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Review article

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Curiosity in children across ages and contexts

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Abstract

Curiosity is a universal characteristic of childhood that can motivate and direct attention during information-seeking to support knowledge development. Understanding the development of curiosity could inform practical applications to support children's curiosity and learning across contexts, such as fostering curiosity-supportive environments at home and in schools. In this Review, we focus on the state component of curiosity, defined as information-seeking behaviour that is internally motivated in response to a specific question or gap in knowledge. We synthesize research on children's curiosity, considering the distinction between internal and external curiosity and variation in curiosity across ages and contexts. On the basis of this research, we suggest several areas for future research.

Sections

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Introduction

"Does my body have gravity?" asked a 5-year-old child after she sat quietly for some time thinking. This question demonstrates the power of children's curiosity for developing an understanding of the world. Although this child had not yet had formal education about gravity, she had asked prior questions such as why things fall to the ground and why people float in space that introduced her to the concept of gravity. Subsequent related questions and answers over time, such as what causes gravity, led to an understanding that she could then build on to wonder about the possibility of her body having gravity simply for the sake of knowing it. Children's curiosity helps explain how even very young children can navigate their way through a novel world.

Developmental scientists often ask how certain adult characteristics come to develop over time, but curiosity is different in that it is often seen as ubiquitous in children[1,2]. There is clear evidence of curiosity from infancy through adolescence, sometimes conceptualized broadly as a 'need to know'[3,4] or defined specifically as the desire to fill a knowledge gap or inconsistency[5]. Although there is general consistency in how adults in the general public define curiosity[6], researchers disagree on whether enough is known about the cognitive and neural processes involved to support a single, universal definition of curiosity or whether researchers should focus on motivations of information-seeking more generally[7,8].

Curiosity in children needs to be clearly operationalized to identify causal associations and mechanisms in order to understand the benefits of curiosity for learning and well-being[9–12] (Box 1) and to inform interventions. Definitions are critical when considering mechanisms for manipulating curiosity[13,14] (Box 2) and identifying what is and is not curiosity across contexts. Curiosity involves internal information processing that is not easily observable[15] and which does not always lead to externally observable information-seeking. The child above likely spent several minutes quietly thinking or searching for information internally, putting together what she had learned and observed previously, which led to the observable behaviour of asking a question to seek information. Furthermore, curiosity can vary across contexts, ages or cultural backgrounds. For example, an older child might use Google to find desired information rather than asking an adult, or they might not externally express curiosity in school because they do not have the quiet mental space to reflect and think of a relevant question. Understanding curiosity in children requires considering all these facets of the phenomenon.

In this Review, we synthesize research on children's curiosity to develop a more comprehensive and ecologically applicable understanding of curiosity. We focus on curiosity as a state, operationalized as involving an instance of information-seeking behaviour[16,17] that is intrinsically motivated and seeks specific information[18]. We first describe our reasoning behind this operationalization and then review how curiosity is expressed in children and the related processes involved in curiosity. We then detail variability in curiosity across childhood and across contexts and the importance of considering cultural and contextual variability. Finally, we outline recommendations for future research.

Defining curiosity

One approach to defining curiosity is to consider how it manifests in observable behaviour. Many behaviours, such as questioning and

Box 1 | Benefits of being curious

Curiosity can motivate children to actively seek out knowledge and explore new information. It has specific positive impacts on learning[5,67,138] and is associated with greater learning from the same types and a lower dosage of exploration[63]. Positive associations between children's curiosity and academic learning suggest the importance of promoting curiosity, especially for children in more academically vulnerable groups[9]. Promoting curiosity in children can have long-lasting effects[11] and the ways that curiosity can support learning can differ across development[67]. Curiosity directs learning-related behaviour through intrinsic motivation rather than extrinsic reward[14], which can be more effective for learning[139] and might support learning in several ways.

Children who are curious are more likely to attend to information that is most relevant for what they are curious about[101]. In adults, there are signs of the benefit of curiosity extending to unrelated information received while curious (incidental learning[58,140]). When people report being more curious about a question, they are more likely to open an envelope to get the answer to that question[31,54]. Children are also likely to perceive information more effectively while curious because they can more easily evaluate and make sense of it. For example, children who explored more uncertainty in an exploration game (exhibiting higher curiosity) were better able to identify whether questions would be helpful or not helpful in solving a mystery[23]. Similarly, when children reported more curiosity after playing an information-seeking game, they were more likely to remember information explored during the game[65].

Working memory and prior knowledge also interact with curiosity and its benefits. When a child becomes curious, they identify a specific gap in their existing knowledge and actively think about what information is needed and how to get it, which will guide attention to the information and how to make sense of it. For example, despite exploration being similar between children with lower and higher curiosity in museum and laboratory settings, children with higher curiosity learned more from the exploration[63,114].

