



## Prequestioning with feedback fosters learning in young children

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### ABSTRACT

**Background:** *Prequestioning*—attempting to answer questions about unfamiliar information before exposure to the correct answers—has shown promise for enhancing learning. Yet its effectiveness for young children, who have limited cognitive capacities and face unique learning challenges, remains unclear.

**Aims:** This study investigated whether prequestioning improves learning from science texts in young children and whether the presence of immediate feedback influences its effectiveness.

**Sample:** Participants were 5- to 6-year-old children (total  $n = 87$ ;  $n = 44$  in Experiment 1,  $n = 43$  in Experiment 2).

**Methods:** Children engaged in each of three activities: prequestioning with immediate feedback, prequestioning without feedback, or a non-prequestioning activity (free-drawing in Experiment 1; studying learning objectives in Experiment 2). After each assigned activity, they listened to an age-appropriate scientific story and completed a learning assessment. Their working memory capacity was also assessed.

**Results:** In Experiment 1, prequestioning with feedback improved learning relative to free-drawing, and this effect did not differ based on whether the information being assessed had been directly prequestioned or not. In Experiment 2, it enhanced learning of directly prequestioned information compared to studying learning objectives. Prequestioning without feedback, however, did not yield statistically significant learning improvements in either experiment. The effects of prequestioning did not differ according to working memory capacity.

**Conclusions:** Prequestioning enhances young children's learning, particularly for directly questioned information, but only when immediate feedback is provided. These findings suggest that although prequestioning might motivate young children to actively seek out and process new information, such information must be presented within a proximate temporal window to the questions themselves.

### 1. Prequestioning with feedback Fosters learning in young children

Childhood is widely recognized as a critical period for learning novel information (Knudsen, 2004). Yet young children often face learning challenges due to their underdeveloped cognitive capacities, such as poor memory functioning (Drumme & Newcombe, 2002; Ngo et al., 2017; Superbia-Guimarães & Cowan, 2023) and difficulty sustaining attention (Betts et al., 2006; Kim et al., 2023; Werchan et al., 2024). Accordingly, identifying effective learning strategies to support children's learning is important. Strategies such as retrieval-based learning (Goossens et al., 2014; Karpicke et al., 2016; Rohrer et al., 2010) and spaced learning (Vlach et al., 2008; Vlach & Sandhofer, 2012) have shown promise in children, although some studies have reported mixed results (Gates, 1917; Marsh et al., 2012). Another learning technique,

*prequestioning* (sometimes also called *pretesting*), has recently gained attention for its potential to enhance learning outcomes, particularly in adults (for a review, see Pan & Carpenter, 2023).

Prequestioning is a form of practice testing in which learners attempt to answer questions about unfamiliar material *before* being exposed to the correct information. Typically, studies of prequestioning compare a prequestioning condition against a non-prequestioning control condition. In the prequestioning condition, learners receive practice questions (i.e., prequestions) prior to engaging with the target learning materials (e.g., a text passage or video lecture), sometimes followed by immediate correct answer feedback (Pan & Sana, 2021). The correct answers are always discoverable in the target materials, either through their literal presence or by inference. Because learners typically do not know much about the information being prequestioned, they often generate incorrect responses and must learn the correct answers through feedback or

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the target materials. In the control condition, learners engage in non-testing activities, such as reading statements (Richland et al., 2009), before exposure to the target materials. Learning outcomes are assessed via a criterial test that is administered immediately or after a delay. On that test, better performance in the prequestioning versus the control condition—a phenomenon known as the *prequestioning effect* (Pan & Carpenter, 2023)—is commonly observed. The present study sought to determine whether that effect extends to young children’s learning from science texts.

### 1.1. The prequestioning effect in adults

Richland et al. (2009) was among the first studies to investigate prequestioning in adults using robust experimental controls and with a specific focus on its unique impact (for a review of earlier related research, see Hamaker, 1986). In a series of experiments, they had undergraduate students answer five prequestions on the visual system (e.g., “What is total color blindness caused by brain damage called?”), then read an essay containing the correct answers. Compared to a control condition that had additional time to read the essay without prequestions, these students achieved higher accuracy on criterial tests administered both immediately and one week later. A growing body of research has since demonstrated similar prequestioning effects in adults across learning materials such as texts (e.g., Sana & Carpenter, 2023), educational videos (e.g., Carpenter & Toftness, 2017), and live lectures (e.g., Carpenter et al., 2018).

The prequestioning effect can manifest in two distinct patterns. In the first pattern, the prequestioning condition outperforms the control condition on both *tested* questions (i.e., very similar or identical to the prequestions) and *untested* questions (i.e., targeting different information) on the criterial test. That pattern reflects a *general benefit*, where prequestions enhance learning across all learning materials. In the second pattern, the prequestioning condition outperforms the control condition on tested questions only, indicating a *specific benefit*, where learning improvements are limited to directly tested content. Most research on prequestioning has found a specific benefit of prequestioning without a general benefit (e.g., Richland et al., 2009; St. Hilaire & Carpenter, 2020), although some studies have reported a general benefit (e.g., Carpenter & Toftness, 2017; Pan, Sana, Schmitt, & Bjork, 2020). Recently, a meta-analysis of the prequestioning literature (St. Hilaire et al., 2024) found much stronger evidence for a specific benefit (Hedges’  $g = 0.54$ ) than a general benefit ( $g = 0.04$ ).

Although many studies of prequestioning have used relatively passive control conditions, such as engaging in no learning activities before being exposed to correct information, a few studies have compared prequestioning against more competitive learning activities. For example, Sana et al. (2020) had participants engage in prequestioning or studying learning objectives (e.g., “In the first passage you will learn where the mouth movements are located in the frontal lobe”) before reading a passage on a neuroscience topic. A prequestioning benefit was still observed, suggesting that prequestioning is uniquely capable of enhancing learning in adults.

### 1.2. The prequestioning effect in children

To date, the prequestioning effect has rarely been investigated in young children. Some relevant research, however, has been conducted with *pedagogical questions*, which refer to questions posed by a knowledgeable person with the intention of teaching. These studies have shown that such questions can encourage children’s exploration (Yu et al., 2018) and enhance causal learning (Daubert et al., 2020). As they have typically been investigated to date, however, pedagogical questions are not specifically presented before or after learning new information and do not require learners to provide an answer. Both of these procedures are hallmark characteristics of prequestioning (in that sense, prequestioning might be regarded as a subtype of pedagogical

questions).

As few as two studies directly relating to the prequestioning effect in children have been published to date. Carneiro et al. (2018) had 4-to-8-year-old children learn paired associate words (e.g., *doctor-nurse*). In the pretesting (analogous to prequestioning) condition, they were shown a cue word and asked to guess the target word, with each guess followed by immediate correct answer feedback. In two control conditions, they listened to correct word pairs or incorrect word pairs with immediate corrective information. Children aged 5–8 years (kindergarten and early elementary school) in the pretesting condition outperformed those in the control conditions on a criterial test. However, 4-year-old preschoolers did not show the same benefit.

The results of Carneiro et al. (2018) and Lima and Jaeger (2020) suggest that prequestioning can enhance learning in early and middle childhood, starting from at least 5 years old. Yet the potential effects of prequestioning in other learning environments that young children typically encounter, such as those beyond paired-associate learning or fill-in-the-blank exercises, have yet to be addressed. Additionally, effects on learning outcomes beyond directly tested content—that is, information that was not directly tested—have yet to be explored fully. For example, if a child is prequestioned on one of three ideas from a text passage, then the other two ideas may or may not be better learned as well. Determining such patterns is potentially valuable both from theoretical and practical perspectives. Thus, an important gap remains in understanding whether the prequestioning effect extends to early childhood and in real-world educational circumstances.

### 1.3. Theoretical perspectives on the prequestioning effect

Given the unique developmental trajectories of children’s cognitive abilities, it is important to consider whether existing theoretical accounts of the prequestioning effect (Mera et al., 2022; Pan & Carpenter, 2023) apply to them. Accounts derived from studies of paired-associate learning include the semantic mediation hypothesis (Huelser & Metcalfe, 2012; Kornell et al., 2009), wherein incorrect guesses act as mediators linking cues to targets; search set theory (Grimaldi & Karpicke, 2012; Kornell et al., 2009), wherein the act of guessing activates potential answers, enhancing encoding and suppressing incorrect retrieval; and recursive reminding theory (Mera et al., 2022; Wahlheim & Jacoby, 2013), wherein errors and feedback are encoded as a single episodic event, facilitating later retrieval. It should be emphasized, however, that paired associate learning differs from learning with science texts, which is the focus of the present study. Other relevant perspectives that are not specific to paired-associate learning suggest that prequestioning increases interest (Little & Bjork, 2011), curiosity (Geller et al., 2017; see also Berlyne, 1954), or attention (Pan, Sana, Samani, et al., 2020; Pan, Sana, Schmitt, & Bjork, 2020).

