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"I Want to Know More!": Children Are Sensitive to Explanation Quality When Exploring New Information

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Abstract

When someone encounters an explanation perceived as weak, this may lead to a feeling of deprivation or tension that can be resolved by engaging in additional learning. This study examined to what extent children respond to weak explanations by seeking additional learning opportunities. Seven- to ten-year-olds ($N = 81$) explored questions and explanations (circular or mechanistic) about 12 animals using a novel Android tablet application. After rating the quality of an initial explanation, children could request and receive additional information or return to the main menu to choose a new animal to explore. Consistent with past research, there were both developmental and IQ-related differences in how children evaluated explanation quality. But across development, children were more likely to request additional information in response to circular explanations than mechanistic explanations. Importantly, children were also more likely to request additional information in direct response to explanations that they themselves had assigned low ratings, regardless of explanation type. In addition, there was significant variability in both children's explanation evaluation and their exploration, suggesting important directions for future research. The findings support the deprivation theory of curiosity and offer implications for education.

Keywords: Conceptual development; Knowledge; Learning; Metacognition; Explanation; Information seeking; Science learning; Curiosity

1. Introduction

Learning often requires seeking out explanations from others, and sometimes those explanations are woefully inadequate. Imagine the follow scenario: While watching some

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animals at the zoo, a child turns to his parents and asks, “How does a cheetah run so fast?” One parent answers, “Yes, isn’t it fast? It can run up to 75 miles per hour.” The child’s brow furrows, and he pushes forward, asking, “But *how*? Why can’t our cat run that fast? She runs on four legs, too.” After another unsatisfying explanation, the child turns to the other parent and asks, “Do *you* know how cheetahs run so fast?”

This anecdote captures something that many adults have experienced when interacting with children: Children are sometimes unsatisfied with the explanations that they receive. Indeed, some have proposed that children are motivated to seek out satisfying explanations in answer to their questions, and in some cases, they will not stop exploring until they receive the answer that brings them that satisfaction (e.g., Gopnik, 1998). This idea taps into a concept researchers have sometimes labeled as the deprivation theory of curiosity (or the information-gap theory of curiosity; Golman & Loewenstein, 2016; Jirout & Klahr, 2012; Litman & Jimerson, 2004; Loewenstein, 1994; see also Keil, 2006): When someone encounters an explanation perceived as weak, this may lead to a feeling of deprivation or tension. A component of this theory is that people often feel driven to resolve that feeling of deprivation, and one way to do so is to engage in additional learning.

Examining how this theory is relevant during child development is a crucial question for research. The learning process often requires recognizing what one does not know, determining where to go for information, gathering additional information, taking stock of one’s updated knowledge, and continuing this cycle of reflection and information gathering until sufficient information has been gathered (Danovitch & Mills, 2018; Mills & Landrum, 2014). This process may be particularly important when learning science, given that science learning often requires building upon overly simple and/or incorrect beliefs about the world (Shtulman, 2017). If developmental, cognitive, and educational psychologists are interested in understanding how to encourage successful learning, especially in complex fields like science, a crucial goal for research needs to be to systematically examine the conditions under which children (a) recognize that an explanation is somehow deficient and (b) seek out additional information to fill the gaps in their understanding. The overarching goal of the research presented here is to examine whether encountering scientific explanations a child perceives to be weak leads to an interest in engaging in additional learning.

Past research examining the relationship between explanation and exploration has tended to focus on whether children respond differently to explanations that provide a mechanism (i.e., some sort of answer to “how” or “why” something may occur) than explanations that very clearly do not. For instance, preschool-aged children engage in greater exploratory behavior when faced with confounding information on how an unfamiliar object works than when the mechanism is clear (Legare, 2012; see also Bonawitz et al., 2011), and they ask more follow-up questions after receiving nonexplanatory responses (e.g., a personal reaction to the topic of the question, like “I like turtles!”) than after receiving explanations (Frazier, Gelman, & Wellman, 2009, 2016). These studies provide some initial evidence that overtly weak explanations can, at times, prompt exploration even in childhood. That said, we think it is important to note two issues related to the breadth of the inferences we can make from these studies.

First, these studies focused on either understanding simple physical mechanisms (e.g., determining which object makes an unfamiliar machine "light up") or reacting to an answer for clearly unusual events (e.g., why someone poured ketchup on ice cream), and the experimental designs were such that weaknesses in explanation quality were extremely easy to detect (e.g., the response was clearly incorrect or off topic). There is far less known about how children respond to weak explanations for more complex causal relationships, such as those that underlie biological systems. Biological explanations, and indeed scientific ones in general, can vary in many dimensions, including their relevance (i.e., is the explanation on topic?), their coherence (i.e., is the explanation internally consistent?), their circularity (i.e., is the explanation moving beyond the information provided in the question?), and their depth (i.e., does the explanation provide enough information? Keil, 2006; Danovitch & Mills, 2018). Particularly given how much children depend on explanations from others when learning about scientific topics like biology (e.g., Crowley, Callanan, Jipson, Galco, Topping, & Shrager, 2001; Gelman & Legare, 2011; Hatano & Inagaki, 1994, Jipson & Callanan, 2003), it is crucial for research to systematically explore how children respond to explanations that are actually found in the domain of science to better understand how to encourage successful science learning.

Second, although these past studies demonstrate that children are more likely to explore in response to extremely weak explanations than to informative ones, we need to be mindful that these studies are focusing on *averages*: For all children in a study, performance on a set of experimenter-defined weak explanations is contrasted with performance on a set of experimenter-defined satisfying explanations. But looking beyond the averages, it is clear that some children explored in a seemingly random way or rarely explored (e.g., see Frazier et al., 2009). Because children's perceptions of the explanations were not examined separately from their exploratory behavior in response to the explanations, it is difficult to clearly interpret the variation in children's performance.

Our proposal is that children's information seeking is driven in some part by their impression that an explanation is weak. That is, children's *perception* of the quality of explanations, rather than the objective quality of the explanations, is important to their decision on whether to seek out additional or clarifying information. If a child encounters what she deems to be a sufficient explanation, she will not seek more information. However, if she deems the explanation to be lacking, this assessment of information deprivation can lead her to request additional explanations.

Although there is certainly a link between the objective quality of explanations and children's perception of those explanations, it is also clear that children frequently do not detect weak explanations. For example, an explanation for how a cheetah can run really fast such as "cheetahs were made to run fast" does not clearly address the mechanism underlying a cheetah's fast speed, and yet some children still rate that kind of response as sufficient (e.g., Mills, Danovitch, Rowles, & Campbell, 2017). Measuring both (a) how children perceive individual explanations and (b) how they follow up individual explanations should begin to provide important insight into what guides children's learning. We must have information on *both* of these factors to understand whether children, on average, seek information directly in response to explanations that they perceive to be weak. If this is indeed established, then future research can begin to examine possible developmental and individual differences in exploration, such as in what ways children who are interested in following up weak explanations might be different from children who are not.

To our knowledge, there is no prior research examining the link between explanation assessment and explanation follow-up in this way. The closest research has instead looked at the relationship between explanation assessment and interest in learning at a general level. In this research, children who were better at detecting low-quality explanations about animal processes took home more animal fact cards after a study than children who struggled to recognize low-quality explanations (Mills et al., 2017). From this research, it is difficult to tell if children took home more animal fact cards because they recognized that they had received many weak explanations or because they were generally more interested in animals and were more carefully evaluating the explanations as a result. Moreover, due to the study's design, it was difficult to assess whether there was a link between how children evaluated single explanations about animal questions and whether they took home an animal fact card for that particular animal. As such, these findings do not address whether children selectively seek information in response to specific questions that they think have been unsatisfactorily answered.

