosity pool. Questions for which participants indicated that they knew the answer (rating of 4) were not used any further in the task. The phase was divided into blocks of 15 questions and continued until, for a given participant, both the high- and low-curiosity pools included 25 questions or all 200 questions from the database had been presented.

Study phase. In this phase, the trivia questions from the high- and low-curiosity pools along with their answers were presented on the screen one by one in random order (see Fig. 2). For each question, first the question was presented (5 s), followed by a delay period, the presentation of the answer (5 s), and a wait screen (1 s; with the text: "next question"), after which the next question followed. The delay period included an attention assessment and, as in the procedure of Fandakova and Gruber (2021), the presentation of incidental information. Specifically, the delay period started with a continue button (self-paced), followed by a pulsating crosshair (1 s), the attention assessment (self-paced), and the presentation of the incidental information (self-paced with a minimal presentation time of 5 s). The attention assessment consisted of a 3 × 3 matrix with nine smileys, eight without sunglasses and one with sunglasses, and participants were instructed to click as fast as possible on the smiley with sunglasses. The attention assessment was developed for the purpose of this study but based on existing selective attention assessments such as the Bourdon Vos Test (Vos, 1998), and the TEA-Ch (Test of Everyday Attention for Children; Manly et al., 1999). For the presentation of incidental information, a face was presented (fixed presentation time of 5 s) alongside the question "Can this person help you?" (rating: 1 = *definitely not,* 2 = *probably not,* 3 = *probably,* 4 = *definitely;* self-paced). The faces were drawn randomly from a database of 90 neutral-friendly faces from people of different races with naturalistic backgrounds that was balanced in terms of gender, age group, and whether the mouth was open or closed. The database was retrieved from the 10K U.S. Adult Faces Database (Bainbridge et al., 2013) that was also used by Fandakova and Gruber (2021) and Gruber et al. (2014). The phase was divided into blocks of 15 questions, and continued until a maximum of 25 questions from each (high- and low-curiosity) pool was presented (50 questions in total). If one of the original pools contained more questions, 25 questions were drawn randomly.

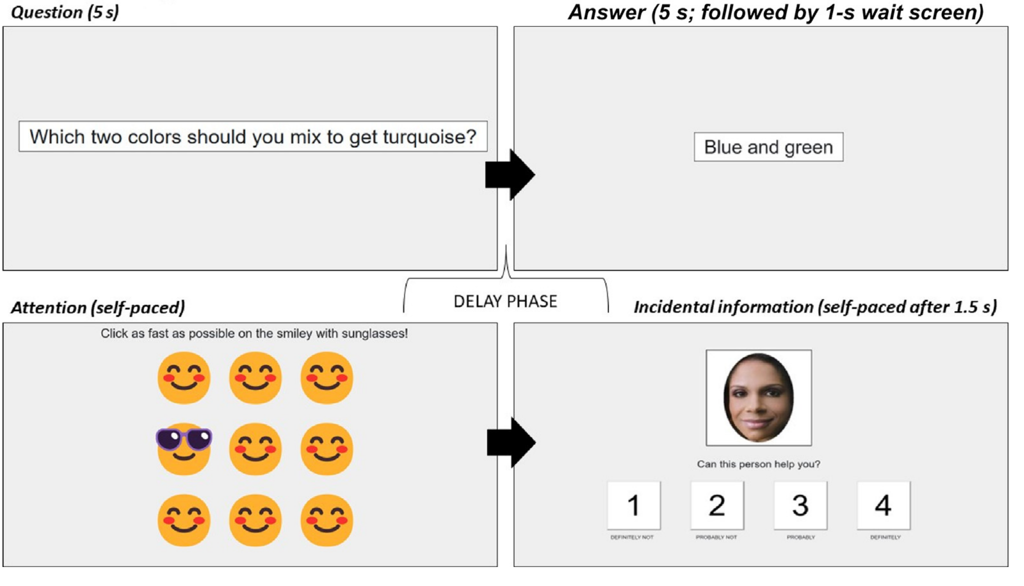

Fig. 2. Study phase of the Trivia task. The attention assessment was preceded by a continue button (self-paced) and a crosshair (1 s).