Recent studies of prequestioning with adults have highlighted the crucial role of attention and memory. For example, St. Hilaire and Carpenter (2020) had adult participants answer prequestions prior to watching a video, during which they were encouraged to take notes or identify key information related to the prequestions. A prequestioning effect emerged only when participants identified the correct answers during the video, which implies that the effect depends on participants attending to and remembering prequestions. It has yet to be determined whether young children can do the same. Further, Sana and Carpenter (2023) demonstrated that when prequestions targeted later content in a text passage, a general benefit was observed, whereas when prequestions targeted earlier content only, a specific benefit occurred. On the basis, they proposed the attentional window hypothesis, which posits that prequestioning creates a temporary window for searching correct answers, which closes once they are found. If so, then the more limited attention spans of young children (Betts et al., 2006; Kim et al., 2023; Werchan et al., 2024) might yield narrower attentional windows, limiting the benefits of prequestioning and especially for information that is temporally distant from prequestioned material.

Overall, if the benefits of prequestioning depend on memory and attentional abilities, then the developmental trajectory of those abilities may influence its effectiveness in young children. To begin, episodic memory—along with associated neural regions such as the prefrontal cortex (Tang et al., 2018) and hippocampus (Riggins et al., 2015)—undergoes significant development during early childhood (Shing et al., 2010). These developmental changes may affect how well young learners encode and retrieve prequestions or information related to prequestions. Additionally, young children are still developing skills in memorizing associations between multiple items in relational memory tasks (Ngo et al., 2018), recalling contextual details (Riggins, 2014), engaging in selective attention (Rueda et al., 2004; Tipper et al., 1989), and managing distractions (Posner et al., 2014). These factors could shape how young children process prequestions, sustain attention on relevant content, and integrate new information with prior knowledge.

Another potentially important cognitive ability is working memory capacity (WMC), particularly the ability to temporarily store and manipulate goal-relevant information (Kane & Engle, 2003). WMC supports many aspects of learning, including reading (de Jonge & de Jong, 1996) and mathematics (Peng et al., 2016), and is a strong predictor of academic success (Alloway & Alloway, 2010). Given that WMC continues to develop throughout childhood (Reynolds et al., 2022), it is possible that younger learners may vary in their ability to pay attention to prequestions and remember their content, integrate new information with prior knowledge, and monitor their learning progress. Overall, each phase of the learning process that occurs in studies of prequestioning—from an initial attempt to answer prequestions to a subsequent criterial test—could be influenced by the constraints of children's WMC.

#### 1.4. The role of immediate correct answer feedback

Correct answer feedback, especially if it is immediate, may help facilitate young children's learning through prequestioning. Even in adults, such feedback can be vital. Specifically, in the context of paired associate learning, a pretesting (i.e., prequestioning) effect has only been observed when adult learners receive immediate correct answer feedback after generating an incorrect response. When such feedback is delayed, there is either no learning benefit or even worse learning outcomes compared to restudying paired associates (Grimaldi & Karpicke, 2012; Hays et al., 2013; Vaughn & Rawson, 2012). Correct answer feedback appears to not just furnish learners with correct information in the case of an error but can also boost memory (Kornell et al., 2011; Kornell & Vaughn, 2016; Pashler et al., 2005; Rickard & Pan, 2018). For more semantically enriched materials, however, such as trivia questions or text passages, prequestioning effects can be observed in adults even when correct answer feedback or exposure to target materials is delayed for several minutes or more (e.g., Kornell, 2014; Richland et al., 2009).

In young children, immediate correct answer feedback might enhance the benefits of prequestioning in various ways. For instance, such feedback could provide contextual details for the prequestions, enabling children to establish more retrieval routes for accessing the content. That process might mitigate negative impacts of limited episodic memory on the prequestioning effect while alleviating working memory demands. Alternatively, immediate feedback could serve as a cue, helping children more efficiently locate the correct answers to prequestions within unfamiliar materials that contain irrelevant information, and in doing so compensate for limited selective attention abilities.

Some empirical evidence provides support for the benefits of immediate feedback for young children's learning and performance. For example, immediate feedback can improve children's performance on cognitive flexibility tasks (Bohmann & Fenson, 2005), as well as in language learning (Bryant & Anisfeld, 1969; Ferman et al., 2022) and auditory skill acquisition tasks (Zaltz et al., 2017). Additionally, immediate feedback can amplify the benefits of other learning techniques,

such as engaging in retrieval practice after learning new materials. For instance, Marsh et al. (2012) observed that immediate feedback enhanced retrieval-based learning in 2nd grade students, and moreover, reduced their susceptibility to selecting incorrect multiple-choice test lures.

#### 1.5. The present study

We investigated the effects of prequestioning on young children's learning and whether immediate correct answer feedback might influence any learning benefits. Our investigation comprised two experiments, each involving 5-to-6-year-old children and including three conditions: *prequestioning with feedback*, *prequestioning without feedback*, and a control condition in which young children engaged in free-drawing (Experiment 1) or listening to learning objectives (Experiment 2). The control conditions represented fairly conventional and more competitive non-prequestioning approaches, respectively.

In a departure from the paired associate words (Carneiro et al., 2018) and the fill-in-the-blank texts (Lima & Jaeger, 2020) used in prior studies with young children, we aimed to simulate a different yet common educational setting in which children learn new scientific knowledge—that is from a text read aloud. The learning materials were age-appropriate scientific stories, along with prequestions targeting important story content. Moreover, in line with prior research on the prequestioning effect (Pan & Carpenter, 2023), we investigated whether any learning benefits manifested according to a general or specific pattern, and to do so we employed a criterial test which featured tested (i.e., targeting identical content as the prequestions) and untested (i.e., targeting different content as the prequestions) question types.

We tested three competing hypotheses as follows:

$H_1$ : Prequestioning facilitates young children's learning compared to non-prequestioning, regardless of whether immediate correct answer feedback is provided or not.

$H_2$ : Prequestioning facilitates young children's learning, but only when coupled with immediate correct answer feedback.

$H_3$ : Prequestioning does not facilitate young children's learning compared to non-prequestioning techniques, even when accompanied by immediate correct answer feedback.

We also measured children's WMC, enabling supplementary analyses into whether WMC influences criterial test scores and the prequestioning effect for tested and untested information.

## 2. Experiment 1

The first experiment investigated the impact of prequestioning on young children's learning of science texts, specifically comparing learning outcomes across three learning conditions: prequestioning with feedback, prequestioning without feedback, and free-drawing.

### 2.1. Methods

Data and materials are available on the Open Science Framework (OSF) website: <https://osf.io/7hvwp/>. This experiment was preregistered: <https://osf.io/7snwz>.

#### 2.1.1. Participants

Typically developing children between the ages of 5 years 0 months and 6 years 11 months were recruited through recruitment advertisements on social media and local childcare centers. All children were bilingual with English as their native language. An a priori power analysis using G\*Power (Faul et al., 2007) indicated that 43 participants was necessary to achieve 95 % power to detect a medium-sized main effect ( $f = 0.25$ ) in a fully within-subjects design with three learning conditions at an  $\alpha$  level of 0.05 (the selection of effect size was based on findings of St. Hilaire et al. (2024), who reported a prequestioning effect of Hedges'  $g = 0.54$  for directly tested information in adults,

corresponding to a medium effect size). That number served as our sample size target.

Fifty-eight children participated in the experiment. Participation occurred via 47 experimental sessions conducted in a psychology laboratory and 11 sessions conducted at local childcare centers. To determine whether children had preexisting background knowledge of the materials covered in the experiment, both children and their parents were queried about the children's familiarity with the science topics tested after the criterial test phase. If both confirmed any significant prior learning on any of the covered topics, then the child was excluded from the experiment. One child was excluded on this basis. An additional 13 children were excluded, six due to procedural errors, six due to unresponsiveness and distraction, and one due to language difficulties.

The final sample comprised 44 children ( $M = 5.8$  years,  $SD = 0.5$ ; 18 girls, 26 boys), aged between 60 and 80 months. All participants resided in Singapore but represented diverse ethnic backgrounds (91 % Chinese, 5 % Malay, 2 % Indian, 2 % mixed, 2 % Vietnamese). The entire study was approved by the Institutional Review Board of National University of Singapore [Protocol Number: NUS-IRB-2023-365]. Written informed consent from parents and verbal assent from children were obtained prior to testing.