Several studies demonstrate general benefits of curiosity for memory and learning[11,65,67,138,140]. These benefits extend to positive associations between curiosity and academic achievement, including at school entry[9]. These effects might be explained by enhanced encoding of information when curious[5], such as by making connections to prior knowledge and experiencing the information in a meaningful way[37,101]. From a metacognitive perspective, effective monitoring can promote optimal control strategies, resulting in boosts in subsequent performance[141]. Prior research also shows consistent impacts of positive emotion on learning, including links between enjoying school and learning[142,143] and between positive affect and broadening thinking when faced with a problem, and thinking objectively[144]. For instance, one study found that enjoyment for learning predicts achievements from preschool to kindergarten[142]. Curiosity can promote greater enjoyment of learning[145]; reciprocal effects between learning and curiosity[146] are similar to those seen with positive affect and learning (see also the broaden and build theory)[144], suggesting the value of promoting curiosity.

Box 2 | Promoting curiosity

A first step in supporting the continuous positive development of curiosity is to understand how to promote curiosity. Effective methods related to momentary curiosity have been presented in the literature. Methods such as generating uncertainty by presenting blurred images[147], including ambiguous causal information[66], creating surprise[148] or modelling curiosity[149] are successful in inducing state curiosity.

Going beyond momentary manipulations, researchers have used similar methods to promote curiosity during school physics lessons[13]. Students aged 12–14 years were randomly assigned to either a low-uncertainty or high-uncertainty condition, manipulated by how much instruction was provided in video introductions to invention activities, such as including example physics formulas and problem-solving tips. After the invention activities, all students received direct instruction on the physics content. The researchers found that the high-uncertainty condition elicited higher curiosity, but only for the first day of the 5-day lesson sequence[13].

Curiosity promotion might need to come from a broader shift in classroom culture and climate, such as the everyday practices teachers use[37]. For example, teachers can model curiosity, provide opportunities for students to act on curiosity, elicit different perspectives and ideas, have students generate questions they are curious about and provide scaffolding to support information-seeking[37]. However, at least in the United States, these practices do not seem to occur very frequently in elementary schools[135] or preschools[136].

Interventions have tested whether it is possible to promote curiosity in school contexts by promoting a climate shift in teachers. In one study, hundreds of children (aged 9–12) across six schools participated in a study in which schools were assigned to either an intervention, control or reference group[150]. The intervention involved a 6-month attitude-focused professional development programme to promote teachers' positive attitudes about inquiry learning and teaching and a 3-month training on including inquiry focus and promoting curiosity[150]. The intervention improved teachers'[151] and students'[150] attitudes about curiosity between pre and post intervention.

Another study was conducted with two large cohorts of children (aged 8–9 years) across 134 primary schools during the 2018–2019 (first cohort) and 2021–2022 (second cohort) school years[152]. Teachers in schools that were randomly assigned to the intervention group received a toolkit about curiosity and were trained to promote student questioning and challenging of ideas, seeking of evidence and open expression of interests during class. The researchers collected students' test scores, educational aspirations and curiosity, with longitudinal outcomes assessed for schools in the first cohort. Curiosity was assessed with a 'willingness to pay' measure in which children indicated the highest amount of tokens they would pay for information from books selected from their interests. Children who received the curiosity-promoting intervention were willing to pay more tokens and retained more information from the books, with retention persisting over time. Benefits of the intervention were also observed on the school science tests and persisted after school closures during the COVID-19 pandemic. Finally, there was some indication that children in the intervention group reported having higher aspirations than children in the control group to pursue science majors in university.

The breadth of these interventions across time and contexts are valuable steps towards understanding the nature of curiosity and how to promote it. Developing students' interests and connection to what they are learning is another promising approach[153]. We caution researchers to have full confidence in their methods of intervention before intervening in educational practice and strongly recommend that researchers partner with educators to understand the most beneficial and achievable methods for incorporating curiosity-promoting practices in classrooms.

exploring, seem to be curiosity but can have other motivations, such as needing clarification or trying to solve a problem. Clearly disentangling what types of information-seeking are curiosity will further understanding of the development of curiosity and its influence on learning and inform targeted interventions[1]. This process is a challenge owing to the complexity and multidimensionality of curiosity[7]. Here we focus on epistemic-focused curiosity, which involves seeking information, rather than more shallow perceptual curiosity, which is characterized by seeking sensory stimulation[19,20]. In addition, we discuss curiosity as a state, but there is also a trait component that can influence the general likelihood of children becoming curious[1] (Box 3).