Recognition test for incidental information phase. After a break of minimally 20 min, the recognition test for incidental information phase followed. In this phase, faces that were and were not shown during the study phase were presented one by one, and participants were asked whether they had seen the face before on the computer during this study (incidental information rating: 1 = *no,* 2 = *I don't think so,* 3 = *I think so,* 4 = *yes;* self-paced after 1.5 s). The (maximally 50) faces that in the study phase were paired with high- and low-curiosity questions made up two thirds of the presented faces, and the remaining third was made up of new faces from the database described above. The faces were presented in three equal-sized blocks, each block consisting of an equal distribution of faces (faces paired with high-curiosity questions, faces paired with low-curiosity questions, and new faces) that were presented in random order.

Recall test for trivia answers phase. In this phase, the (maximally 50) questions from the low- and high-curiosity pools were shown one by one in random order. Participants were asked to type in the answer and press a save button or to press a button with question marks when they did not know the answer (self-paced), after which the next question followed. After administration, raters determined the accuracy of answers.

Exploration phase. In this phase, participants were asked, for five randomly selected questions from their high-curiosity pool and five randomly selected questions from their low-curiosity pool, whether they later wanted to learn more about the question (exploration rating: 1 = *not at all,* 2 = *not so much,* 3 = *kind of,* 4 = *very much;* self-paced).

Raven's Standard Progressive Matrices

We used the RSPM (Raven, 1965) to assess children's intelligence.

The RSPM consisted of a total of 60 items divided over five sets of 12. For each item, children were shown an incomplete picture and asked to select the missing element completing the picture from six options. The paper-and-pencil test was printed in black and white. Children were given a maximum of 20 min to perform the test (Hamel & Schmittmann, 2006). To control for the effect of age on RSPM performance, RSPM total scores were regressed on age. The residuals expressed individual differences, independent of age, and were used in further analyses.

Results

Descriptives

All participants obtained scores in the high- and low-curiosity conditions because the experiment had a within-participants design. Three participants had fewer than 12 questions in the low-curiosity pool, and one participant had fewer than 12 questions in the high-curiosity pool. As mentioned in Method, data from these participants were excluded from further analyses. Table 1 shows the average performance on the memory tests (recall and recognition test phases Trivia task), the average score on the exploration questions (exploration phase Trivia task), and the speed on the attention task (study phase Trivia task) by curiosity condition.

Table 1
Average performance on memory tests, scores on the exploration questions, and speed on the attention task compared across curiosity conditions

	Curiosity condition		Paired *t* test	
	High	Low	$t(27)$	d
Recall: p(correctly recalled trivia)	.40 (.17)	.27 (.15)	4.27^{***}	.81
Recognition: p(correctly recognized faces)	.54 (.14)	.55 (.15)	−0.56	−.11
Average exploration (range = 1–4)	2.29 (0.82)	1.75 (0.68)	4.90^{***}	.93
Average speed attention: RT (ms)	1445 (415)	1554 (657)	−1.14	−.26

Note. N = 28. Standard deviations are in parentheses. RT, response time.
*** $p < .001$.

Curiosity and memory

To test whether curiosity was related to recall of trivia information (Research Question 1) and recognition of incidental information (Research Question 2), proportions correct were compared across conditions (high vs. low curiosity) within participants. Distributions of the difference scores of both memory tests did not deviate from a normal distribution. Table 1 shows the results of the paired t tests for both memory tests. Performance on the recall test was higher for high-curiosity versus low-curiosity questions, suggesting that participants memorized trivia information better when they were in a high-curious state than when they were in a low-curious state. However, performance on the recognition test did not depend on curiosity condition, suggesting that participants did not memorize incidental information better when they were in a high-curious state. Subsequent analyses on the relation between curiosity and memory therefore were performed for the responses to the recall data only.