1.1. The current study

The current study addresses these issues by examining the conditions under which children respond to weak explanations regarding biological explanations by requesting more information. In order to examine how children respond to weak explanations, we needed to first find a type of explanation sometimes given in response to questions about science that children could recognize was weak. Most research has examined children's ability to determine which of two explanations in a pair is strongest, not how children assess the quality of explanations presented one at a time (see Mills et al., 2017 for a review). But based on research to date, circular explanations (i.e., explanations reiterating information from an original question without offering any meaningful new information) appear to be an ideal weak explanation candidate for initial work examining the link between recognizing weak explanations and interest in gathering more information. Seven- to 10-year-olds can assign lower ratings of quality to circular explanations than to mechanistic ones (i.e., explanations providing a simple mechanism that address the topic of the question; Baum, Danovitch, & Keil, 2008), even when each explanation is presented in isolation (Mills et al., 2017). However, there is still significant variability in children's performance, with some children more successful than others at recognizing weak explanations. Although we do believe that, in some circumstances, children younger than 7 can recognize circular explanations to be weak, the evidence is far less consistent, particularly when children are not presented with contrasting explanations (see Mills et al., 2017). Because of this, we chose to focus on working with 7- to 10-year-old children using a mixture of circular and mechanistic explanations.

In order to measure how children respond to different types of explanations, we needed to create a naturalistic self-directed learning context in which children would feel comfortable exploring explanations and their alternatives. To that end, we developed a novel Android tablet application that allowed children to guide their own information gathering and exploration regarding features of unusual animals. In this application, children could click on different unusual animals, hear a question about the animal followed by a circular or mechanistic explanation, rate the explanation, and then either request additional information or return to a main menu to hear about another animal. Because this tool allowed children to direct their own learning experience instead of simply responding to experimenter-mediated prompts, it increased the likelihood of children expressing interest in future learning due to personal interest rather than social compliance pressures. Focusing the study on 7- to 10-year-olds instead of younger children also increased the likelihood that participants would be reasonably comfortable exploring a tablet platform, given developmental differences in tablet ownership and usage as of 2017 (Rideout, 2017). To our knowledge, this is the first usage of a self-directed learning environment to study the children's evaluation of and response to different qualities of explanations.

Our design allowed us to examine several different aspects of how children respond to weak explanations. First, we examined whether children in this age range evaluated circular explanations, on average, as being lower in quality than mechanistic explanations, consistent with prior research (Mills et al., 2017). Second, we examined requests for more information in response to the different kinds of explanations. We took two approaches to understand this exploration. In one, we examined whether children were more likely to selectively seek information in response to explanations that we designed to be circular than explanations that we designed to be mechanistic. In the other, and crucial to examining the deprivation theory of curiosity, we analyzed whether children's *own* ratings for each explanation related to whether or not children requested more information for each item—in other words, do *their perceptions* of explanation quality drive information seeking? We expected that children would be more likely to request more information in response to explanations that *they* rated as weak than to explanations *they* rated as strong. If found, this evidence would provide support that children's exploration is guided by their own impressions of explanatory weakness.

Third, to address the possibility that children might choose to simply request additional information for every item, we also examined whether children's information seeking depended on their access to information. We developed a between-subjects manipulation such that half of the children were restricted in how frequently they could request additional information (i.e., only 8 of 12 items) and half were not (i.e., could request for all 12 items if desired). We speculated that when resources were limited, children might choose to be more selective in seeking information, choosing to ask questions only when feeling significantly deprived as opposed to just marginally so. In contrast, when resources were plentiful, children might be less selective, although we still anticipated that they would be more likely to follow up weak explanations than strong ones. That said, we thought that older children would be more likely than younger ones to deploy a selective information-seeking strategy in response to restrictions on information availability. This speculation was based on research finding developmental improvements through the elementary school years in another kind of selective seeking of information (i.e., remembering which objects are hidden behind a subset of a larger set of doors; DeMarie-Dreblow & Miller, 1988; Gregan-Paxton & John, 1997; Mata, von Helverson, & Rieskamp, 2011).

Finally, to begin understanding possible contributions to individual differences in children's performance in (a) recognizing weak explanations and (b) seeking out additional information, we included several individual difference measures in our test battery. Based on research finding a link between children's verbal intelligence and both their evaluation of circular explanations and their general interest in engaging in additional learning (Mills et al., 2017), we included a brief measure of verbal intelligence from the NIH Toolbox Cognition Battery (Gershon et al., 2013), the Picture Vocabulary Test. We also included two measures of executive function, both from the NIH Toolbox Cognition Battery—the Dimensional Change Card Sort Task and the Flanker Task (Zelazo et al., 2013)—given past research finding links between executive functioning skills and biological conceptual knowledge (Zaitchik, Iqbal, & Carey, 2014) and given that selective information seeking may require the ability to carefully manage one's cognitive resources. Thus, we explored the possibility that these individual difference measures might relate to children's ratings of weak explanations as well as children's information-seeking behavior.

2. Method

2.1. Participants

Participants were thirty-eight 7- and 8-year-olds (M_{age} = 7.96, SD = 0.62; 23 females) and forty-three 9- and 10-year-olds (M_{age} = 9.89, SD = 0.59; 18 females) from the North Dallas area. Of the participants 61.7% identified as Caucasian, 13.6% as Asian, 2.5% as Black or African-American, 8.6% as other races or mixed race, and 13.6% did not disclose their race. Of those who disclosed their ethnicity (N = 68), 8.7% of participants identified as Hispanic or Latino.

2.2 Materials and design

Children were shown 12 animals that were likely to be unfamiliar (e.g., saiga antelope, tarsier). For each animal, a "how" question was prepared that asked about a biological process of that animal (e.g., "How do saiga antelopes use their noses to keep their lungs clean?"). For each of those questions, three different types of explanations were created (for a total of 36 explanations; see Appendix): circular explanations, simple mechanistic explanations, and detailed mechanistic explanations. Circular explanations reiterated information from the original question without adding any meaningful or new information (e.g., "Their noses are able to keep their lungs from getting dirty"), whereas simple mechanistic explanations provided one piece of new and meaningful information ("Their noses have special filters that stop dirt from reaching their lungs"). Finally, detailed mechanistic explanations, which were provided when a child tapped the "more information" button, briefly expanded on the information provided in the original mechanistic explanation, providing about two pieces of new and meaningful information related to the original question (e.g., "Saiga antelopes travel in herds that kick up dirt and dust into their air. To keep their lungs clean, they have special filters in their noses that stop the dirt and dust from getting into their lungs"). A larger set of explanations were piloted with adults and narrowed down to items that were seen to best fit the above explanation categories. Similar to previous research (e.g., Corriveau & Kurkul, 2014; Mills et al., 2017), circular and mechanistic explanations were matched for length and complexity, as measured by Flesch Reading Ease Scores (Flesch, 1948; $M_{\text{circular}} = 93.14$, $M_{\text{noncircular}} = 89.73$, $t(22) = 0.76$, $p = .455$). One female recorded the voice for the questions and a different female recorded the voice for the explanations.