Whereas most information-seeking can lead to information gain, curiosity-related information-seeking typically leads to more robust learning and rewards (for example, information as a reward, the process of exploring as a reward and the associated neural responses such as dopaminergic processes[5,8,21]) than other types of information-seeking These differences are similar to differences observed among other types of motivational impact on learning[22]. Curiosity tends to be studied as the resulting behaviour rather than internal thoughts or factors that lead to decisions to act. For example, researchers record children's questioning or exploration behaviours[23], or parents report on observed behaviours by endorsing statements such as 'My child enjoys talking about topics that are new to him/her'[24]. Studies that focus on the purely cognitive or purely observable behaviour aspects of curiosity often underspecify what distinguishes curiosity from other cognitive processes and information-seeking. For example, prior research does not always differentiate whether information-seeking is curiosity-driven (rather than motivated by other goals)[19,25,26], nor does it control for factors that are usually present and influence motivations in competition with curiosity[27–29]. For example, children's goals in different contexts can influence whether they become curious, as we discuss further below.

Specific criteria that can be used to identify information-seeking that is indicative of curiosity are proposed in the following sections, as well as overlapping characteristics between curiosity and several other constructs that necessitate the proposed criteria. Several methods of measuring curiosity in alignment to the proposed characteristics are also presented.

Operationalizing curiosity

There are some similarities across prior definitions of curiosity but a lack of consistency and specificity, which presents challenges in

Box 3 | Trait curiosity

Trait-based theories describe curiosity as a stable characteristic of having a general propensity to be driven by the desire to resolve uncertainty[12]. This definition differs from state-based curiosity: the in-the-moment experience of wanting to know something in relation to a knowledge gap or specific uncertainty[12]. Higher state curiosity in children is indicated by a higher intensity or duration of curiosity experienced[1], whereas higher trait curiosity could be a higher frequency of seeking information or a higher preference for uncertainty to explore[1]. In adults, research suggests that 'openness to experience', as measured by the Big 5 personality assessment, is associated with trait curiosity[154], although this has not been examined with children.

Trait curiosity and state curiosity are interdependent and associated with information-seeking behaviour and learning. Influences of trait curiosity are underexplored, but are likely to include a range of personality-related factors (for example, risk-taking and sensation-seeking[155]) and experiential factors (such as having comfort with uncertainty and experiencing support or hinderance during exploration[37]). Adults and children who have higher trait curiosity should be more likely to experience state curiosity across contexts. However, state curiosity is also influenced by factors including components of motivation (such as goals, perceived value and interest)[156]. Furthermore, state curiosity is influenced by physical context and how individual characteristics interact with the context[121]. For instance, a child might respond differently to feeling curious when in a chaotic versus calm context, or a child might avoid exploration in a classroom context for fear of getting into trouble with their teacher[157].

The relations among trait curiosity, state curiosity and learning are likely to be cyclical. Trait curiosity can lead children to notice things to become curious about in the moment, and this state curiosity can induce information-seeking to resolve the uncertainty that sparked the state curiosity[101]. Information-seeking can promote both state and trait curiosity. State curiosity-related information-seeking can lead to learning, which can promote recognition of new knowledge gaps one can become curious about (state curiosity)[146,157]. Information-seeking can also result in feedback and development of information skills, fostering greater comfort with and willingness to seek out larger knowledge gaps in the future (trait curiosity)[37,81].

generalizing results across studies. Often, the definitions used in conceptual papers are not operationalized in a way that enables their use in measuring curiosity in empirical work, and empirical studies use broad measures that miss one or more important characteristics of curiosity. To refine and clarify existing definitions in the literature, we provide three criteria for determining whether internal cognition or external behaviour is curiosity. First, we posit that curiosity as a state involves information-seeking behaviour[16,30]. This criterion diverges from early theories of curiosity that suggest that curiosity is a need or desire[31]. Thus, a fleeting feeling of wondering or a state of not knowing some information that does not lead to further thought or seeking the information would not be curiosity. The challenge in this criterion is recognizing mental information-seeking, which we discuss further below. Second, we posit that the information-seeking aspect of curiosity must arise from an internal desire for information[15,30,32,33]. For example, a child who is given a toy and told to figure out how it works would not be demonstrating intrinsically motivated information-seeking, and therefore not curiosity, if they explore the toy purely as a response to the instructions they were given and not with an internal desire to learn about it. Third, to distinguish curiosity from sensation-seeking, boredom or a more general interest (Box 4), we posit that the information sought should be specific and related to something a child wants to know in a given moment[18]. For example, curiosity is expressed when a child asks what will happen if they drop a toy, what something tastes like or whether their favourite animal lives in the desert. A child choosing to read a book about a topic they are interested in without the goal of learning something specific is information-seeking, but this is more interest than curiosity[34]. Although not part of our definition, we also consider curiosity to relate to positive affect[35], especially in children, although curiosity is sometimes also measured as feelings of deprivation related to knowledge gaps (Box 5).