Curiosity and exploration

To test whether curiosity was related to the desire to further explore a topic (Research Question 3), scores on the exploration questions were compared across conditions (high vs. low curiosity) within participants. Distribution of the difference scores of the exploration questions deviated slightly from a normal distribution given that the Kolmogorov–Smirnov test was significant, $KS(28) = .18$, $p = .027$, whereas the Shapiro–Wilk test was not, $W(28) = .93$, $p = .062$. Table 1 shows that exploration scores were significantly higher for high-curiosity versus low-curiosity topics, $t(27) = 4.90$, $p < .001$, $d = .93$. The 95% confidence interval of the difference score, obtained by bootstrapping (1000 samples), ranged from 0.32 to 0.77. The results indicated that participants' desire to further explore was higher for topics for which they expressed high curiosity compared with topics for which they expressed low curiosity.

Curiosity and attention

To investigate, in an exploratory manner, whether the relation between children's curiosity and their recall of trivia facts was mediated by attention (Research Question 4), as a first step we tested whether curiosity was related to the speed of identifying stimuli that were surrounded by distractors. Speed was the average response time of correctly identified stimuli. Participants performed nearly perfect on the attention task; the average percentage of correctly identified stimuli was 95%. Table 1 shows the results of the across-condition (high vs. low curiosity) comparison of speed on the attention task. Distribution of the difference score was skewed left and deviated significantly from a normal distribution, $KS(28) = .22$, $p < .001$, $W(28) = .74$, $p < .001$. The difference between the curiosity conditions was not significant, $t(27) = -1.14$, $p = .092$ (the 95% confidence interval of the difference was obtained through bootstrapping and ranged from −271 to 55), indicating that the speed of identification did not relate to the level of curiosity for the question preceding the attention trial. A paired t test on log transformed response times, with very fast and slow responses excluded (200 ms ≤ response time < 4000 ms), also did not show a significant speed difference between the curiosity conditions.

Next, mediation analysis for repeated measures (Montoya & Hayes, 2017) was conducted with curiosity condition (high or low) as the independent variable, speed in the attention task as the mediator, and proportion correct on the recall task as the dependent variable. In accordance with the results of the paired t test (Table 1), the direct effect of curiosity condition on recall was significant, $t(25) = 4.00$, $p < .001$. However, the indirect effect was not significant (the 95% confidence interval obtained by bootstrapping [1000 samples] ranged from −.02 to .02), indicating that speed on the attention task did not mediate the relation between curiosity condition and recall.

The role of intelligence and perceived prior knowledge in the relation between curiosity and memory

First, we investigated, in an exploratory manner, the role of intelligence in the relation between state curiosity and recall of trivia facts (Research Question 5). To this end, we used the MEMORE syntax (Montoya & Hayes, 2017), with curiosity (high or low) as the independent variable, RSPM residuals as the moderator, and proportion correct on the recall task as the dependent variable. Overall, RSPM residuals were not significantly related to the difference in memory performance between the two curiosity conditions, $t(17) = 0.71$, $p = .49$. Because of the exploratory nature of the analysis, we did inspect the relation between state curiosity and recall for RSPM residuals below and above the median. The association between curiosity and performance on the recall test was not significant for participants with an RSPM score below the median, $t(8) = 1.47$, $p = .09$ (one-sided), but it was significant for participants with an RSPM score above the median, $t(9) = 4.30$, $p < .001$ (see Fig. 3). It cannot be concluded that RSPM residuals moderated the relation between curiosity and recall, but the relation seemed stronger for higher versus lower RSPM residuals.

Last, we investigated, in an exploratory manner, whether the relation between curiosity and memory would still hold when taking into account perceived prior knowledge of trivia facts (Research Question 6). In the screening phase, questions for which the answer was unknown (knowledge rating of 1, 2, or 3) were categorized into either the low-curiosity pool (curiosity rating of 1 or 2) or the high-curiosity pool (curiosity rating of 3 or 4). For 19 participants, questions in each curiosity pool were available for each perceived prior knowledge level. Table 2 shows the mean proportion correct on the recall test (trivia facts) for these participants for each combination of curiosity and perceived prior

