



ELSEVIER



Explanation-seeking curiosity in childhood

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Children are known for asking ‘why?’ — a query motivated by their desire for explanations. Research suggests that explanation-seeking curiosity (ESC) is triggered by first-person cues (such as novelty or surprise), third-person cues (such as a knowledgeable adults’ surprise or question), and future-oriented cues (such as expectations about information gain or future value). Once triggered, ESC is satisfied by an adequate explanation, typically obtained through causal intervention or question asking, both of which change in efficiency over development. ESC is an important driver of children’s learning because it combines the power of active learning and intrinsic motivation with the value of explanatory content, which can reveal the unobservable and causal structure of the world to support generalizable knowledge.

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Introduction

From early in development, children exhibit curiosity about the properties [1] and names [2–4] of objects, and about visual and auditory patterns [5,6]. Moreover, they often seek *explanations* for their observations, and in so doing construct intuitive theories that equip them to better predict and intervene upon the world [7,8]. Here we focus on children’s ‘explanation-seeking curiosity’ (ESC), which we define as an affective drive state [9] that motivates learning *how* or *why* something is the case [10]. We review recent research addressing two questions: (1) What triggers ESC? And (2) How is ESC satisfied?

Our focus on ESC complements two existing bodies of research. First, research has considered the epistemic power of explanations. Seeking explanations supports learning in young children [10,11], and explanations can drive subsequent exploration [12] and improve

metacognition [13]. For example, when prompted to generate explanations (versus report observations) while learning novel causal rules, preschoolers are more likely to learn causal rules that are broad [14], are simple [15], and emphasize internal properties over perceptual similarity [16]; when prompted to explain aspects of a story, 5-year-olds to 6-year-olds are more likely to extract its lesson [17]. However, this research has rarely focused on ESC — the drive state that prompts explanation search.

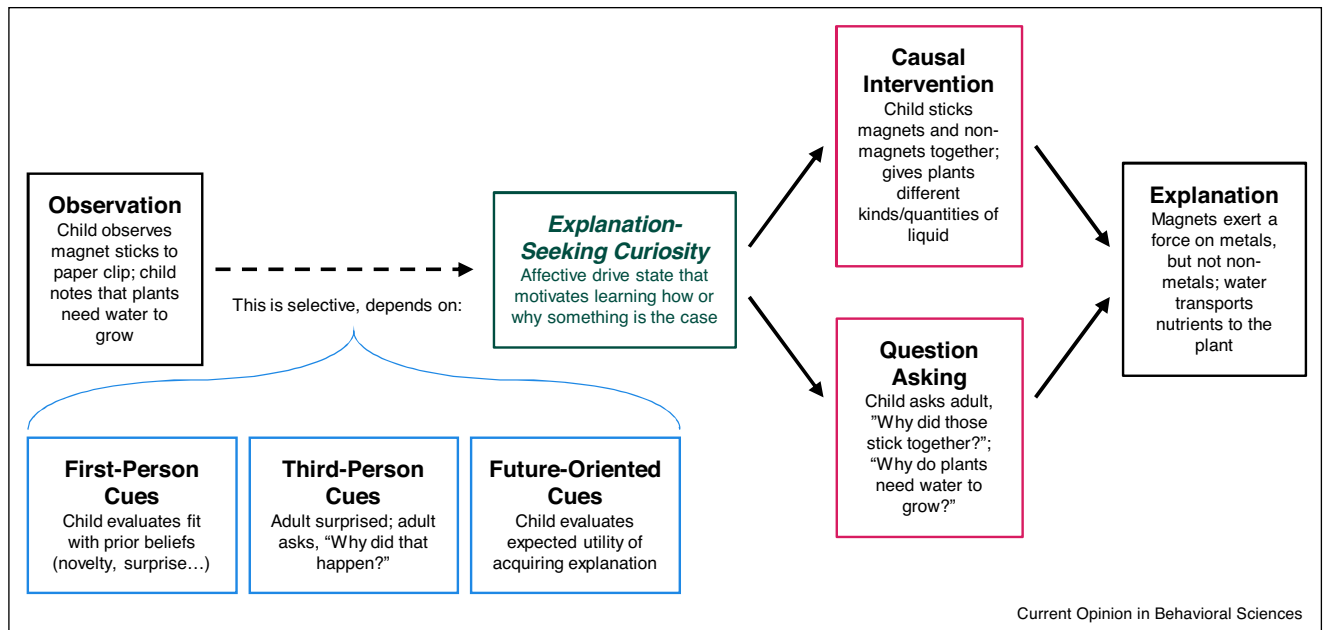
Second, research on curiosity (including developmental prerequisites to experiencing and expressing curiosity [18,19]) has been pursued in many contexts, including active word learning [3] and question asking [20]. Among other benefits [21,22], there is evidence that curiosity-driven exploration can be as efficient as direct pedagogy for causal learning [23] and lead to better memory for target information [24–29], and that exploration efficiency relates to IQ in young children [30]. However, this work has typically focused on curiosity directed towards non-explanatory targets, such as facts, object labels, or object properties.