## 2.1.2. Materials

**2.1.2.1. Science texts.** Three science text passages were adapted from the *National Geographic Kid Super Readers Series* by National Geographic (Zoehfeld, 2012) and articles from *National Geographic Education* (Boudreau et al., 2023; National Geographic Society, 2024a, 2024b), covering the topics of rocks (122 words), cells (118 words), and camouflage (128 words). Modifications included simpler word choices and more concise sentences to make the stories more suitable for young children. Each passage presented three main concepts—for instance, the “rocks” passage focused on magmatic rocks, sedimentary rocks, and metamorphic rocks. The Flesch-Kincaid grade level was 2.9 for the “rocks” passage, 4.4 for the “cells” passage and 4.5 for the “camouflage” passage.

**2.1.2.2. Illustrations.** Four illustrations were created for each passage, with the first illustration showing the overall theme (e.g., rocks) and the other three illustrating the three concepts under that theme (e.g., magmatic rocks, sedimentary rocks, and metamorphic rocks). Each illustration was adapted from images obtained through an online image search, printed in color on A4-sized paper that was subsequently laminated, and contained no text. All four illustrations were presented during reading of the passage. Three of those illustrations were also presented during the initial learning phase when prequestions were posed.

**2.1.2.3. Prequestions.** Three prequestions were developed for each science text, with each question targeting one of the main concepts. For example, in the “rocks” passage, the prequestion designed for the “magmatic rocks” concept was: “Do you know what hot liquids deep inside the Earth are called?” and the correct answer was *magma*. The correct answers and the prequestions were derived almost verbatim from the passages. Each prequestion was presented in an open-response format and accompanied by an illustration. The length of the prequestions for each passage ranged from 35 to 59 words.

**2.1.2.4. Criterial test.** Three prequestions from each science passage were presented again on the criterial test, and for analysis purposes were labelled as *tested* questions. Additionally, three new questions for each science passage, each addressing one of the main concepts, were developed and presented exclusively in the criterial test. These questions were labelled as *untested* questions. Thus, for each of the three main concepts in a science passage, there was one corresponding tested

question and one untested question. The untested questions occasionally referred to the content of the tested questions. For example, the untested question related to the “magmatic rocks” concept was: “When a volcano erupts, magma comes out. Can you tell me how magma turns into rocks?” and the correct answer was “It cools”. Tested and untested questions were intermixed, with an untested question following each tested question.

All criterial test questions were presented in a multiple-choice format, consisting of four answer options, one of which was correct. Pilot testing with five children was conducted to evaluate the difficulty levels of the criterial test questions; in the pilot test, children read each science passage and completed the respective criterial test immediately afterward. Comparable average performance was observed across the topics of rocks ( $M = 23\%$ ,  $SD = 23\%$ ), cells ( $M = 27\%$ ,  $SD = 30\%$ ), and camouflage ( $M = 17\%$ ,  $SD = 32\%$ ).

**2.1.2.5. Working memory task.** The Backward Digit Span (BDS) task was used to assess working memory capacity (WMC) (Alloway et al., 2006; Bialystok, 2010; Carlson et al., 2002; Davis & Pratt, 1995). The task involved sequences of digits ranging in length from two to eight digits, with each sequence length consisting of two trials, for a total of up to 14 trials. During each trial, the experimenter read a sequence of numbers aloud once, and the child was asked to repeat the numbers in reverse order. The length of the digit sequence increased only if the child correctly responded to at least one of the two trials at the current length. If the child failed both trials of a given sequence length, the task was discontinued. Please refer to 2.1.4 for details about BDS scoring.

## 2.1.3. Procedure

A 3 x 2 within-subjects design with factors of Learning Condition (feedback vs. non-feedback vs. control) and Question Type on the criterial test (tested vs. untested) was employed wherein each child completed all three learning conditions, each followed by an immediate criterial test containing tested and untested questions, and with a 5-min break in between each condition. Within each learning condition, children either answered prequestions or engaged in free-drawing and then listened to a science passage. The order of learning conditions and science passages were counterbalanced. After completing all of these tasks, the working memory task was administered. In all cases, the experiment was conducted in a room with only the experimenter and the child

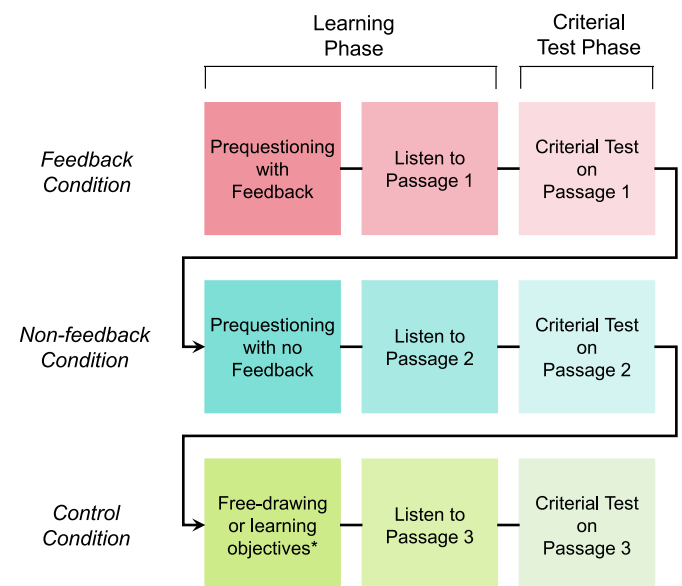


Fig. 1. Overview of the experimental procedure.

Note. The order of learning conditions and passages was counterbalanced among children. (\*) In Experiment 1, the control condition engaged in free-drawing; in Experiment 2, learning objectives were presented instead.

present, sitting across from each other at a table. Fig. 1 presents an overview of the experimental procedure and Fig. 2 depicts the setting.

#### 2.1.4. Experimental setting and phases

**2.1.4.1. Learning phase.** The procedure in each condition was as follows. Total time spent was approximately 1–3 min in the feedback and non-feedback conditions and 3 min in the control condition.

**2.1.4.1.1. Feedback Condition.** Children were first provided with instructions about the prequestioning procedure, including being encouraged to guess if they were uncertain about the correct answers. The instructions were tailored to the specific passage being learned. For example, the instructions for the “rocks” passage stated: “Do you want stickers? Later, I would like to see how much you know about rocks. I will ask you some questions. If you know the right answer, you can tell me. If you don’t know the answer, it’s fine. Just try to guess! Whether you get it right or not, you’ll get a sticker!”

Subsequently, the experimenter, holding the illustrations, read aloud the three prequestions, one question at a time. If the children were unsure of their answers, the experimenter encouraged them to guess: “Can you try to guess?” After each prequestion, the children were informed of the correct answer and told that they would learn more about the correct answer from the subsequent story. For example, the feedback to a prequestion about “rocks” was, “The right answer is magma. Later, I will tell you a story, and you will learn more about magma.” A sticker was awarded to the child following each prequestion response. The prequestion phase lasted between one and 3 min.

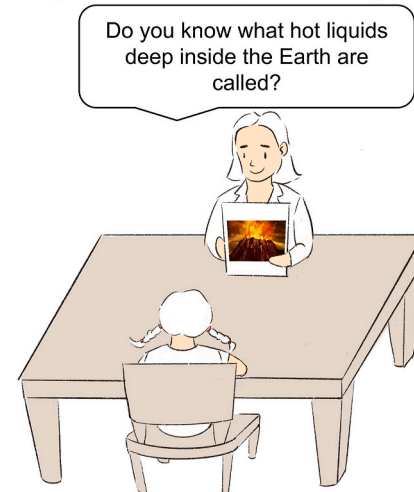
Next, the experimenter informed the children that they would be listening to a story, then be asked to answer several more questions. Children were also instructed that they would learn the correct answers to the previously encountered prequestions from the story using the instructions, “Please listen carefully, because you will hear the right answers to the questions I just asked you.” Then, the children were asked to repeat the instructions and try to restate the prequestions from memory (this step was borrowed from prior research on prequestioning with adults and was meant to ensure comprehension of the instructions and to further establish whether the participants had been paying attention; it was understood, however, that due to 5- to 6-year-old children’s developing linguistic and other cognitive abilities, they would not necessarily be able to articulate the instructions and the prequestions in the same manner as adults). Regardless of their responses, the experimenter reiterated both the instructions and the prequestions afterward to reinforce understanding.