To examine how children respond to circular and mechanistic explanations, we created a novel Android tablet application (see Fig. 1 for screenshots). The home page for the application contained a 3×4 grid of pictures of real but unusual animals. Four different versions of the grid were created so that the order of the placement of the animals and the type of initial explanation for each animal (i.e., circular or mechanistic) were counterbalanced across children. No more than two of the same explanation type were placed next to each other in the grid, and each row had roughly two of each explanation type. The application recorded each choice the child made throughout a session. Additional information about the application is described in Section 2.3.

An iPad Air 2 was used to administer selected measures from the NIH Toolbox Cognitive Battery: the Picture Vocabulary Test, the Flanker task, and the Dimensional Change Card Sort task, all described in more detail below.

2.3. Procedure

2.3.1. Training phase

After parents provided informed consent for their children's participation, children were individually brought into a laboratory testing space. Before beginning testing, children were told that the purpose of the project was to learn about "how kids your age think about things," that they would play some games and learn about some different things, that they would get a small prize and a certificate once the games were over, and that they could stop whenever they wanted.

After assenting to participate, children were told that they were going to play a game on a tablet application where they would see pictures of strange but real animals, hear questions and explanations someone had about them, and then would be able to rate "how well the explanation answers the question."

As practice, children were walked through a tutorial on PowerPoint that mimicked the layout of the tablet application. The tutorial looked the same as the test phase (see Fig. 1) except the picture grid on the home page included two pictures—one of a car and one of

Fig. 1. Screenshots from tablet application.
Note: (a) 3 × 4 animal grid, (b) "Jane" asking a question about an animal, (c) person responding to the question, (d) prompt to rate the explanation, (e) prompt to choose the next animal or use a key to request more information, and (f) animal grid with the animal chosen so far lightly grayed out.

a truck—to introduce children to the task in a simple way without biasing them for the Test phase involving animals. The experimenter directed the child through the example with the car item, explaining that once the car was clicked on, an audio recording of a question would play followed by an explanation to answer that question. Tapping on the item caused a larger image of that item to appear with a stick figure to its left. After a small delay, a speech bubble appeared next to the stick figure and an audio clip played of that stick figure asking a "how" question about the vehicle. Afterward, a second stick figure appeared on the other side of the screen with her own speech bubble and provided a corresponding explanation. After the explanation played, a box appeared on the screen prompting children to either (a) listen to it again or (b) rate the explanation for how well it answered the question. If the user selected option (a), the entire process was repeated until this option screen.

Children were then introduced to the rating scale, which consisted of five circles, each progressively more filled to denote how much information an explanation provided (see Fig. 1d). Children were told that if the explanation “answers the question really well and gives you all the information you need to understand something,” they should click on the mostly filled circle. If an explanation “does not answer the question at all and does not give you any of the information you need to understand something,” they should click the mostly empty circle. If children thought the explanation “answers the question somewhere in the middle—so it gives you some of the information you need to understand something but not all the way,” they should click the half-filled circle in the middle. Importantly, children were told they could use any of the five circles, and that they were not to judge whether they thought an explanation was right or true, but how well it answered the question. The same scale was successfully used in previous research with this age group (Mills et al., 2017).

Once the rating option was selected and completed, another box appeared prompting children to either (a) use a key to “unlock” more information about that same animal or (b) return to the main grid in order to see more animals. The experimenter explained that children would have a certain amount of “keys” in the real game, and that these keys would “unlock” the option to hear more information. Children in the *unrestricted access* condition were told that, in the real game, they would have 12 keys to use for the 12 animals and, thus, would be able to use a key for every animal if they wanted to. Children in the *restricted access* condition were told that in the real game, although there would be 12 animals, they would only have eight keys, and thus, they needed to carefully choose when to use keys because they would not be able to use a key for every animal. In both conditions, children were told that they could use all of their available keys, none of them, or some of them. Children were told that whenever they came to this screen, a note on the box would tell them how many keys they had remaining (e.g., “You will lose one of your ___ remaining keys”).

Regardless of condition, the experimenter clicked to receive more information about the car to show children how the application worked. The same question that was played originally was played again, though now it was followed by the detailed mechanistic explanation. The same options as those presented after the first explanation were presented again; children could either replay the question and explanation or move on to rate the explanation, and then, children would use the circle scale to rate how well the new explanation answered the question. After children completed this process, they were returned to the same home screen grid as before, except this time the previously selected vehicle was shaded a lighter gray color and could not be selected again. The experimenter pointed out that the vehicle was gray and could not be selected again, so they could only look through each item once. Once the experimenter finished walking through the procedure with the car example, the child then clicked on the truck and went through the item on their own as practice.

2.3.2. Test phase

Once children were familiarized with how the general procedure worked, children were told that "Jane" saw pictures of strange but real animals, had questions about those animals, and went out and asked a lot of different people to answer her questions. The experimenter explained that "some people seemed to know a lot, some seemed to know a little bit, and some didn't seem to know very much at all," and that Jane wanted the child's help in determining how well each explanation she received really answered her questions. Children were then reminded that they would see a grid of 12 animals and of how many keys they had in order to select the more information option (i.e., either 12 keys or 8 keys). A brief check of the rating scale was included where children were asked to indicate which circle they would choose for various situations. They were told that they could choose the animals in any order they wanted to and that they could look at as many animals as they wanted. Finally, the experimenter let the child know that he or she was going to work on some paperwork but would be available if the child had questions, allowing the child to freely explore on his or her own as the experimenter pretended to review papers in a manila folder.

The experimenter then started the application for the main game and children were free to explore the grid of animals as they wished. Children would click on each animal one by one and would hear explanations and rate them in the same way that they did in the tutorial. Six of the initial explanations were circular explanations, and the other six were mechanistic (see Section 2.2 for counterbalancing information). Children were able to use a key to unlock more information at their discretion as long as they had not run out of keys. Once a child completed one animal, that animal's picture would be grayed out on the grid, indicating that the animal could not be clicked on again. The game would end once the child either looked at all 12 animals or decided they were finished playing. See Appendix for full list of explanations.

2.3.3. Check question phase

Immediately following the testing phase, the experimenter pulled up a PowerPoint on the tablet containing check questions. These questions were created to verify that children were willing to use the range of the circle rating scale. Six check questions about different unusual animals were provided and children heard explanations that fell into three different categories: strong explanations, which were similar to the mechanistic explanations of the testing phase; bizarre explanations, which were on topic but provided an intentionally improbable explanation (e.g., Question: "How does the gobi jerboa use its ears to stay cool?"; Bizarre explanation: "The gobi jerboa uses its ears to buy ice from the supermarket"); and nonexplanations, which did not address the question (e.g., Question: "How does the okapi use its stripes as protection?"; Nonexplanation explanation: "The okapi has fur that looks like chocolate!"). The experimenter walked the child through this phase and used a printed version of the rating scale to obtain ratings. See Supplemental Material for the list of check questions.

2.3.4. Individual differences phase

This phase consisted of three different measures: the Picture Vocabulary Test, the Flanker task, and the Dimensional Change Card Sort. All of the measures were administered on an iPad Air 2 through the NIH Toolbox Cognitive Battery. Scores for all three tests were converted into age-corrected standard scores, which had a normative mean of 100 and a standard deviation of 15.

The Picture Vocabulary Test (PVT) is a measure of verbal intelligence. For this test, children saw four pictures presented on the screen and heard audio of a word describing one of the pictures. Children had to touch the picture that matched the word, and once doing so, would see four more pictures with a new word. Testing was adaptive, so which picture set was displayed next was dependent on children's previous performance.