Given the epistemic power of explanation and the learning benefits of curiosity, ESC is poised to be an especially important driver of children’s learning. While it is yet unclear precisely how ESC diverges from other forms of curiosity [31,32] or fits into existing taxonomies for curiosity [e.g. Ref. 33], ESC is unique in its ability to drive the discovery of *unobservables* and *causal structure* — important foundations for generalizable knowledge. For these reasons, the study of ESC is likely to lead to important insights about how (young) human learners come to know so much about the world given limited evidence, time, and cognitive resources, with potential implications for education and for the development of artificial learners [34,35], as well.

What triggers explanation-seeking curiosity?

Children encounter far more unexplained observations than they have the time or resources to pursue as targets of inquiry. In fact, there is evidence that merely lacking information is insufficient to trigger information search: in one study, 5-year-olds to 9-year-olds explored following some types of underinformative evidence, but not others (though this may in part stem from a developing capacity to recognize whether evidence is informative) [36]. Thus, both theoretically and perhaps empirically, we have reason to believe that ESC is selective, and that additional cues make some unexplained observations call out for explanation more strongly than others [37,38]. We review three categories of cues: first-person cues, third-person cues, and future-oriented cues (Figure 1). The evidence

Figure 1



Model of explanation-seeking curiosity, including cues that trigger it (first-person cues, third-person cues, and future-oriented cues), and two methods by which it is satisfied (causal intervention and question asking).

for these cues comes from studies of ESC as well as studies of curiosity more broadly; we discuss the potentially unique triggers of ESC in the Conclusions section.

First-person cues

First-person cues, such as surprise and novelty [39], are those that relate unexplained information to an individual's epistemic state. We refer to these cues as first-person because observations are not intrinsically surprising or novel; they are surprising or novel with respect to a set of expectations or prior experiences. Indeed, recent research has clarified the first-personal (subjective) nature of these cues. Infants preferentially explore objects that violate their expectations, whether those expectations are formed on the basis of core knowledge [27], inferred rules [40], or probabilistic information [41,42]. Furthermore, infants' exploration after an expectation violation may be specifically geared towards uncovering an explanation for that violation [43].

One proposal is that curiosity is piqued not by maximally surprising or novel information, which may be too far beyond a learner's grasp, but by *moderately* surprising or novel information, which presents the best opportunity for learning [44]. Infants preferentially direct their visual attention to patterns that are moderately predictable [5, see also Ref. 6]. However, this 'moderate information gap' hypothesis has been studied primarily in adult populations [e.g. Ref. 45], and has not been applied to ESC.

Third-person cues

Third-person cues rely on social information from others. For example, infants use others' surprised expressions to guide visual exploration [46], and preschoolers spend more time exploring a novel toy after viewing an experimenter's surprised expression while playing with it [47]. Adults can also highlight information through the use of *pedagogical questions*: questions with answers that are known to the asker, but posed to facilitate learning [48]. After a pedagogical question from a knowledgeable teacher, children spend more time playing with a novel toy and discover more of its functions [49]. However, relying on knowledgeable others can also suppress exploration — direct pedagogy decreases preschoolers' exploration and learning of non-target information [50], and preschoolers (though not elementary schoolers) forgo exploration of counterintuitive claims offered by reliable sources [51].