The experimenter then held the illustrations and read the science passage to the children in a normal tone but at a slow pace, which took approximately 2 min. No text was presented to the children visually; rather, the entire passage was presented aurally.

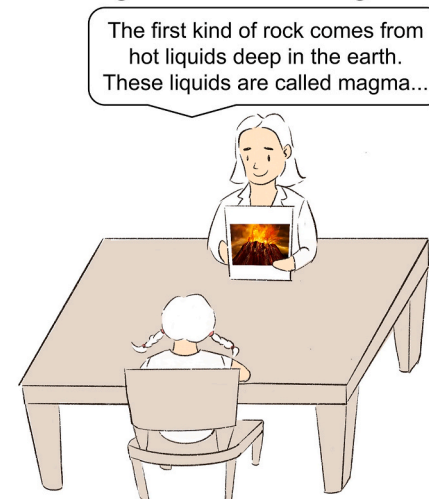
**2.1.4.1.2. Non-feedback Condition.** The procedure in the non-feedback condition was the same as in the feedback condition, with the following exceptions. First, the children were not informed of the correct answer immediately after responding to the prequestions. Instead, they were informed that they would learn the correct answer from the subsequent story. Specifically, the experimenter said, “Later I will tell you a story, and you will learn the right answer.” Second, when the experimenter reiterated the prequestions, the correct answers were not provided. The total time taken in the prequestion phase was typically 30–45 s shorter than in the feedback condition.

**2.1.4.1.3. Control Condition.** Children were initially provided with instructions regarding the free-drawing activity. The instructions were tailored to the specific passage being learned. For example, the instructions stated: “Today, we’re going to learn about rocks. Before that, you have some time to draw anything you like.” The children were then given paper and drawing tools. After drawing for 3 min, they were informed that they would be listening to a story, then be asked to answer several questions. Additionally, they were told that the story was interesting:

### Learning Phase: Prequestioning or Control



### Learning Phase: Listening to Story



### Criterion Test Phase

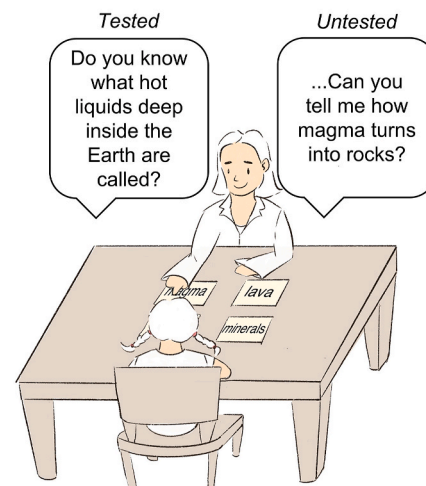


Fig. 2. Experimental setting and phases. Note. The top panel depicts one of three possible learning phase activities (prequestioning with feedback, prequestioning without feedback, or control). “Rocks” story activities shown.

“Please listen carefully, because it is very interesting!” The experimenter then read the science passages to the children in the same tone and pace as in the other two conditions.

**2.1.4.2. Criterial test phase.** The criterial test phase occurred immediately after the story was read and began with verbal instructions that, to reduce pressure on the children, framed the test as a game. Additionally, children were encouraged to guess if they were unsure of the answers using the instructions: “Do you want some stickers? Now, we will play a game. I will ask you some questions. Whether you get it right or not, you’ll get a sticker, okay? For each question, there are four answers. If you know the right answer, you can tell me. If you don’t know the answer, it’s fine. Just try to guess!”

For each question, four flashcards, each displaying one answer option in text, were presented in a standardized order. This format was intended to make the test feel like a game and sustain engagement. The experimenter first read the question aloud without displaying the text, then pointed to each answer option while reading it. Children were allowed to respond only after the experimenter had read aloud all four options. If a child did not respond, then they were encouraged to guess and point to an answer. Once the child selected an answer, the experimenter confirmed their choice (e.g., “Magma, right?”). Once the choice was confirmed, the experimenter proceeded to the next question. No feedback was provided. After the criterial test, children were awarded stickers.

#### 2.1.5. Scoring and reliability

In the learning phase, the experimenter recorded children’s responses to each prequestion both in writing and via audio recording. After the session, the same experimenter scored each response, assigning 1 point for a correct answer and 0 for an incorrect one. A second coder was not involved, as all responses were unambiguously correct or incorrect. In the criterial test phase, children’s responses to the multiple-choice test questions were similarly recorded in writing and via audio. A response received 1 point if the child selected the correct option; otherwise, it received 0. Because children confirmed their choices when the experimenter reiterated them (e.g., “Magma, right?”), there was no ambiguity, and a second coder was not required.

To assess the internal reliability of the criterial test questions (where performance was the dependent variable of interest), we calculated separate intercorrelations among all three tested questions and among all three untested questions. Tetrachoric correlations ranged from 0.45 to 0.60 for tested questions and 0.055 to 0.35 for untested questions (full values in the Appendix). The moderate-to-low intercorrelations, especially among untested questions, likely reflect the distinct and independent concepts that each question assessed (Note: since average performance remains a meaningful measure of learning under each condition, our analyses of criterial test performance used participant-level average criterial test scores in accordance with our preregistered analysis plan; however, to address the implications of lower reliability, we also conducted an exploratory supplementary analysis examining individual question performance).

Scoring of the working memory task (BDS) occurred using the standard and previously-established procedure for that task. Specifically, the BDS score corresponded to the length of the longest digit sequence the child successfully recalled. If a child was unable to recall even a two-digit sequence, they were assigned a score of 1. Therefore, BDS scores ranged from 1 to 8. The BDS task has shown acceptable test-retest reliability in the literature (Blackburn & Benton, 1957), including with preschoolers (Müller et al., 2012,  $r = 0.71$ ).

#### 2.1.6. Analysis plan

The analysis plan comprised four steps. First, we computed descriptive statistics for performance on prequestions in both the feedback condition and in the non-feedback condition. Second, we explored

our primary research question—that is, potential differences on criterial test scores among the three learning conditions—by fitting a linear mixed effects model (using participant-level average proportion correct for tested and untested questions, as intended in our preregistered analysis plan). Age (months) was included as a covariate<sup>1</sup> in this model. Third, given that participant-level performance across the three tested and untested questions was not very consistent (as indicated by the reliability data), we explored whether different test questions moderated the observed effects using question-specific scores (binary outcomes) as the outcome variables in a generalized linear mixed-effects model (note: this analysis was not preregistered). Finally, we conducted exploratory supplemental analyses to address potential effects of learning condition order and working memory capacity. For reference, a correlation table of criterial test scores are included in the Appendix. No data was removed during the analysis stage in the entire study.

## 2.2. Results

### 2.2.1. Learning phase

Performance on the prequestions was practically zero in both the feedback condition ( $M = 0\%$ ,  $SD = 0\%$ ) and the non-feedback condition ( $M = 0\%$ ,  $SD = 0\%$ ).

### 2.2.2. Criterial test performance

A planned analysis investigating the potential effect of gender (female vs. male) on participant-level average criterial test scores revealed no significant gender difference on criterial test scores,  $t(42) = -0.86$ ,  $p = .396$ . We next analyzed criterial test scores using a linear mixed effects model with learning condition, question type, the interaction term between learning condition and question type, and age (months) as the predictors (see Fig. 3) (gender was dropped from the analysis). Crossed random intercepts for participants were included. To further probe the model’s results, we conducted planned post hoc comparisons. Specifically, to examine overall differences among learning conditions and question types, we performed pairwise comparisons with Tukey correction. Moreover, to examine whether the effect of condition differed across question types—that is, the interaction—we conducted pairwise comparisons using Holm correction. If the performance differences between any two conditions were significantly moderated by question type, we additionally conducted pairwise comparisons with Tukey correction to examine the effect of condition within each level of question type (see Table 1).

Overall, the feedback condition yielded significantly higher participant-level average performance ( $M = 60\%$ ,  $SD = 35\%$ ) compared to the non-feedback ( $M = 45\%$ ,  $SD = 32\%$ ) ( $p = .002$ ) and the control condition ( $M = 36\%$ ,  $SD = 32\%$ ) ( $p < .001$ ). There was no significant difference between the non-feedback and control conditions ( $p = .109$ ). Question type did not have a significant overall effect: performance on tested questions ( $M = 51\%$ ,  $SD = 37\%$ ) did not differ significantly from performance on untested questions ( $M = 44\%$ ,  $SD = 31\%$ ) ( $p = .063$ ).