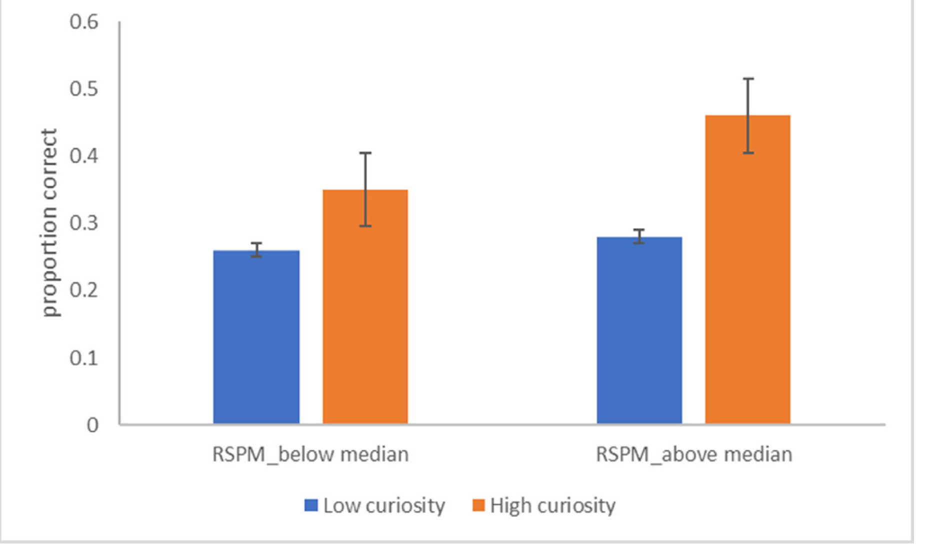

Fig. 3. Performance on recall for trivia questions by curiosity level and two levels of Raven's Standard Progressive Matrices (RSPM) residuals (determined by median split). Error bars show standard errors of the means.

Table 2
Proportions correct on recall test by curiosity condition and knowledge level

	Curiosity condition	
	High	Low
Knowledge Level 1	.33 (.25)	.27 (.16)
Knowledge Level 2	.44 (.25)	.28 (.28)
Knowledge Level 3	.53 (.26)	.41 (.27)

Note. $N = 19$.

knowledge level. A repeated measures analysis with two within factors (curiosity: low or high; perceived prior knowledge: *no, I don't think so,* or *I think so*) was performed to predict proportion correct on the recall test. Both main effects were significant: curiosity, $F(1, 18) = 6.29$, $p = .022$, partial $\eta^2 = .26$; perceived prior knowledge, $F(2, 17) = 4.22$, $p = .032$, partial $\eta^2 = .33$. The interaction effect was not significant, $F(2, 17) = 0.69$, $p = .513$, partial $\eta^2 = .08$. In line with the dependent *t* test (see "Curiosity and memory" section above), the proportion correct for recall of trivia facts was higher in the high-curiosity condition than in the low-curiosity condition (see Table 2). Post hoc analyses showed that proportion correct was significantly higher for perceived prior knowledge Level 3 than for perceived prior knowledge Level 1, $F(1, 18) = 8.92$, $p = .008$, partial $\eta^2 = .331$, indicating that memory for trivia facts was better when participants indicated that they thought they knew the fact than when they indicated that they did not know it. Taken together, the results show an association between perceived prior knowledge and recall, but importantly they also show that the association between curiosity and recall still holds when perceived prior knowledge of trivia facts is taken into account.

Discussion

With this study, we set out to contribute to filling several gaps in the research on children's curiosity-driven learning. Specifically, we aimed at integrating different lines of curiosity-driven learning research, investigating a possible mechanism through which curiosity affects learning, and taking into account control variables in investigating the relation between curiosity and memory.

In line with our hypothesis, we found 10- to 12-year-olds' state curiosity for trivia facts to be positively related to their memory recall for these facts, suggesting that children memorized trivia information better when they were in a high-curious state than when they were in a low-curious state. This result corresponds with the results of Fandakova and Gruber (2021) with children and adolescents and the results of Walin et al. (2016) with 8-year-olds but not 7-year-olds. In adults, the curiosity recall effect has also been demonstrated with a delay (e.g., Gruber et al., 2014, Kang et al., 2009; Stare et al, 2018), and in line with Fandakova and Gruber (2021), we suggest that future research also explores the relation between curiosity and delayed recall in children.