Future-oriented cues

Future-oriented cues concern expectations about how acquiring information will serve the learner in the future. In one task, 4-year-olds to 5-year-olds were more likely to explore unknown rewards over known rewards only when the unknown rewards would inform future choices [52]. While this could be explained by reward-seeking behavior (and not curiosity), there is evidence that 4-year-olds to 5-year-olds explore a causal system more than older children and adults, but fail to efficiently exploit their knowledge to gain rewards (EG Liquin *et al.*, unpublished) [see also 53–55]. These findings cast doubt on reward pursuit as

the sole motivation behind children's future-oriented exploration. Furthermore, children sometimes pursue information that may be relevant for future action even when this information will not impact immediate reward: in one study, children displayed greater curiosity about counterfactual outcomes that were under their control, relative to outcomes they could not have caused [56**].

Future-oriented cues are in tension with approaches that define curiosity as the pursuit of information as an end in itself [e.g. Ref. 44]. In fact, in both adults [57] and non-human animals [58], curiosity has been operationalized as costly information-seeking without immediate benefit. We propose that curiosity is defined by the phenomenological *experience* of pursuing information for its own sake, even in cases where the psychological *function* of this experience is instrumental. The willingness to pursue information with no immediate benefit is good evidence that such a phenomenology is present. However, adults report experiencing curiosity even when instrumental goals are at play, and this reported curiosity is in part guided by the future utility of information [31**,59–61]. Our model predicts the same for young children (and potentially for many non-human animals), but direct evidence for this claim will require moving away from paradigms that rely on exploration as an index of curiosity, and towards paradigms that more directly measure the phenomenology of curiosity.

How is explanation-seeking curiosity satisfied?

ESC can be satisfied when the child acquires what they judge to be an adequate explanation. Children prefer explanations that are simple [62] and general [63*], and that contain a moderate amount of detail [64] that is explanatorily relevant [65,66*]. Children also prefer teleological explanations (which appeal to function or purpose) [67,68] and explanations that appeal to properties inherent to the thing being explained [69], though these preferences decrease across development. When children receive a non-explanatory response rather than an explanatory response, they are more likely to re-ask their original question [70] (though children's reactions to explanatory and non-explanatory responses are moderated by socio-economic status [71,72] and age [73]). The perceived quality of a provided explanation predicts subsequent explanation-seeking behavior, as well [74**].

Often, children are not simply offered an explanation, but must solicit an explanation, reason their way to one, or discover one for themselves. Children have many tools for eliciting information — such as pointing [4,75–77] and social referencing [78] — but these are unlikely to elicit specifically explanatory information. *Causal intervention* and *question asking*, by contrast, are likely to be especially useful for the pursuit of explanations because they allow the learner to infer causal relations [79,80] and inquire about unobservable entities [81] (Figure 1).

Causal intervention

Effective causal intervention in pursuit of explanations relies on the ability to perform informative experiments: typically, interventions that isolate a single causal variable and control confounds. Early research suggested that children's ability to design informative experiments is limited until adolescence [82], but recent research has demonstrated that preschool-aged children choose interventions that disambiguate causal structure [83], use conjectured explanations to inform their later exploration [84], and selectively deploy different exploratory actions based on their relative informativeness for the task [85*]. Older children selectively deviate from controlled experiments in contexts where testing multiple variables at once is more efficient [86]. In more complex tasks, however, 3-year-olds to 6-year-olds fail to spontaneously create disambiguating interventions after receiving evidence that disconfirms their expectations [87]. Instead, they use intervention strategies like the 'positive test strategy,' which privileges positive evidence consistent with a single target hypothesis [87–89]. However, some have argued that a positive test strategy could be quite useful in some contexts [90] or given particular learning goals [91].

Question asking

Causal intervention is not appropriate in all circumstances; unobservable entities (e.g. germs) and inaccessible entities (e.g. the moon) cannot be readily manipulated, and thus question asking may be the only way for children to learn about explanations involving these entities. Indeed, by the age of six, children ask fact-seeking questions about unobservable entities but directly explore observable entities [92].