The pairwise comparisons conducted to explore the interaction revealed that question type did not significantly moderate the performance differences between the feedback and non-feedback conditions ( $p = .508$ ), the feedback and control conditions ( $p = .087$ ), nor the non-feedback and control conditions ( $p = .508$ ).

### 2.2.3. Question-specific analyses

To address the possibility that inconsistencies in performance among the three tested questions and (especially) three untested questions may have influenced the conclusions that can be drawn (as intercorrelational data suggest), we analyzed the question-specific scores (binary

<sup>1</sup> Although an ANCOVA with age as a covariate was preregistered, we opted for a linear mixed-effects model to account for repeated measures within participants and to better capture variability across individuals.

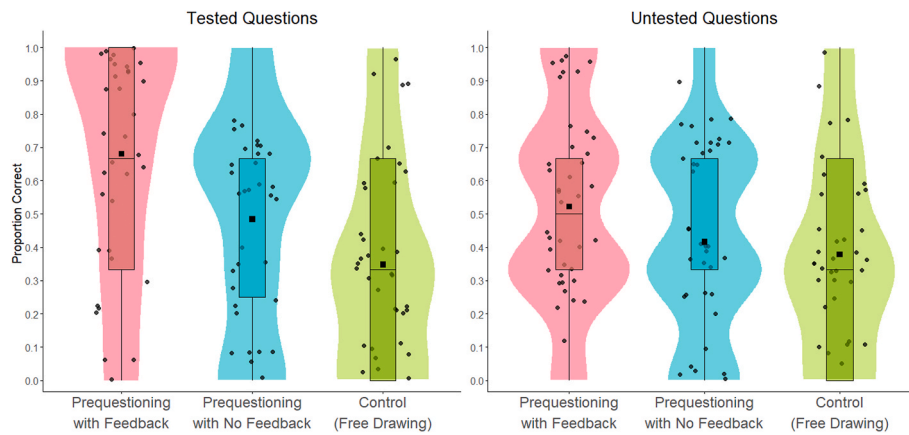


Fig. 3. Experiment 1 criterial test results.

Table 1

Experiment 1 pairwise comparisons of learning condition and its interaction with question type on the criterial test.

Analysis type	Pairwise comparisons	<i>b</i>	<i>SD</i>	95 % CI	<i>p</i>	<i>d</i>
Main effects	Feedback vs. Control	0.24	0.043	[0.14, 0.34]	<0.001***	0.84
	Feedback vs. Non-feedback	0.15	0.043	[0.050, 0.25]	0.002**	0.53
	Non-feedback vs. Control	0.087	0.043	[-0.015, 0.19]	0.109	0.31
	Tested vs. Untested questions	0.066	0.035	[-0.0036, 0.14]	0.063	0.23
Moderating effects of question type	Feedback vs. Control	0.189	0.086	[-0.018, 0.40]	0.087	0.66
	Feedback vs. Non-feedback	0.091	0.086	[-0.12, 0.30]	0.508	0.32
	Non-feedback vs. Control	0.099	0.086	[-0.11, 0.31]	0.508	0.35

Note. Main effects refer to pairwise comparisons of learning conditions. Moderating effects of question type refer to pairwise comparisons of the interaction between learning condition and question type. \* =  $p < .05$ ; \*\* =  $p < .01$ ; \*\*\* =  $p < .001$ .

outcome) using a generalized linear mixed-effects model with learning condition, question number, the interaction term between learning condition and question number, and age (months) as the predictors. Crossed random intercepts for participants were included, along with random slopes for question number within each participant. Pairwise comparisons conducted to explore the interaction indicated that interaction between learning condition and question number was not significant ( $p$ -values  $>0.651$ ), indicating that the effect of condition on question-specific scores did not vary across specific questions.

#### 2.2.4. Order effects

It is possible that when a participant experienced prequestioning prior to the control condition, performance in that condition would improve due to a phenomenon known as test-potentiated new learning (Gupta et al., 2022; see also Arnold & McDermott, 2013). To explore potential condition order effects, we analyzed participant-level average performance using a linear mixed-effects model featuring learning condition (control condition as reference), learning condition order (whether the control condition appeared first or later), the interaction between learning condition and learning condition order, and age (in months) as predictors. Crossed random intercepts for participants were included. Pairwise comparisons indicated that learning condition order did not moderate the effects of learning condition on criterial test scores ( $p$ -values = 1.00). In other words, a test-potentiated new learning effect was not observed.

#### 2.2.5. Working memory capacity

Given prior evidence of developmental differences in working memory abilities, as well as recent evidence in adults suggesting that individuals with lower WMC exhibit larger prequestioning effects (Pan et al., 2025), we explored the potential effects of WMC on the observed patterns. To do so, we analyzed participant-level average performance using a linear mixed-effects model. The predictors included learning condition, BDS scores, the interaction between learning condition and

BDS scores and age (in months). Crossed random intercepts for participants were included. WMC positively predicted criterial test performance ( $b = 0.10$ ,  $SE = 0.036$ ,  $p = .005$ )—that is, children with higher WMC achieved higher criterial test scores. Crucially, pairwise comparisons of WMC slopes between conditions indicated that WMC did not moderate the effects of learning condition on criterial test scores ( $p$ -values  $>0.585$ ).

#### 2.3. Discussion

In Experiment 1, prequestioning with feedback enhanced learning compared to free-drawing. This effect was not moderated by question type on the criterial test, demonstrating a general prequestioning benefit. Prequestioning without feedback, however, did not show statistically meaningful benefits. Additionally, the observed effects were not moderated by specific questions, condition order, or individual levels of WMC. These results support our second hypothesis: prequestioning facilitates learning only when accompanied by immediate feedback. Hence, in the context of prequestioning, providing correct answer feedback may be essential for supporting children’s learning.

### 3. Experiment 2

The second experiment investigated the relative benefits of prequestioning on children’s learning of science texts relative to a more competitive control condition, namely studying learning objectives (Sana et al., 2020). In this control condition, children were informed of the learning objectives of the relevant scientific passage prior to encountering it. This approach gave children a preview of the forthcoming story in a similar fashion as occurred in the prequestioning conditions.

### 3.1. Methods

Data and materials are available on the Open Science Framework (OSF) website at: <https://osf.io/7hvwp/>. This experiment was preregistered: <https://osf.io/5pq82>.

#### 3.1.1. Participants

Typically developing, English-speaking children between the ages of 5 years 0 months and 6 years 11 months were recruited through recruitment advertisements on social media in the same manner as occurred in Experiment 1. The same sample size target as Experiment 1, determined by its corresponding power analysis, was also used.

Forty-seven children participated. All experimental sessions were conducted in a laboratory setting. Four children were excluded from the experiment due to distraction and inattentiveness. A final sample of 43 children ( $M = 5.3$  years,  $SD = 0.5$ ; 18 girls, 25 boys), aged between 60 and 83 months, were included in the analysis. All participants resided in Singapore but represented diverse ethnic backgrounds (69 % Chinese, 12 % Indian, 7 % Malay, 5 % Burmese, 5 % Eurasian, 2 % Vietnamese). Written informed consent from parents and verbal consent from children were obtained prior to testing.

#### 3.1.2. Materials

The materials, including the science texts, prequestions, criterial test and working memory task were almost entirely the same as in Experiment 1. A new addition was short learning objectives that were created based on the three main concepts in each science text. The learning objectives outlined the expected outcomes from listening to the passage, which included children being introduced to a specific topic, being able to identify and name key concepts related to it, and developing a deeper understanding of the subject. The word count of the learning objectives (between 56 and 62 words) was similar to that of the prequestions for each science text. For example, the learning objectives for the “rocks” passage stated, “*Today, we are going to learn about rocks! We will learn more about different kinds of rocks. You will be able to name different kinds of rocks and learn to identify these rocks. After this, you can enhance your knowledge of the rocks that make up our planet. This deeper understanding will give you a better appreciation of the natural world.*”

#### 3.1.3. Procedure

The procedure was identical to Experiment 1 except for the following changes. In the control condition, children were first given instructions regarding the learning objectives: “*First, I would like to tell you what we are going to learn. Please listen carefully, because you’ll be able to get stickers.*” The experimenter then read aloud the learning objectives, rather than having the children engage in free-drawing before encountering the passage. Additionally, the three illustrations used in the prequestions conditions were displayed alongside the presentation of the learning objectives. Subsequently, children were awarded one sticker. The reading of the learning objectives took about a minute. Since the prequestions were reiterated in both the feedback and non-feedback conditions, a shorter version of the learning objectives was also repeated before children listening to the science passage in the control condition to better equate item exposure. For example, the shorter version of the learning objectives for the “rocks” passage stated, “*We are going to learn about different kinds of rocks and have a deeper understanding of these rocks.*” In total, the learning objectives—both initial reading and subsequent re-reading—took about 2 min (versus about 1–3 min in the feedback and no-feedback conditions).