The Flanker task is a measure of children's inhibitory control and attention. Children were presented with a row of five arrows with each arrow pointing either left or right, and children were instructed to push a button indicating which direction the middle arrow was pointing. Sometimes the arrows on the sides pointed in the same direction as the middle arrow, but sometimes they pointed in the opposite way. For these trials, children had to inhibit the response of selecting the direction that most of the arrows were pointing and attend only to the middle arrow. Scoring is based on a combination of accuracy and reaction time and calculated within the NIH Toolbox program.

Finally, children completed the Dimensional Change Card Sort task (DCCS), which measures children's cognitive flexibility. DCCS has three phases: the shape phase (training), the color phase (training), and a combination phase (test). For each phase, two target pictures were shown that could vary along two dimensions (e.g., shape and color; e.g., yellow balls and blue trucks). After a test image appeared on the screen, children would have to click the target picture that shared a certain feature with the test image (i.e., shape during the shape phase, color during the color phase, and switching back and forth during the combination phase). For the combination phase, children needed the flexibility to switch which rule they were employing on a trial-by-trial basis. Children completed 30 trials of this combination game. Scoring is based on a combination of accuracy and reaction time and calculated within the NIH Toolbox program.

Children received a certificate and a small prize after completing all measures.

3. Results

3.1. Overview

We first report preliminary analyses examining children's understanding of the scale and their ability to differentiate between simple and detailed mechanistic explanations (Section 3.2). Next, we report analyses examining both developmental (Section 3.3.1) and individual differences (Section 3.3.2) in children's evaluation of circular and mechanistic explanations. Finally, we examine children's requests for more information, exploring children's overall rates of information seeking (Section 3.4.1), the relationship between explanation type and information seeking (Section 3.4.2) as well as relevant correlates (Section 3.4.3), and the relationship between perceived explanation quality and information seeking (Section 3.4.4) and possible predictors of performance (Section 3.4.5).

3.2. Preliminary analyses

To confirm that children understood the scale, we reviewed responses to the check items. First, we examined whether children rated solid explanations as higher in quality than bizarre explanations and nonexplanations. Paired samples t tests revealed this to be the case for both age groups, all ts > 8.03, ps < .001. Second, we examined whether children rated solid explanations higher than the scale midpoint (a rating of 3). One-sample t tests revealed that both age groups rated the solid explanations higher than the scale midpoint, all ts > 5.78, ps < .001. Third, we examined whether children rated the two weak check explanations—bizarre explanations and nonexplanations—as lower than the scale midpoint. Both age groups did so for the bizarre explanations, all ts > 4.34, ps < .001, and for the nonexplanations, ts > 3.99, ps < .001. Together, the data from these check items support that children both understood the rating scale and were willing to give explanations high and low ratings when clearly appropriate.

To confirm that children recognized that the detailed mechanistic explanations were higher in quality than the other kinds of explanations, we conducted several tests examining responses to the explanations received in the main task. First, we compared average ratings of the detailed mechanistic explanations to each of the shorter types for each age group. Overall, both age groups rated the detailed mechanistic explanations higher than the two types of shorter explanations, all ts > 4.78, all ps < .001 (for detailed mechanistic: $M_{7–8} = 4.55$, $SD_{7–8} = 0.61$ and $M_{9–10} = 4.53$, $SD_{9–10} = 0.41$; for simple mechanistic: $M_{7–8} = 3.72$, $SD_{7–8} = 0.75$ and $M_{9–10} = 3.62$, $SD_{9–10} = 0.70$; for circular: $M_{7–8} = 3.07$, $SD_{7–8} = 1.12$ and $M_{9–10} = 2.16$, $SD_{9–10} = 0.92$). Thus, children recognized that the detailed mechanistic explanations were providing more information than either the circular explanations or the simple mechanistic explanations.

Second, we compared ratings for detailed mechanistic explanations when they followed circular explanations to when they followed simple mechanistic explanations, finding no statistical difference, $t(45) = 0.64$, $p = .53$. Thus, children's assessments of the detailed mechanistic explanations were not based on how weak or strong the initial explanation was.

3.3. Understanding how children rated circular and mechanistic explanations

3.3.1. Did children rate circular explanations as lower in quality than mechanistic explanations?

Our next set of analyses examined whether children rated the circular explanations as lower in quality than the simple mechanistic explanations (henceforth labeled as mechanistic explanations). To examine this, a 2(explanation type: circular vs. mechanistic) × 2 (age group: 7- to 8-year-olds, 9- to 10-year-olds) × 2(condition: restricted access vs. unrestricted access) mixed measures ANOVA was conducted on the average ratings. No effect of condition was found in these analyses, suggesting that children's ratings were not affected by whether their access to more information was restricted or unrestricted. A main effect of explanation type supported that, overall, children rated circular explanations lower in quality than mechanistic explanations, $F(1, 77) = 85.41$, $p < .001$, $\eta_p^2 = 0.53$. A main effect of age group revealed that younger children assigned higher ratings on average than older children, $F(1, 77) = 9.70$, $p = .001$, $\eta_p^2 = 0.11$. Importantly, though, these findings were qualified by an explanation type by age group interaction, with older children making a greater distinction between mechanistic and circular explanations than younger children, $F(1, 77) = 12.80$, $p = .001$, $\eta_p^2 = 0.14$. This seemed primarily driven by responses to the circular explanations, which older children rated significantly lower than younger children, $t(79) = 4.04$ $p < .001$; in contrast, the two age groups rated the mechanistic explanations similarly, $t(79) = 0.61$, $p = .55$. This is in line with previous research (Mills et al., 2017). See Fig. 2.

3.3.2. *What correlated with how children rated the explanations?*

To explore possible explanations for individual differences in explanation ratings, we calculated the correlation between age, our three individual difference measures included in our protocol (PVT, Flanker, and DCCS), and children's average ratings for circular as well as mechanistic explanations. Note that sample sizes differ slightly for the different correlations based on the number of children who completed the individual difference measures. See Table 1.

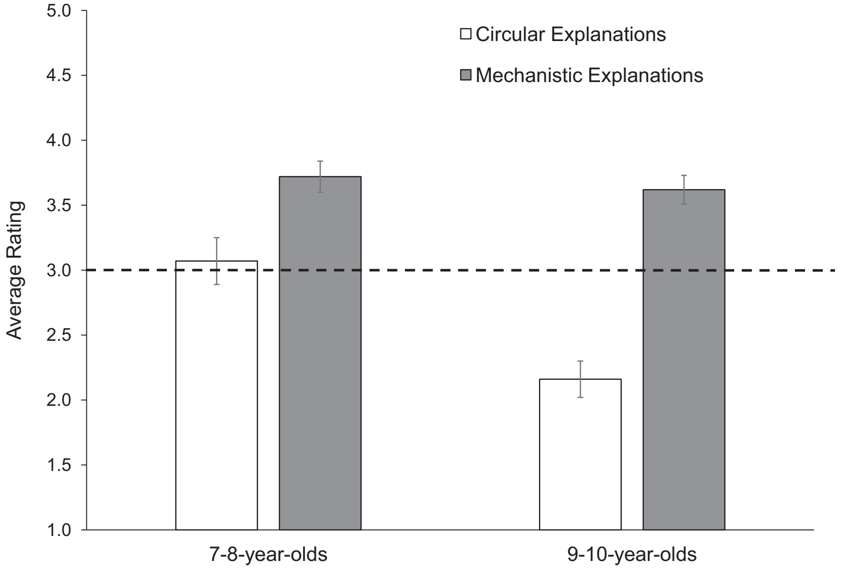

Fig. 2. Average ratings for circular and mechanistic explanations for the two age groups.