Children begin asking questions before the age of two, and the proportion of questions that are explanation-seeking increases with development, peaking around age three [93]. While children begin to direct questions to appropriate sources in preschool [20*,52,94], children's ability to ask maximally informative questions to solve a specified problem continues to develop during the preschool years and beyond. In one set of studies [95], 3-year-old to 5-year-old children were asked to identify the most informative question to discover the explanation for an event. With increasing proficiency with age, children preferred questions that targeted an individual explanation when that explanation was more likely than others, but chose questions that eliminated several candidate explanations when all were equally likely. Other studies using similar methods have also shown age-related improvements in question-asking efficiency [96–98, but see Ref. 99], and that question efficiency can be influenced by certain structural supports [96].

To summarize, children use both causal intervention and question asking to seek explanations, with both strategies improving in efficiency over the preschool and early

elementary school years, and with the former continuing to develop through adolescence. Additional research will be required to link these exploratory behaviors to the drive states that motivate them over development, and to identify whether and when these behaviors are triggered by first-person, third-person, or future-oriented cues. For example, in tasks that involve seeking rewards, there are age-related changes in the extent to which exploration is random (the result of decision noise) or systematic (directed towards uncertainty) [54,100], and in tasks that involve learning about categories, children direct their exploration differently from adults [101]. Future research is needed to determine how and why exploration that is motivated by curiosity and directed at acquiring explanations changes (in quantity or in nature) across development.

Conclusions

Combining the motivational drive of curiosity with the epistemic power of explanations, explanation-seeking curiosity is likely to be an important driver of children's learning, especially when it comes to the unobservable and causal structure of the world captured by intuitive theories. We reviewed evidence that very young children are selective in their ESC and preferentially seek explanations when cued by first-person cues, third-person cues, and future-oriented cues. Children's ability to seek explanations also develops, with causal intervention and question asking playing critical roles.

While much of our analysis is based on studies of actual learners, many of the papers we review argue that fully rational learners *should* explore when a relevant cue is present, or that exploration *should* be pursued in a particular way to resolve uncertainty, typically using Bayesian approaches. Bayesian models have provided a powerful method for understanding active learning in development, but additional questions arise when combining these individual analyses into a single model: How should a rational learner weigh competing cues to curiosity against each other? How should a rational learner choose between question asking, causal intervention, and other available behaviors? And how do actual learners navigate these problems? Answering these questions will require building more complex models, designing more sophisticated experiments, and better characterizing children's exploration in real-world environments [78,94,102–105,106*,107]. Ultimately, however, these efforts will improve our understanding of learning throughout the lifespan.

Future research may also provide insight into whether and how we should expect ESC to diverge from other forms of curiosity. Explanation search often involves consultation with and deference to experts [108,109], suggesting third-person cues may be especially powerful in triggering ESC. Additionally, the future-oriented cues that trigger ESC may focus on unique criteria — for example, how likely it is that the received information will constitute a 'good'

explanation [31**]. Finally, satisfaction methods may differ: for example, causal intervention is more likely than pointing to elicit explanatory information.

Lastly, research on decision making under risk [110] and on how costs are weighed against the benefits of information gain [53–55,111] will shed light on when we can expect children to pursue their curiosity. With adults, it has been proposed that information is itself rewarding, and that curiosity motivates learners to obtain this reward [112–114]. In settings where children are more exploratory than adults [53–55], do children find information more rewarding than adults, or are the costs associated with exploration less steep for young learners? If explanatory information is indeed especially powerful for learning, do learners find the satisfaction of ESC especially rewarding, and correspondingly experience stronger curiosity towards explanatory targets?

Despite these open questions, recent research has dramatically deepened our understanding of children's ESC. Through question asking and exploration, children actively pursue information that helps them make sense of the world, and they do so with increasing proficiency over the course of development. Motivated by explanation-seeking curiosity, children come to know not just *what* events and phenomena they can expect to encounter, but *why* such events and phenomena occur — providing a powerful means for prediction, intervention, and understanding.

Conflict of interest statement

Nothing declared.

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