In the feedback and non-feedback conditions, children were also informed about the type of answers they could expect from the stories following each prequestion. This step, which represented a modification to the procedures used in Experiment 1, aimed to facilitate the process of searching for answers to the prequestions within the stories. For instance, in the non-feedback condition, children were told, “*Later I will tell you a story, then you will learn more about the right name of this liquid,*”

following one of the prequestions. In Experiment 1, children were only told that they would learn more about the correct answer.

#### 3.1.4. Scoring, reliability, and analysis plan

The scoring procedure was identical to that used in Experiment 1. Tetrachoric correlation analyses revealed that intercorrelations among tested questions ranged from 0.29 to 0.48, whereas intercorrelations among untested questions ranged from 0.14 to 0.19. A complete list of correlation values is provided in the Appendix. As in Experiment 1, a likely explanation for the low intercorrelations is that each of the tested and untested questions assess different, independent concepts within science passages.

The analysis plan was also identical to Experiment 1. For reference, a correlation table of criterial test scores are further included in the Appendix.

### 3.2. Results

#### 3.2.1. Learning phase

Children’s performance on prequestions was nearly zero in the feedback condition ( $M = 0$  %,  $SD = 0$  %), with a slight positive performance for the non-feedback condition ( $M = 1.6$  %,  $SD = 7.1$  %).

#### 3.2.2. Criterial test

A planned analysis investigating the potential effect of gender (female vs. male) on total criterial test scores revealed a significant difference, with females performing better than males,  $t(41) = -2.06$ ,  $p = .045$ . Next, just as for the preceding experiment, we analyzed criterial test scores using a linear mixed effects model with learning condition, question type, the interaction term between learning condition and question type, and age (months) as the predictors (see Fig. 4), with random intercepts for participants and subsequent pairwise comparisons performed in the same fashion as in the corresponding analyses for Experiment 1 (see Table 2). Although gender was dropped from those analyses, owing to the significantly better overall performance among girls than boys, we performed supplementary analyses involving gender; the results for these analyses are reported after the following planned analyses.

Across the entire dataset, there was no significant difference in participant-level average performance between the feedback ( $M = 51$  %,  $SD = 35$  %), non-feedback ( $M = 47$  %,  $SD = 34$  %) and control conditions ( $M = 45$  %,  $SD = 31$  %) ( $p$ -values  $>0.396$ ). Question type did not have a significant overall effect: performance on tested questions ( $M = 49$  %,  $SD = 35$  %) did not differ significantly from performance on untested questions ( $M = 46$  %,  $SD = 32$  %) ( $p = .437$ ).

Pairwise comparisons conducted to explore the interaction indicated that question type significantly moderated the performance differences between the feedback and non-feedback conditions ( $p = .005$ ), as well as between the feedback and control conditions ( $p < .001$ ). However, it did not moderate the difference between the non-feedback and control conditions ( $p = .299$ ).

To further probe these interaction effects, simple effects analyses were conducted. For tested questions, participants in the feedback condition ( $M = 63$  %,  $SD = 35$  %) performed significantly better than those in the control condition ( $M = 40$  %,  $SD = 27$  %) ( $p < .001$ ,  $d = 0.82$ ), suggesting that prequestioning with feedback enhanced learning of tested material even when compared to a more competitive, non-prequestioning learning activity. In contrast, there was no significant difference between the feedback ( $M = 39$  %,  $SD = 30$  %) and control ( $M = 51$  %,  $SD = 35$  %) conditions for untested questions ( $p = .124$ ,  $d = -0.42$ ).

Performance on tested questions in the feedback condition was also significantly higher than in the non-feedback condition ( $M = 45$  %,  $SD = 38$  %) ( $p = .014$ ,  $d = 0.61$ ). However, for untested questions, performance did not significantly differ between the feedback and non-feedback conditions ( $M = 48$  %,  $SD = 29$  %) ( $p = .306$ ,  $d = -0.32$ ).

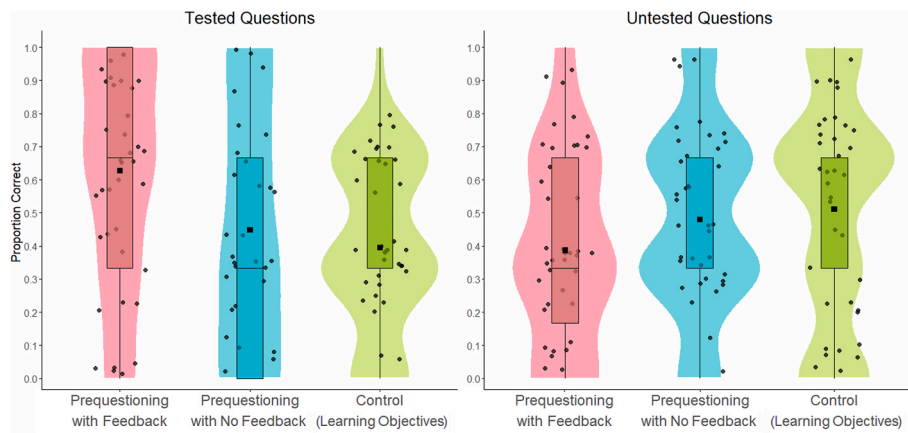


Fig. 4. Experiment 2 criterial test results.

Table 2

Experiment 2 pairwise comparisons of learning condition and its interaction with question type on the criterial test.

Analysis type	Pairwise comparisons	<i>b</i>	<i>SE</i>	95 % CI	<i>p</i>	<i>d</i>
Main effects	Feedback vs. Control	0.058	0.045	[-0.047, 0.16]	0.396	0.20
	Feedback vs. Non-feedback	0.043	0.045	[-0.063, 0.15]	0.606	0.15
	Non-feedback vs. Control	0.016	0.045	[-0.090, 0.12]	0.936	0.053
	Tested vs. Untested questions	0.028	0.037	[-0.044, 0.10]	0.437	0.097
Moderating effects of question type	Feedback vs. Control	0.36	0.089	[0.15, 0.58]	<0.001***	1.24
	Feedback vs. Non-feedback	0.27	0.089	[0.056, 0.49]	0.005**	0.93
	Non-feedback vs. Control	0.093	0.089	[-0.12, 0.31]	0.299	0.32

Note. Main effects refer to pairwise comparisons of learning conditions. Moderating effects of question type refer to pairwise comparisons of the interaction between learning condition and question type. \* =  $p < .05$ ; \*\*\* =  $p < .001$ .

### 3.2.3. Question-specific analyses

As in Experiment 1, we also analyzed the question-specific scores (binary outcome) using a generalized linear mixed-effects model. Given that question type moderated the condition effect, we included a three-way interaction among learning condition, question number, and question type, along with age (in months) as predictors. The model also included crossed random intercepts for participants, and random slopes for question number within each participant, followed by pairwise comparisons to explore the interaction with Holm correction. These exploratory analyses helped address the role of inconsistencies in performance (i.e., low intercorrelations) among the three tested questions and (especially) three untested questions. The interaction between learning condition and question number was not significant for either tested questions ( $p$ -values  $>0.635$ ) or untested questions ( $p$ -values  $>0.651$ ), suggesting that the effect of condition on question-specific scores did not vary across different specific questions.

### 3.2.4. Order effects

A linear mixed-effects model was fitted to examine order effects for tested and untested questions. The predictors included a three-way interaction among learning condition, learning condition order, and question type, as well as age (in months). Pairwise comparisons conducted to explore the interaction indicated that learning condition order did not moderate the effects of learning condition on either tested questions ( $p$ -values = 1.00) or untested questions ( $p$ -values  $>0.183$ ).

### 3.2.5. Working memory capacity

A linear mixed-effects model was fitted to examine the interaction between WMC and learning condition for tested and untested questions. The predictors included a three-way interaction among learning condition, WMC, and question type, as well as age (in months). The results showed that WMC did not predict performance on both tested questions ( $p = .506$ ) and untested questions ( $p = .452$ ). Moreover, pairwise comparisons of WMC slopes between conditions indicated that WMC

also did not moderate the effects of learning condition on either tested questions ( $p$ -values  $>0.837$ ) or untested questions ( $p$ -values  $>0.705$ ).