These three criteria are presented to define curiosity, but there are many factors beyond the scope of this Review that influence curiosity (or one's likelihood to become curious or to express curiosity). These factors include beliefs about one's ability to attain the desired information and the value placed on it[36], goals one holds in the moment and the context one is in[37], and the utility or cost of seeking information[16].

Metacognition and curiosity

It can be challenging to distinguish curiosity from other constructs that are closely related to it and each other, such as interest (Box 4), metacognition, open-mindedness, creativity and critical thinking (Fig. 1). These shared features and associations span behavioural, cognitive and emotional factors. For example, several epistemic emotions (including curiosity, surprise and boredom) lead to information-seeking but have different triggers, and the resulting actions taken can differ in type, such as changing behaviour or becoming absorbed, and intensity or arousal level[38]. The exploratory systems of curiosity develop in a way that supports continuous and evolving discovery[39]. This natural and universal quality of curiosity enables it to be disassociated from metacognition, which typically refers to processes that require some amount of conscious decision-making[40–42]. However, curiosity has also been characterized as a metacognitive feeling[15,43] because it involves the two stages of metacognition: monitoring, or the assessment of what one knows; and control, the selected behaviours that enable the individual to seek more information[44]. In curiosity, these stages correspond to first identifying gaps in one's knowledge and then exploring to seek the information that one is curious to know.

Just as not all information-seeking is curiosity, not all metacognition is curiosity. Yet research on metacognition could suggest methods for understanding the internal processes involved in curiosity as they relate to classic metacognitive frameworks[15,45,46]. For example, after metacognitive monitoring enables an individual to assess their ongoing learning, control enables them to select the appropriate behaviours to fill in any gaps in their learning. Whereas curiosity has been more commonly defined and measured by observable information-seeking, the metacognitive literature has spent decades of research investigating the more invisible types of control strategy, such as searching in the mind for a target[47], quiet persistence on a task[48,49] or scheduling how or when to seek more information[50,51]. This search has led to a thorough understanding of metacognition in children, although this research also faces the challenges of measuring internal processes in young children[52]. Similar to curiosity, metacognition is probably not unidimensional and is not likely to follow a linear developmental

path[53]. An individual's information-seeking behaviours might change with different types of judged gaps in knowledge — simply not knowing a fact might be insufficient to instigate an observable curious act to seek information, but not knowing a fact and being in a tip-of-the-tongue state tends to be a powerful stimulant for curiosity-related information-seeking behaviours[31,54]. Furthermore, similar to curiosity, the development of metacognition is heavily influenced by many different social influences[55]. Thus, metacognition is important for curiosity, and what is known about metacognition in children might inform the understanding of children's curiosity. However, just as not all information-seeking is curiosity, metacognitive awareness of a knowledge gap will not always result in curiosity, and curiosity goes beyond metacognition, further demonstrating the need for precision in defining and operationalizing curiosity.

Measuring curiosity

Measures of curiosity mostly fall into two types: self-ratings and observations of information-seeking (Table 1). The internal aspect of curiosity makes it challenging to observe and particularly challenging to assess in children, who have more limited ability to use methods of assessing cognition, such as think-aloud protocols. Adult research has long used survey measures for self-assessed curiosity, including internal curiosity, and surveys are now shown to be reliable with children[56]. Self-ratings include asking people to rate how curious they are about something with a Likert-style scale — akin to a metacognitive monitoring judgement — or surveys with questions about the frequency of expressing curiosity[54,57,58]. Self-ratings can be an effective way to assess internal curiosity because they can focus on the cognitive aspect of an intrinsic desire to know something specific[59]. Self-ratings of curiosity tend to positively relate to information-seeking behaviour when both are measured in the same participants[54]. Young children can reliably self-report their academic orientations, such as school enjoyment and growth mindset, according to one study[56], but a reliable and validated self-report survey measure of children's curiosity does not yet exist.

Careful design is needed to focus measures on internal curiosity. For example, self-report measures include items such as 'when I don't know something, it makes me want to learn more' to determine the cognitive aspect of curiosity within children rather than behaviour[56,60]. The use of simplified or graphical scales and audio can make it possible for even young children to self-report[60] (Fig. 2a). Self-report measures can also be used to assess external curiosity. Self-report questions can ask about information-seeking behaviour (such as 'I love exploring new and different')[61,62]. Related measures are aimed at parents, asking them to report on their children's curiosity[24] .