Before discussing the details of the analysis, we note that participants in our study were of slightly higher than average levels of verbal intelligence: the average scores for the PVT were higher than the standardized population mean of 100 (M = 111.48, SD = 16.50; $t(76)$ = 6.11, p < .001). The average scores for the Flanker (M = 99.96, SD = 15.20) and the DCCS (M = 98.14, SD = 16.88) were roughly at standardized population mean of 100 (ts < .97, ps > .33). There were no significant outliers, and no age group differences in any measures, all ts < 1.2, ps > .27.

Turning now to the correlational data, the two executive functioning measures correlated with each other, $r(77)$ = .36, p = .001, but nothing else. Creating a composite EF variable did not change this finding. This suggests that children's assessment of explanations were not strongly influenced by executive functioning skills (at least for children within normal limits with the measures used in this study).

Overall, with higher PVT scores, children were more negative in their ratings of circular explanations, $r(77) = -.41$, p < .001, but no such relationship was present in ratings of mechanistic explanations, $r(77)$ = .03, p = .83. So, with stronger verbal intelligence, children were better at assigning low ratings to the circular (i.e., weaker) explanations. Even after statistically controlling for age, higher PVT scores were linked with lower ratings of circular explanations, $r(74) = -.38$, p < .001. This provides additional evidence to support past research finding a relationship between verbal intelligence and success at recognizing weak explanations (Mills et al., 2017).

3.4. Understanding requests for more information

3.4.1. How often did children click for more information?

The tablet application was designed to give children the opportunity to guide their own exploration, clicking on animals and requesting additional information as often or as rarely as they liked without pressure from adults. Overall, 79 of 81 participants clicked on all of the animals in the grid before deciding they were done participating in the study; the other two children clicked on 92% and 75% of the animals. Thus, in general, children appeared interested in exploring the animals with the application.

To check to see if children felt comfortable requesting more information as much or as little as desired, within the constraints of their condition, we examined the descriptive data. Overall, children frequently requested more information, but there was a lot of variability. In the unrestricted condition, children requested more information anywhere between 0 and the maximum of 12 times ($M_{7–8}$ = 4.43, $SD_{7–8}$ = 4.48; $M_{9–10}$ = 4.52, $SD_{9–10}$ = 3.93); in the restricted condition, children requested more information anywhere between 0 and the maximum of eight times ($M_{7–8}$ = 3.26, $SD_{7–8}$ = 3.09; $M_{9–10}$ = 4.09, $SD_{9–10}$ = 3.19). More than two-thirds of 7- and 8-year-olds and three-quarters of 9- and 10-year-olds requested more information at some point during the session. The total number of requests for more information did not differ between the two age groups for either condition, all ts < 0.85, ps > .40. Additional information about children's information seeking is shown in Table 2. Our impression from this data is that children generally felt comfortable requesting additional information but did not feel obligated to do so.

3.4.2. Was children's interest in seeking out more information affected by either the type of explanation or access to information (or both)?

One central focus of this project was to examine whether children were more likely to request additional information in response to circular explanations than to mechanistic ones, and if that might vary depending on access to information.

To begin examining this issue, we calculated the proportion of explanations for which the child clicked for more information. We chose to examine the proportion of items instead of the number because two of the 81 participants did not click on all of the animals in the table before deciding that they were done participating in the study, and so proportions better capture how all children responded based on how many of the items they saw.

A 2(explanation type: circular vs. mechanistic) × 2(age group: 7- to 8-year-olds, 9- to 10-year-olds) × 2(condition: restricted access vs. unrestricted access) mixed measures ANOVA was conducted on the proportion of items children clicked for more information for all participants. See Fig. 3. Overall, we found a main effect of explanation type, with children requesting additional information more frequently in response to the circular explanations than the mechanistic ones, $F(1, 77) = 24.56$, $p < .001$, $\eta_p^2 = 0.24$. We also found an interaction between explanation type and age group, with older children showing more sensitivity to explanation type than younger children, $F(1, 77) = 9.63$, $p = .003$, $\eta_p^2 = 0.11$.

In addition, there was a three-way interaction between explanation type, age group, and information access condition, $F(1, 77) = 4.42$, $p = .039$, $\eta_p^2 = 0.05$. To interpret this interaction and based on a priori expectations regarding differences according to information access, we looked at response patterns for each age group in the two different information access conditions. For 7- and 8-year-olds, we found that when information access was unrestricted, they were more likely to request more information in response to circular explanations than in response to mechanistic ones, $t(18) = 2.35$, $p = .03$. In contrast, when information access was restricted, 7- and 8-year-olds did not distinguish between the two explanation types in their requests for more information, $t(18) = 0.26$, $p = .80$. For 10-year-olds, we found that regardless of information access, children were more likely to request more information in response to circular explanations than in response to mechanistic ones, ts > 2.95, ps < .009. Thus, contrary to expectations, restriction did not lead to more selective

Table 1
Percentage of children who fit into four categories of requests for more information based on whether access to information was restricted or unrestricted

			Requested More Information		
		Never Requested More Information	More Often for Mechanistic	Equally for Both Item Types	More Often for Circular
Restricted access	7- to 8-year-olds	31.5	26.3	15.8	26.3
	9- to 10-year-olds	31.8	4.5	4.5	59.1
Unrestricted access	7- to 8-year-olds	26.3	5.3	26.3	42.1
	9- to 10-year-olds	19.0	19.0	4.8	57.2

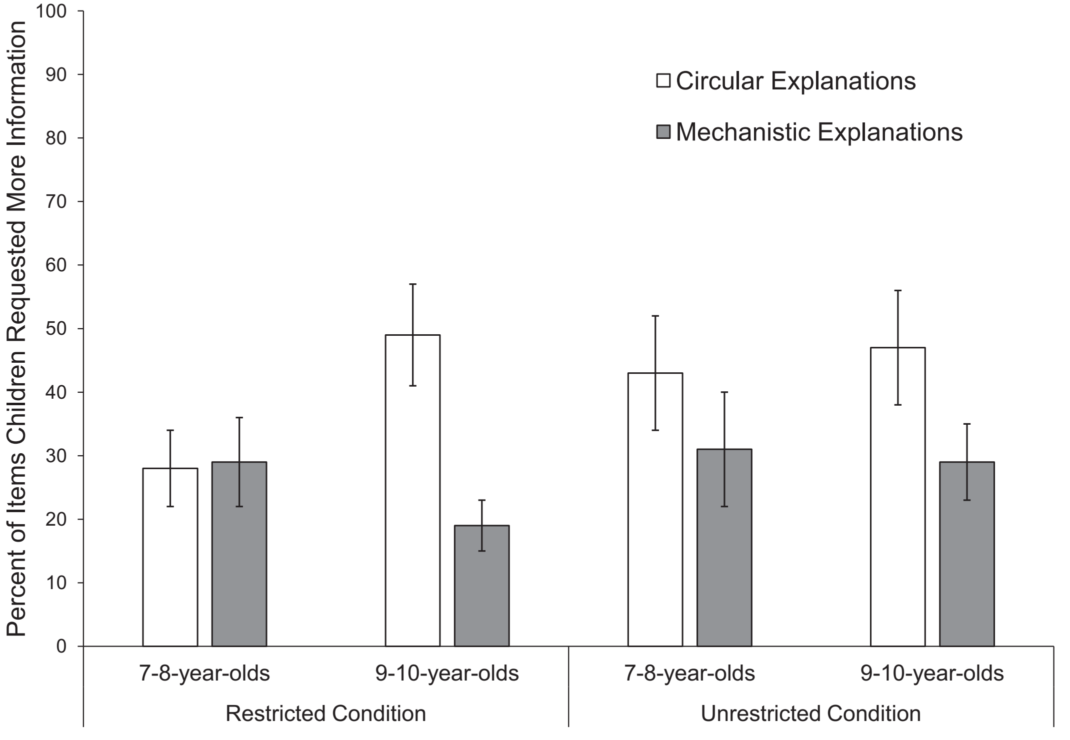

Fig. 3. Percentage of items for which children requested more information for each explanation type and condition.