### 3.2.6. Gender effects

Given the gender differences in the criterion test performance, we explored whether gender influenced the observed results. To do so, we analyzed participant-level average performance using a linear mixed-effects model. The predictors included a three-way interaction among learning condition, WMC, and question type and age (in months). Pairwise comparisons conducted to explore the interaction indicated that gender did not moderate the effects of learning condition on either tested questions ( $p$ -values  $>0.304$ ) or untested questions ( $p$ -values = 1.00).

## 3.3. Discussion

Experiment 2 replicated the findings of Experiment 1 with respect to the learning of tested materials. Specifically, prequestioning with feedback enhanced children’s learning of tested materials relative to a more competitive control condition—studying learning objectives. In contrast, prequestioning without feedback did not confer any learning benefits. Unlike the results of Experiment 1, however, prequestioning with feedback demonstrated a specific benefit: it did not enhance learning of untested materials compared to the control condition and, in fact, resulted in numerically lower performance on these items. These patterns were not moderated by specific questions, condition order, WMC, or gender.

## 4. General discussion

We investigated the effects of prequestioning on 5-to-6-year-old children’s learning of science texts. Across two experiments, prequestioning was beneficial for such learning, but only when coupled with immediate correct answer feedback. Specifically, in Experiment 1,

prequestioning with feedback improved learning compared to free-drawing, and this effect did not differ by the type of question on the criterial test (addressing tested or untested materials), whereas in Experiment 2, prequestioning with feedback yielded greater learning of tested materials than studying learning objectives, although that benefit did not extend to untested materials. Importantly, neither experiment found any significant learning benefits of prequestioning without feedback for tested or untested materials.

Overall, the current findings falsify our first and third hypotheses and support our second hypothesis, namely that prequestioning enhances young children's learning only when coupled with immediate feedback. That pattern may arise due to the learning challenges that such children ordinarily face. We next consider those challenges in further detail.

#### 4.1. Barriers to the prequestioning effect in young children

Why did a common implementation of prequestioning—that is, without immediate correct answer feedback—fail to enhance learning in young children? A likely culprit involves the cognitive abilities of 5-to-6-year-old children. As previously noted, children of that age are underdeveloped in several cognitive abilities, ranging from working memory (Gathercole et al., 2004) to selective attention (Tipper et al., 1989). These cognitive limitations may prevent them from benefiting from prequestioning in the absence of feedback, as they lack the necessary resources to effectively engage with the target materials without support.

A related issue concerns young children's ability to remember the prequestions. In both experiments, when asked to restate the prequestions from memory before listening to the science texts, they generally struggled to do so (with responses ranging from mentioning general details about the prequestioned topic to simply stating that they did not know). It should be noted, however, that these patterns may reflect the general challenge of remembering full sentences rather than a complete failure to process the prequestions (Morrison & Haith, 1976). Indeed, it is possible that had a recognition-based measure had been used, children's familiarity with the prequestions may have been more apparent, although such a measure was not used nor feasible in the present experiments. Nevertheless, if strong memories for the prequestions are a prerequisite for a prequestioning effect, as suggested by St. Hilaire and Carpenter (2020), then poorer memory for the prequestions among young children may help explain the present results.

Young children might also struggle to encode correct information after producing errors in response to prequestions. For instance, there is evidence that young children are unable to suppress error-prone utterances (Dell et al., 1997; see also Waller et al., 2024). Similarly, after producing incorrect answers to prequestions, young children might form strong associations between those errors and the prequestions themselves. If so, then without additional facilitation they may fail to encode the correct answers through answer discovery, as the initial errors interfere with the learning process.

The finding of a prequestioning effect with immediate feedback is in alignment with the results of Carniero et al. (2018), which found evidence of this effect in paired-associate learning for children aged 5–8 years. However, it is important to note that Carniero et al. (2018) did not find evidence of the effect for 4-year-old preschoolers, an age group not covered in the current study. The distinction between paired-associate learning tasks and our paradigm leaves open the question of whether children younger than 5 years old would exhibit a prequestioning effect with our materials. The lack of a prequestioning effect in the absence of feedback, however, contrasts with the results of Lima and Jaeger (2020), who found a prequestioning effect in 4th and 5th grade children using fill-in-the-blank prequestions without feedback. One possible explanation for this discrepancy is the fact that the present study involved preschool rather than elementary school children, with the latter having better developed cognitive abilities. Another possibility involves the modality of learning. Specifically, the present study involved a

storytelling-based scenario in which children interacted with an adult, whereas Lima and Jaeger employed paper-and-pencil exercises. Merely listening to stories and prequestions without seeing the words (although a feasible approach for young children given their limited reading abilities) might increase the difficulty of learning new information.

Finally, it is notable that children with lower and higher WMC performed similarly under both prequestioning conditions. That finding contrasts with prior research involving adults, where those with lower WMC showed greater benefits from prequestioning (Pan et al., 2025; Study 2). Specifically, prequestioning led to similar performance for all adults on prequestioned items, but because lower-WMC adults performed much worse on non-prequestioned (i.e., reading-only) items, they benefited relatively more from prequestioning. If extended to young children, that pattern might predict greater benefits given their less developed working memory abilities, but no such advantage was observed. One possible explanation is that the benefits of prequestioning for individuals with lower cognitive abilities may only emerge in adults who exceed a certain developmental threshold not yet reached by young children. It is also important to note that complex span tasks, commonly used to assess WMC in adults, are not suitable for children under 7 years old due to developmental limitations (Gonthier et al., 2018). Accordingly, whereas Pan et al. (2025) used complex span tasks, the present study employed the backward digit span to assess WMC in young children—a difference that limits direct comparison. Meta-analyses suggest only weak correlations between complex span and *n*-back tasks, and it remains unclear whether tasks such as backward digit span capture individual differences in strategy use that may influence complex span performance (Redick & Lindsey, 2013).

#### 4.2. The necessity of immediate correct answer feedback

The impact of immediate correct answer feedback on the prequestioning effect appears to differ between adults and children. As previously noted, although feedback appears to be crucial for pretesting (i.e., prequestioning) benefits with paired-associate learning in adults (Grimaldi & Karpicke, 2012; Hays et al., 2013; Vaughn & Rawson, 2012), its importance is reduced in semantically rich contexts, such as learning from text passages (e.g., Kornell, 2014; Richland et al., 2009), which more closely resemble the materials used in the present experiments. Yet in the case of young children, feedback appears to play a critical, potentially facilitative role in supporting the prequestioning effect. As previously noted, prior research has underscored the importance of immediate feedback in children's learning across domains such as language acquisition and auditory skill development (e.g., Bryant & Anisfeld, 1969; Zaltz et al., 2017), and in amplifying the benefits of other learning techniques, including retrieval practice (Marsh et al., 2012). It appears that similar patterns apply in the case of prequestioning with children.

In our estimation, the crucial role of feedback in the present study stems from its ability to compensate for the cognitive limitations of young children. As one possibility, children may have used the correct answers as cues to encode new information while listening to the stories. Feedback might also have helped direct children's attention to the correct answers, thereby minimizing interference from incorrect responses. Additionally, repeated exposure to correct answers during prequestioning and story listening could have enhanced procedural learning (cf. Schwab & Lew-Williams, 2016). Yet another possibility is that feedback provided contextual details which improved memory for prequestioned information (discounting that possibility, however, is the fact that the children were still unable to recall the prequestions when asked directly). Even without directly strengthening memory for the prequestions, feedback may have facilitated text integration, helping children comprehend the topic introduced by the prequestions. This process could be particularly crucial for young children, who often struggle with integrating and abstracting information (Brown et al., 1986), as well as comprehending ambiguous content (Yacovone et al.,

2021). Finally, it is possible that the feedback itself was the crucial learning event, driving improved criterial test performance on tested questions only, irrespective of any learning that might occur during the act of prequestioning or when the stories were presented. Any of these mechanisms could have enhanced the encoding of relevant information, improving the likelihood of successful retrieval during the criterial test.

Relatedly, Pan and Carpenter (2023; see also Kornell & Vaughn, 2016) recently proposed a three-stage framework for prequestioning effects wherein (1) the act of prequestioning triggers cognitive processes, which then (2) influence the learning of correct answers through feedback or target materials, leading to (3) improved recall or ability to answer questions on a criterial test. When applied to young children, it appears highly likely that processing of feedback in stage 2 is the most critical step, with the act of prequestioning per se having less impact. Without that feedback, there was no improved learning and criterial test performance did not benefit substantially. If so, then other hypothesized mechanisms of the prequestioning effect in adults—such as curiosity or even those that may occur during paired-associate learning (e.g., semantic mediation)—may have been less relevant in the present experiments. However, it should be noted that the finding of a general benefit in Experiment 1 raises the possibility that feedback may provide broader learning benefits, rather than merely directing children's attention to the correct answer.