In investigating the relation between curiosity and recall, we took into account two control variables and examined, in an exploratory manner, the role of intelligence and perceived prior knowledge. First, the results suggest that the positive relation between curiosity and recall for trivia facts may increase with intelligence. However, the analysis was based on a small number of participants for which intelligence could be assessed. We are not aware of other studies examining the role of intelligence and intelligence-related variables in the relation between state curiosity and learning. Previous studies concerning children's trait curiosity demonstrated that intelligence did not moderate the relation between curiosity and learning (Van Schijndel et al., 2018) and, at the same time, that socioeconomic status did moderate the relation between curiosity and academic achievement (Shah et al., 2018). Future research therefore might pay further attention to the role of intelligence in children's curiosity-driven learning.

Second, we found the relation between curiosity and recall of trivia facts to still hold when taking into account perceived prior knowledge. This result corresponds with results in adults showing that (perceived) prior knowledge positively relates to memory performance in the Trivia task but does not "explain away" the effect of curiosity (Stare et al., 2018; Wade & Kidd, 2019). Note that the design of the Trivia task was suboptimal for investigating the role of perceived prior knowledge in the curiosity–memory relation given that the design did not require all knowledge levels to be evenly represented within children. In addition, in this study, in line with the method of Fandakova and Gruber (2021), we assessed participants' confidence in knowing the answer, that is, their perceived prior knowledge. Wade and Kidd (2019) demonstrated in a Trivia task study with adults that such a subjective prior knowledge assessment positively relates to a more objective prior knowledge assessment. In addition, both types of prior knowledge assessments have been shown to relate to participants' recall of trivia facts; the results of both Stare et al. (2018) (adults) and the current study (children) demonstrated perceived prior knowledge to be related to recall of trivia facts, and Wade and Kidd (2019) found a marginal effect of perceived prior knowledge and a larger effect of prior knowledge as assessed by independent raters on recall. However, future research could look into replication of the current study's effects with a more objective measure of prior knowledge.

This study did not shed any further light on how curiosity affects memory recall in children. By adding an attention assessment to the existing Trivia task (Fandakova & Gruber, 2021; Gruber et al., 2014; Kang et al., 2009), we examined, in an exploratory manner, the role of increased attentional processes. We did not find curiosity to be related to the speed of identifying stimuli in the attention assessment, nor did we find the relation between curiosity and recall of trivia facts to be mediated by attention. A possible explanation for this null result concerns the association between the attention assessment and the object of children's curiosity being indirect and therefore not clear enough for participants. Gruber and Ranganath (2019) hypothesized that when curiosity is provoked, during information seeking an attentional bias leads one to focus on stimuli associated with rewards. That is, the reward and associated attentional processes are directed at stimuli that fill the information gap: the trivia facts. In the current study's design, the attention assessment was placed in between the presentation of the trivia question and its answer, and the faster children responded on the attention task, the faster the trivia fact was shown. However, there was no direct relation between the attention assessment and the trivia facts given that the delay period between the trivia question and its answer also included the presentation of incidental information. A suggestion for future research on children's curiosity-driven learning with the Trivia task therefore would be to assess attention in a way that is more closely associated with the presentation of the trivia answers both in time and in content. To establish a more direct relation in time, the presentation of incidental information could be removed from the task's delay period so that a trivia fact would directly follow the attention assessment. To establish a more direct relation in content, participants could be told that when they click on the target smiley in the attention assessment, this smiley will immediately provide them with the trivia fact. Alternatively, children's attention in relation to the trivia facts could be assessed in a different manner such as has been done in adults with pupil dilation (Kang et al., 2009) and anticipatory gaze orientation (Baranes et al., 2015).