information seeking, and with the 7- and 8-year-olds, restriction actually led to *less* selective information seeking. We will return to this issue in the discussion.

3.4.3. What correlated with how frequently children requested more information?

To explore possible explanations for individual differences in the frequency of requests for more information, we correlated the number of times children requested additional information (for both circular and mechanistic explanation types) with the other study variables, including age, PVT performance, and explanation ratings for each explanation type and overall (see Table 1).

In short, nothing related to the total number of times children requested more information except for how frequently they asked for more information for each explanation type. Next, we looked at correlates with each explanation type separately. The only statistically significant findings was for circular explanations: the lower children rated the circular explanations on average, the more frequently they requested more information in response to those explanations, $r(81) = -.233$, $p = .036$. Notably, though, this result was no longer statistically significant once we controlled for age, $r(81) = -.13$, $p = .28$. Similar findings were present when the correlations were conducted separately based on access to information.

3.4.4. Was children's interest in seeking out more information affected by their own *ratings of the explanations?*

All of the analyses reported so far focus on how children responded to the two types of explanation—circular and mechanistic—on average. These findings do not tell us whether children's responses to an individual explanation were influenced in part by their own perceptions of explanation quality.

Here, we examined whether children were more likely to request additional information for explanations they rated to be weak than to explanations they rated to be strong—regardless of what category the explanation was designed to be. For instance, if a child found one of the mechanistic explanations to be weak, would that child be more likely to request additional information for that item than for a mechanistic explanation he or she thought to be strong? This analytical approach is crucial for understanding whether the deprivation theory of curiosity partially explains how children seek out information.

To examine this issue, we conducted a multilevel model analysis. A multilevel model analysis allows us to have a better sense of how each child's individual ratings relate to that child's choice to request additional information (see Hoffman & Rovine, 2007; Nezlek, 2008 for additional information about using mixed models approaches in experimental psychology). In other words, while the ANOVA approach focuses on whether children, in general, were more likely to request more information for explanations that we categorized as circular than for explanations that we categorized as mechanistic, the multilevel modeling approach allows us to look at requests for information based on how a child rated an item compared to how that same child rated other items. This kind of approach takes into account the fact that children varied in how they used the scale (i.e., one child might have used ratings between 1 and 3 only, whereas another child might have used the full span of the scale) and how they perceived individual explanations. In other words, it allows us to examine whether children seek information based on *their own perceptions* of the quality of the explanations.

To prepare for this analysis, we aggregated the data such that we calculated each child's mean rating for the 12 items. We then took each child's rating for each item and subtracted out that child's mean rating to create a new variable that we call the *child-centered rating*. For each child, positive numbers for an item would indicate that the child

Table 2
Correlations between primary study measures

	1	2	3	4	5	6	7
1. Age	–	–		–	–	–	–
2. PVT	0.17	–		–	–	–	–
3. EF composite	0.03	0.20	–	–	–	–	–
4. Circular rating mean	−0.40**	−0.41**	−0.06	–	–	–	–
5. Mechanistic rating mean	−0.13	0.03	0.04	0.35**	–	–	–
6. Circular requests for more	0.19†	0.13	−0.19	−0.23*	−0.10	–	–
7. Mechanistic requests for more	−0.08	0.00	−0.12	0.13	−0.08	0.66**	–
8. Total requests for more	0.09	0.09	−0.18	−0.09	−0.10	0.94**	0.88**

Note. †$p < .10$, *$p < .05$, **$p < .01$.

rated that item better than the child's average rating while negative numbers would indicate worse. Within SPSS, our generalized linear multilevel model examined whether there was a relationship between child-centered ratings for each item and requests for more information. Our dependent variable was binary: for each item, whether or not the child clicked for more information for that particular item. To account for participant variation, we included participants as a random effect. We also included a random effect for the child-centered mean predictor given the possibility that the relation between the perceived quality of an explanation and the request for more information may vary across children. The reference category was set such that the results indicate how increases in the child-centered mean relate to changes in request for more information.

The results were consistent with our predictions: There was a significant negative relationship between children's centered ratings and requests for more information, $B = -0.60$, $SE = 0.13$, $OR = .55$, $95\%\ CI = [0.43, 0.71]$, $p < .001$. The odds ratio indicates that for every increase in one rating point in how a child rated an item compared to the child's mean ratings, a child was 45% less likely to request more information. Note that we also conducted this same analysis adding in condition to test if information seeking differed based on whether children were restricted or not restricted in their information seeking (i.e., condition), but there were no significant effects (neither for condition on its own nor for an interaction between condition and children's ratings; ps > .30). There were also no significant effects or interaction with age (ps > .20). Thus, these analyses support that children, overall, are adjusting their information seeking based on how they themselves perceive the quality of the explanations.

3.4.5. Were there differences between selective information seekers and unselective ones?

On average, children (a) requested additional information more frequently in response to circular explanations than noncircular ones, and (b) requested additional information more frequently in response to explanations that they themselves thought were weak than explanations that they thought were strong. In other words, children, in general, demonstrated selective information seeking. Information access had little effect on performance, with the exception of 7- and 8-year-olds in the restricted access condition being less likely to engage in selective information seeking.

Although it is clear that children in this age range generally showed a pattern of selective information seeking, it is also clear that there were significant individual differences. Therefore, the final analyses focused on comparing children who showed a selective pattern of seeking information based on their own ratings (i.e., requested additional information more frequently in response to explanations that they rated lower than their own average rating than for explanations that they rated equal or higher than their own average rating; $N = 36$) to those who did not ($N = 45$).

First, we compared the two groups on age, PVT, Flanker, and DCCS scores, finding no significant differences between them for any measure, all ps > .05. Next, in thinking through how to approach this data, we wondered if children who selectively sought information *in response to their own ratings* were, in general, more attuned to the quality of the explanations used in our study than children who did not. It may be worthwhile to point out that these variables do not necessarily have to be related; in order to request more information in response to the set of items a child perceived as weak compared to the set of items seen as strong, it is not necessary to have assigned low ratings to circular explanations. To explore the possibility of a relationship between selective information seeking and assessment of circular explanations, we compared average ratings for circular explanations for the two groups. We found that children who were selective in seeking information in response to their own ratings rated the circular explanations lower than children who were not selective, $t(79) = 2.31$, $p = .023$. Logistic regression supported that lower ratings for circular explanations predicted membership in the selective information-seeking group, $\beta = -4.89$, $SE = 0.22$, Wald $\chi^2 = 4.88$, $df = 1$, $p = .03$, $OR = 0.613$. These findings suggest that although there is a distinction between how we designed the explanations and how children perceived them, the children who were better at assessing the circular explanations to be weak were also better at selective information seeking in response to their own ratings of explanation quality. We speculate that this finding is tapping into something about children being attuned to the process of explanation evaluation and exploration, as we will expand on below.