#### 4.3. Specific versus general benefits of prequestioning

The differing extent of the effects of prequestioning with feedback on Experiments 1 and 2—that is, general versus specific benefits—could be seen as indicating inconsistent or unreliable benefits for untested information. That pattern is however not uncommon in the prequestioning literature with adults (St. Hilaire et al., 2024), even among similar experiments conducted within a single study (Pan & Sana, 2021). Indeed, achieving general benefits of prequestioning appears to be one of the most difficult challenges facing researchers and users of the technique (for discussion, see Sana et al., 2020). Given young children's narrower attentional windows (Betts et al., 2006; Kim et al., 2023; Werchan et al., 2024), it seems likely that they may struggle to focus on untested materials, hindering the occurrence of general benefits. In such a scenario, immediate feedback might reduce memory load, freeing cognitive resources and increasing the likelihood of a general benefit (as in the case of Experiment 1). On the other hand, once children have received correct answers, their attentional windows might close prematurely, leaving untested materials neglected (Sana & Carpenter, 2023). Further research is needed to explore these possibilities.

It should also be emphasized that the control condition differed between experiments. In the case of free-drawing (Experiment 1), the control condition involved an activity that was entirely unrelated to the materials being learned, whereas in the case of studying learning objectives (Experiment 2), the activity had far greater relevance to the target materials (Sana et al., 2020). That inconsistency in the effects of prequestioning with feedback for untested information might therefore be attributed, at least in part, to the varying competitiveness of the control condition. Even in adults, a general benefit of prequestioning seems to be more likely against a less competitive control condition (for related discussions see Pan & Carpenter, 2023; St. Hilaire et al., 2024). Nevertheless, the finding that prequestioning with feedback conferred learning benefits over listening to learning objectives highlights the potent efficacy of this technique, which may largely be attributed to the provision of feedback itself.

Notably, although mean performance on tested questions in the feedback condition remained relatively stable across experiments, performance on untested questions declined by approximately 13 % in Experiment 2, suggesting a potential negative prequestioning effect relative to the control condition. Importantly, the procedures for both the feedback and no-feedback conditions were identical across experiments, prompting questions about the source of this variability. One

possibility raised by prior research is that prequestioning may narrow learners' focus, enhancing recall for targeted information at the cost of untested material (for related discussions see Anderson & Biddle, 1975; Hamaker, 1986), but this explanation is not supported by the results of Experiment 1. Another possibility is that the within-participants design, particularly the addition of the learning objectives condition in Experiment 2—which increased the overall amount of content to be learned—led children to concentrate more on feedback-related material, potentially at the expense of broader learning.

#### 4.4. Practical implications

The present findings offer several practical recommendations and implications for improving young children's learning, particularly in the context of acquiring new scientific knowledge. First, prequestioning with immediate feedback can serve as a useful tool for fostering young children's learning of science texts and potentially other learning materials. It is a potential solution, at least in part, to the longstanding challenge of helping young children overcome their cognitive limitations. Second, the importance of immediate feedback for prequestioning with young children cannot be overlooked. Our results suggest that no reliable learning benefits can be expected if that feedback is absent, at least in the context of learning from science texts. The provision of immediate feedback also aligns with the "desirable difficulties" framework (Bjork & Bjork, 2011), which posits that introducing challenges into the learning process—without exceeding cognitive limits—can optimize learning outcomes (see also Fazio & Marsh, 2019). Third, given the narrower attentional windows observed in young children, it is likely that prequestioning with young children should occur in close temporal proximity to the target materials. By doing so, the likelihood of meaningful learning benefits will increase.

#### 4.5. Limitations and future directions

The present study has several limitations, as well as unanswered questions, that future research could address. First, only young children from a particular cultural context were examined. To determine generalizability, studies with different cultural and socioeconomic groups are needed. Second, learning was assessed only after a few minutes. The long-term effects of prequestioning in young children, which appear to be promising in adults (e.g., Kliegl et al., 2023), remain to be explored. Relatedly, there were subtle time-on-task differences between conditions that might be reduced in future studies. Third, the degree to which young children learn from feedback versus prequestioning per se can be examined further. Fourth, future studies could also include alternative control conditions, such as reading sentences with the correct answers prior to hearing the stories, as well as other forms of practice questioning (e.g., pedagogical questions), and involve different types of learning materials (Foo et al., 2025). Fifth, future research could investigate other factors not explored in the present study, including curiosity (Geller et al., 2017) and attention (Pan, Sana, Schmitt, & Bjork, 2020), in the context of prequestioning with young children. Finally, comparing younger with older age groups could reveal whether the indispensable role of feedback in driving the prequestioning effect still persists, providing insights into the cognitive capacities necessary for the prequestioning effect and the developmental stage at which they emerge.

### 5. Conclusions

The present study contributes novel evidence that prequestioning can benefit preschool-aged children in the context of science text learning, but only when immediate correct answer feedback is provided. These findings suggest that although prequestioning holds promise as a learning tool for young children, its effective implementation may require greater consideration than for adults, who are less dependent on immediate feedback. More broadly, this study underscores the critical

role of feedback in facilitating learning and highlights the importance of presenting correct answers in close temporal proximity to prequestions in order to maximize learning benefits.

**Declaration of competing interest**

None.

**CRediT authorship contribution statement**

**Liwen Yu:** Data curation, Conceptualization, Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis. **Janelle T. Heng:** Methodology, Investigation. **Laura S.**

**Arden-Gardner:** Writing – review & editing, Investigation. **Xiao Pan Ding:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization. **Steven C. Pan:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization.

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**Appendix**

*Correlation Analyses of Study Variables*

Tetrachoric correlation analyses were conducted to examine the intercorrelations among question-specific scores within the tested and untested categories for Experiment 1 (see Table A1) and Experiment 2 (see Table A2). Moreover, Pearson correlation analyses were conducted on participant-level performance for tested and untested questions in each condition for Experiment 1 (see Table A3) and Experiment 2 (see Table A4).

**Table A1**  
Intercorrelations Among Question-Specific Scores for Tested and Untested Questions in Experiment 1

	1	2	3	4	5	6
1. Tested question 1	1.00					
2. Tested question 2	0.45	1.00				
3. Tested question 3	0.60	0.47	1.00			
4. Untested question 1	–	–	–	1.00		
5. Untested question 2	–	–	–	0.35	1.00	
6. Untested question 3	–	–	–	0.055	0.11	1.00

**Table A2**  
Intercorrelations Among Question-Specific Scores for Tested and Untested Questions in Experiment 2

	1	2	3	4	5	6
1. Tested question 1	1.00					
2. Tested question 2	0.48	1.00				
3. Tested question 3	0.41	0.29	1.00			
4. Untested question 1	–	–	–	1.00		
5. Untested question 2	–	–	–	0.25	1.00	
6. Untested question 3	–	–	–	0.19	0.14	1.00

**Table A3**  
Correlation Matrix of Scores on Tested and Untested Questions in Each Condition for Experiment 1

	1	2	3	4	5	6
1. Feedback condition tested	1.00					
2. Feedback condition untested	0.20	1.00				
3. Non-feedback condition tested	0.25	0.24	1.00			
4. Non-feedback condition untested	0.27	0.16	0.33*	1.00		
5. Control condition tested	0.30*	0.20	0.16	0.41**	1.00	
6. Control condition untested	0.28	0.15	0.15	0.21	0.29	1.00

Note. \* =  $p < .05$ ; \*\* =  $p < .01$ .

**Table A4**  
Correlation Matrix of Scores on Tested and Untested Questions in Each Condition for Experiment 2

	1	2	3	4	5	6
1. Feedback condition tested	1.00					
2. Feedback condition untested	0.17	1.00				
3. Non-feedback condition tested	0.02	0.27	1.00			
4. Non-feedback condition untested	0.31*	0.21	0.36*	1.00		
5. Control condition tested	0.37*	0.42**	0.21	0.29	1.00	
6. Control condition untested	0.25	0.01	-0.02	0.20	0.05	1.00

Note. \* =  $p < .05$ ; \*\* =  $p < .01$ .

## Data availability

Data/code is archived on OSF and link shared in manuscript

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