Besides memory recall, the current study also investigated how curiosity relates to a second memory-related learning outcome: recognition of incidental information. In line with our hypothesis, we did not find children's curiosity for trivia facts to be related to their recognition for incidental information that was paired with these facts. This result corresponds with the results of Fandakova and Gruber (2021) with children and adolescents, but it contrasts with the results of adult studies (e.g., Gruber et al., 2014; Stare et al., 2018) as well as the results of an infant study demonstrating that curiosity enhanced the processing of incidental objects in 8-month-olds (Chen et al., 2022). A suggestion for future research using the Trivia task to investigate spillover effects on memory in children would be to present trivia facts and incidental information simultaneously, for example, by using color or pattern as incidental information and showing trivia facts in different color fonts or with different colored and/or patterned backgrounds. Such an operationalization would also have the advantage of making this information strictly incidental. The current operationalization, faces, bears the risk that children relate specific trivia questions to specific faces because they are asked whether the person presented can help them to find the answer to the trivia question. Finally, such simultaneous presentation of incidental information and trivia facts would imply that incidental information is removed from the Trivia task's delay period, which may strengthen the temporal relation between the attention task and the presentation of the trivia facts.

To integrate different lines of curiosity-driven learning research, we investigated children's curiosity in relation to not only their memory performance but also their willingness to explore. To this end, we added an exploration assessment to the existing Trivia task (Fandakova & Gruber, 2021; Gruber et al., 2014; Kang et al., 2009). In line with our hypothesis, we found children's curiosity for trivia facts to be positively related to their desire to, in the future, further explore the concerning topic. Whereas previous research related curiosity either to young children's exploration (Bonawitz et al., 2012; Cook et al., 2011; Schulz & Bonawitz, 2007; Van Schijndel et al., 2015) or to older children's memory performance (Fandakova & Gruber, 2021; Walin et al., 2016), the current study brought these research lines together by showing that 10- to 12-year-olds' curiosity for trivia facts related to not only their recall for these facts but also their willingness to further explore the question's topic. A question for future research is whether the mechanisms through which curiosity enhances recall and exploration are similar. On the one hand, the PACE framework (Gruber & Ranganath, 2019) connects exploration with selective attention, which is presumed to play a role in how curiosity affects recall, possibly suggesting one underlying mechanism. On the other hand, Poli et al. (2024) posited an account of curiosity entailing that curiosity is the result of multiple underlying mechanisms and that the degree to which these mechanisms affect behavior may differ between people.

In the current study, we focused on children's state curiosity. Given that state curiosity is considered malleable, it has a clear relevance for educational practice (Fandakova & Gruber, 2021). In addition, several authors have emphasized the limited number of studies addressing children's state curiosity in relation to their learning and academic performance (Fandakova & Gruber, 2021; Lamnina & Chase, 2019). State curiosity is seen as experienced in the moment and resulting from the environment, whereas trait curiosity is seen as experienced enduringly and resulting from internal characteristics (Grossnickle, 2016). Individuals with different levels of trait curiosity are considered to differ in their preference for uncertainty or the size of a knowledge gap (Jirout & Klahr, 2012) and the frequency with which they experience state curiosity (Grossnickle, 2016; Peterson, 2020). Aligned with the current study, previous studies on children's curiosity-driven learning have focused on either state curiosity (e.g., Fandakova & Gruber, 2021; Lamnina & Chase, 2019, 2021) or trait curiosity (e.g., Arnone et al., 1994; Jirout & Klahr, 2020; Van Schijndel et al., 2018). A suggestion for future research therefore would be to simultaneously examine the role of trait and state curiosity in children's information seeking and learning, including the extent to which these curiosity dimensions interact.

Conclusion

Considering the role of curiosity in educational practice, previous research has shown that in some contexts teachers do not consider promoting curiosity to be an educational priority (Engel, 2011; Spektor-Levy et al., 2013), the occurrence of curiosity-promoting teaching practices is low (Evans et al., 2023), and children express little curiosity in school (Engel, 2011; Post & Walma van der Molen, 2018). This study's results suggest that a teacher provoking children's state curiosity might find children not only to better recall information but also to show a higher desire to further explore a topic. Therefore, an important value of this study for educational practice lies in the reinforcement of the notion of curiosity being a key driver of children's learning.

CRediT authorship contribution statement

Tessa J.P. van Schijndel: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Brenda R.J. Jansen:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Data availability

Data will be made available on request.

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