4. Discussion

In everyday life, children sometimes receive weak explanations in response to their questions. But what do children do when they receive weak explanations? According to the deprivation theory of curiosity, if children think that an explanation is unsatisfying, then they should sometimes feel inclined to seek out a better answer to their question to bolster their knowledge; the same is not true for explanations appraised as high in quality. To our knowledge, our research is the first to investigate this theory in regards to children's science learning, examining whether 7- to 10-year-olds are more likely to seek out additional information in response to weak explanation than informative ones in the domain of biology.

In setting up this research, we noted the importance of examining both a) how children perceive individual explanations and b) how they explore in response to individual explanations. Therefore, the first part of our study focused on how children rated a specific kind of weak explanation—a circular one—in comparison to how they rated explanations that provided a mechanism. Given the recent credibility crisis in psychology (see Open Science Collaboration, 2015), we think that it is crucial to place value on research that conceptually replicates past research and then extends it. Consistent with past research (Mills et al., 2017), 7- to 10-year-old children generally assigned lower ratings to circular explanations than mechanistic ones. Crucially, unlike past research, we found this pattern of explanation evaluation in a self-directed exploration context, with children using a novel tablet application that they navigated themselves without interference from adults. This finding, along with the fact that we found significant variability in both how children evaluated explanations and how frequently they explored for more information, supports that a tablet platform is an excellent tool to use in future research examining explanation evaluation and exploration.

In understanding how explanation evaluation relates to interest in learning, it is important to continue to investigate the factors that lead children to successfully evaluate different kinds of scientific explanations. In this study, we focused on manipulating an explanation's circularity, and the explanations were fairly short and easy to follow. For these explanations, we found evidence that vocabulary skills measured by a brief tablet-based measure (the PVT) related to success in detecting circular explanations. This finding is consistent with past research that used a more comprehensive measure of verbal intelligence (Mills et al., 2017). Together, these findings support that verbal intelligence helps children detect that circular explanations are not providing clear answers to questions.

With this age range and paradigm, executive function skills did not clearly link to explanation evaluation. That said, we speculate that the child characteristics that relate to success at explanation evaluation may be somewhat context dependent. In this study, we focused on manipulating an explanation's circularity, and the explanations were fairly short and easy to follow. However, scientific explanations can vary in many other dimensions beyond the degree to which they are circular. For instance, explanations can provide a mechanism that requires topical knowledge to evaluate; in this case, prior knowledge will clearly play a strong role in children's assessments. Explanations can also vary in depth and/or complexity; in this case, executive function skills may play a role in decomposing the explanations into meaningful components to understand, particularly for younger children. Future research is needed to examine the factors that contribute to how children evaluate different kinds of explanations.

The second part of our study moved beyond past research to examine what drove children to seek out additional information in response to the initial question and explanation exchange. We took two approaches to examine these data. Our initial approach focused on comparing the average number of requests for the two types of explanations, finding that children, overall, were more likely to request additional information in response to circular explanations than in response to mechanistic ones. But importantly, we also examined the link between children's own perceptions of individual explanation quality and information seeking, finding that children were more likely to request additional information in response to explanations they rated as weak than explanations they rated as strong. In other words, children's perceptions of weaknesses in explanations predicts the likelihood of engaging in additional learning in response to those explanations.

This evidence supports that children are interested in responding to relative deprivation, as proposed by the deprivation theory of curiosity; they are more likely to seek out additional information in response to explanations that leave them feeling deprived (i.e., to which they have assigned low ratings) than to explanations that leave them feeling reasonably satisfied. Of course, we would be remiss not to mention the challenges determining with certainty at this point that children's information seeking was driven by wanting to resolve a feeling of deprivation than, say, by a desire to maximize information gain (see Ruggeri, Lombrozo, Griffiths, & Xu, 2016). Either motivated by a feeling of deprivation or driven by a calculation of how much they had to gain by clicking for more information, children were more likely to request additional information for weak explanations than stronger ones. That said, given that children and adults often appear satisfied with skeletal explanations (e.g., Keil, 2006; Mills & Keil, 2004), our strong speculation is that, in many cases, the feeling of deprivation drives children's information seeking, and once a child feels suitably satisfied, the child will not feel the need to seek additional information, even if expected information gain is great. But this is a question for future research.

The third part of our study was more exploratory, examining what related to children's patterns of information seeking. We had wondered if children would seek out information indiscriminately unless access to information was somehow restricted: after all, why not just click for more information every time they are asked if there are no costs to doing so? In reality, although children were not boundlessly curious, they sought out more information for about a third of the items, on average, with extensive variability. Only for the youngest age group did information access seem to affect information seeking: when information access was restricted, 7- and 8-year-olds were *less* discriminating in their information seeking, requesting more information about as often for weak explanations as for strong ones. Restriction did not make children less certain about the quality of the explanations (i.e., ratings for circular explanations were not different based on information access) nor make them less likely to seek additional information (i.e., there were no differences in the overall rate of requesting additional information based on information access).

In attempting to understand this finding, we found some previous evidence that 7- and 8-year-olds can be less successful at selective information search when under constraints, like time pressure (Davidson, 1996). Although this past research was focused on how children gather information from multiple sources to make a single decision instead of how children gather information for curiosity's sake, both findings support that younger elementary school-aged children can have trouble directing their attentional resources wisely, particularly when under constraints. These findings imply that we need to be particularly careful to minimize distraction and other possible constraints when young children are engaging in inquiry.

Part of our interest in exploring how children respond to weak explanations is that past research has suggested (but not investigated) significant variability in children's exploration. Here, we took a first pass at exploring possible factors related to (a) the frequency of information seeking and (b) the selectivity of information seeking. In short, though, we found no evidence that age, intelligence, or executive function skills related to either the overall frequency or patterns of selectivity of information seeking. Instead, we found that children who were selective in seeking information in response to their own ratings rated the circular explanations lower than children who were not selective. We believe that children who assigned lower ratings to the circular explanations were more comfortable with the inquiry process; they were better at recognizing objectively weak explanations, better at using the scale to distinguish weak explanations from stronger ones, and more likely to decide that it makes more sense to follow up explanations they thought were weak than explanations they thought were strong. In contrast, children who assigned higher ratings to the circular explanations appeared less well-tuned to explanation quality, leading to an inconsistent relationship between judgments of explanation quality and requests for more information. So some children—for reasons beyond age, intelligence, and executive function skills—are more attuned to explanation quality and the idea that it is more worthwhile to follow up weak explanations than strong ones.

These individual differences in exploration may be partially explained by a domain-general approach to explanation evaluation and follow-up. In adulthood, there appear to be individual differences in what level of detail is considered "sufficient" in an explanation, with some adults preferring detailed explanations and others preferring more shallow ones (Fernbach, Sloman, Louis, & Shube, 2012). Children could vary in how much detail they prefer in explanations, and/or they could have a domain-general preference for a certain kind of explanation that might influence the extent to which they evaluate different kinds of explanations to be acceptable (e.g., explanations that refer to mechanisms—i.e., mechanistic—vs. explanations that refer to purposes—i.e., teleological; see Kelemen & DiYanni, 2005; Lombrozo, 2016; Lombrozo, Bonawitz, & Scalise, 2018). Although there is scant research specifically focused on this issue in childhood, some recent findings support that some children are more interested than others at gathering simple causal information about the functions of novel objects and the characteristics of novel animals (e.g., Alvarez & Booth, 2016). It is possible that children who are generally more interested than others at obtaining basic causal information are also more likely to track whether an explanation has provided a mechanism to address a question, and if not, follow it up.

There may also be domain-specific factors that influence children's explanation evaluation and/or explanation follow-up. For instance, children's assessment of explanation quality may sometimes depend on the strength of their background knowledge for that particular domain. A child with expertise in a certain domain (e.g., space science) may be better at detecting that some information is missing from an explanation relevant to that domain (e.g., an answer to a question regarding phases of the moon) than a child with less expertise. Or a child asking a question about a domain of personal interest may be more driven to a complete answer than a child listening to a question outside of his or her interests. Both prior knowledge and interest may influence how deprived children feel by an explanation and how invested they are in resolving it (see also Mills, 2013).

More broadly, when investigating how children respond to weak explanations, it is worthwhile to note that there are a number of approaches one could take, from classroom-focused intervention projects to field-based museum exploration. Each approach has its own contributions. For this project, we used a self-directed context to examine how children's information gathering may be influenced by their perceptions of the weaknesses of explanations. This context is important, given that the current state of technology provides children with ample opportunities to explore their interests both with and without intervention from others. Yet despite children's increasing access to self-directed avenues of information acquisition, very few studies have examined how children respond in this context, perhaps in part because it is challenging to capture. Here, we designed and successfully used a novel tablet application that allowed children to seek information on their own terms with minimal social pressure from an adult. We found evidence that even when exploring an application on their own, children seek more information for explanations they find to be weak in quality than explanations they find to be satisfactory. Future research should build upon these findings and employ a range of approaches to examine how children respond to weak explanations in order to gain a better sense of the kinds of factors that influence information gathering.

Overall, the research presented here demonstrates that elementary school-aged children can, at times, use their explanation evaluation abilities to determine if the information they have received is sufficient, and they move forward accordingly if it is not. That said, there also appear to be significant individual differences in both how children evaluate explanation quality and how they respond to explanations they perceive to be weak. These findings have important implications for both formal and informal education. In formal education settings, the concept of *learning progressions*—the idea that children should "continuously build on and revise their knowledge and abilities, starting from their curiosity about what they see around them and their initial conceptions about how the world works"—has been integrated into school curricula as a result of the Next Generation Science Standards adopted by the National Research Council (National Research Council, 2012). In informal education settings, caregivers are often bombarded with questions from children, and caregivers can vary drastically in how much information they provide (e.g., Kurkul & Corriveau, 2018). In both settings, it is clear that young children have ideas about science that they must regularly reflect on and modify as they learn and grow, and yet much is still unknown about this process, including how to best understand and respond to individual differences in children's approach to inquiry. Understanding these two abilities in conjunction—the ability to recognize that an explanation is somehow deficient and the ability to seek out additional information to fill the gaps in understanding—is crucial to helping children develop tools to become more effective learners.

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Supporting Information

Additional Supporting Information may be found online in the Supporting Information section at the end of the article:

Data S1. Check questions.

Appendix A: Questions and explanations

Question	Circular	Mechanistic	Detailed Mechanistic
How do pink fairy armadillos use the thin white hair on their underbellies to stay healthy?	Their underbellies have thin white hair that helps them not get sick.	Their thin white hair keeps their bodies from getting too hot or cold.	Pink fairy armadillos live in deserts where temperatures get too hot or too cold. They have thin hair on their underbellies which pushes or pulls heat away from their bodies to keep them at a normal body temperature.
How do colugos use their skin flaps to travel?	Their skin flaps help them to move from one place to another.	Their skin flaps allow them to glide from treetop to treetop.	Colugos have many flaps of skin between their arms, legs, fingers, and tails. Their skin flaps catch the air, allowing them to glide from higher tree branches to lower tree branches and from tree to tree.
How do tarsiers use their huge eyes to stay alive?	Their huge eyes can help them to live a lot longer.	Their huge eyes help them find their food in the dark.	Tarsiers hunt at night when there is less light. Bigger eyes can collect more light, so their big eyes let them see their prey in the dark. Eating this food means they are healthier and live longer.
How do wombats use their backward pouches to keep their babies clean?	Their backward pouches help them keep their babies from getting dirty.	Their backward pouches face their babies away from the dirt wombats dig up.	Wombats have pouches that are backward so that their babies face away from their front paws. That way, they do not cover their babies in dirt while they are digging to burrow underground for shelter and safety.

(continued)

Appendix A. (continued)

Question	Circular	Mechanistic	Detailed Mechanistic
How do thorny dragons use the grooves between their thorns to help them drink water?	Their thorns have grooves that can help them drink water.	Their grooves collect water and send the water to their mouths.	Thorny dragons have grooves between their thorns, which are able to collect water. The water is drawn from groove to groove until it reaches their mouths, so they can suck water from all over their bodies.
How do saiga antelopes use their noses to keep their lungs clean?	Their noses are able to keep their lungs from getting dirty.	Their noses have special filters that stop dirt from reaching their lungs.	Saiga Antelopes travel in herds that kick up dirt and dust into their air. To keep their lungs clean, they have special filters in their noses that stop the dirt and dust from getting into their lungs.
How do mudskippers breathe when there is little air?	They can breathe even when there is not much air around them.	They store a pocket of air inside of them to breathe from.	Mudskippers can live in or outside of water. They carry an air pocket inside of them. They can breathe the oxygen from the air pocket when they cannot get enough oxygen from the air itself.
How do gerenuks get the water they need without drinking?	They do not drink in order to get the water they need.	They get the water they need by eating plants that have water inside.	Gerenuks do not need much water to survive, even though they live in dry places. They get the water they need by eating plants with water in them. So, they do not need to actually drink water.
How do aye-ayes use their fingers to find hidden food?	They can use their fingers to know where their food is hidden.	They tap hollow trees with their finger nails to hear bugs inside.	Aye-ayes use their fingernails to tap on hollow trees. When they tap over where a bug is located, their tapping sounds different. This lets them know where to dig into the tree to find their food.

(continued)

Appendix A. (continued)

Question	Circular	Mechanistic	Detailed Mechanistic
How do streaked tenrecs use their quills to communicate?	Their quills are used to help them communicate with each other.	They rub certain quills together to make different sounds to send messages.	Streaked tenrecs have special quills on their backs that can be rubbed together to make high-pitched noises. They use certain noises to tell other tenrecs about where food is located or if predators are nearby.
How do racket-tailed drongos use their voices to steal food?	They use their voice to help them take food that they can eat.	They copy alarm sounds of animals to scare them and steal their food.	Racket-tailed drongos do not like hunting for their own food. So, drongos will follow other animals and copy those animals' warning calls to scare them away so they can eat the food those animals left behind.
How do yeti crabs' hairy arms keep them safe in poisonous water?	Their hairy arms keep them from getting harmed in poisonous water.	Their hairy arms have helpful germs that clean the water around them.	Yeti crabs live deep in the sea, where it is poisonous. They have hairy arms, which have lots of helpful germs that remove poison from the water around them. This keeps yeti crabs safe from harm.