Young children's curiosity can also be measured by observing information-seeking behaviour, which involves the challenge of determining whether the observed behaviour is intrinsically motivated. For example, some studies ask children to accomplish specific goals, such as discovering information about a specific variable[63] or for a reward such as earning stars[64], without knowing whether the child is intrinsically motivated to do so. The ideal alternative would be to observe natural behaviour while a child discovers something based on their own curiosity, but this is a challenging task to present in a controlled and consistent way[29]. The former type of observation might capture something entirely other than curiosity, such as problem-solving ability or causal reasoning unrelated to curiosity.

Measures of exploration require observable behaviour and therefore can assess only external curiosity. For example, in the free exploration task, children click on shapes on a computer screen to hear facts about different topics (Fig. 2b). When they click the same shape again, they hear more about the same topic[65]. There is no external goal for this task, so children's exploration can be assumed to be intrinsically motivated for the sake of gaining information about the different topics. Removing extrinsic goals makes it possible to assume intrinsic motivation, but it can still be unclear why children make the specific choices they do. Another way to explore children's motivations is to limit the choices they have to assess their preferences or priorities. In forced-choice paradigms (Fig. 2c), children are given the choice between alternatives that might differ in the amount of uncertainty about what that choice will lead to[23] or between novel or familiar toys to explore[66]. By observing the choice made, it is possible to assess their preference levels for uncertainty or novelty.

Although new methods are continuously being developed[60], they still have limitations and are in need of further validation. In addition to self-reports and observations of information-seeking, biophysical measures can measure physiological markers during behavioural information-seeking or markers of cognition without observable behaviour. Biophysical measures include devices such as eye trackers to assess gaze, blink rates or pupil dilation[67], which can provide insight

Box 4 | Interest

The distinction between curiosity and interest is a contemporary topic of debate in the literature[158] (see ref. 156 for a special issue on the topic that provides important perspectives on the overlap and distinctions). One challenge in distinguishing between curiosity and interest is that they are likely to be reciprocal. If someone is seeking information out of interest, they might come up with a specific curiosity they want to explore, and curiosity-driven information-seeking might lead to interest in a topic[34]. Thus, children's curiosity can foster the development of a specific interest, and children with a developed interest are prone to generating questions fuelled by curiosity[18].

However, distinct goals of interest and curiosity have been posited[153]. Seeking information in relation to a specific knowledge gap is classified as curiosity, whereas an ongoing desire for understanding is typically classified as interest. There are also specific triggers of curiosity, often related to an experience that creates or draws attention to something a child wants to know. By contrast, interest has broader and more varied triggers. These triggers relate to the knowledge state difference, with curiosity associated with a moderate or optimal level of knowledge that is more fleeting, whereas interest seems unrelated to knowledge level and is more sustained[153]. Importantly, most researchers agree that both curiosity and interest are intrinsically motivated and involve positive affect (Box 5). However, several researchers suggest that curiosity also includes an initial discomfort or tension at the initial point of the trigger causing cognitive conflict[153,159–161], which is typically expected to be followed by a positive, rewarding experience through seeking information[6,160,162]. In our view, the positive affective experience related to curiosity is an important similarity between curiosity and interest in children. Thus, curiosity and interest motivate and direct children's attention and support their learning experiences, rather than focusing on reducing unpleasant feelings[101,144,159]. From this perspective, curiosity experienced as feelings of discomfort or deprivation might be maladaptive for learning.

Box 5 | Curiosity as a positive affective experience

We consider children's curiosity to be experienced as affectively positive[35]. However, several theories suggest that curiosity results from feelings of discomfort related to missing information or a knowledge gap[31,163,164]. Multidimensional models of curiosity suggest a specific deprivation type of curiosity in addition to 'interest curiosity' or 'joyous exploration', which are associated with more positive affective experiences[57,165]. Deprivation type and interest curiosity seem to have different neural signatures[166,167]. Data from a parent-report measure developed for children's interest and deprivation curiosity suggest that these two constructs are very highly related yet distinguishable aspects of children's curiosity[24].

Positively experienced curiosity is positively related to information-seeking behaviour, happiness, confidence in problem-solving, knowledge and accuracy, and discernment and open-mindedness[14,168,169]. Positive affective experiences are generally expected to lead to broader cognition and learning in future experiences[170] and have been empirically shown to support learning in children. For example, in a study of older children that experimentally manipulated uncertainty to influence curiosity and affect, positive — but not negative — affect was related to learning[171]. Thus, to understand curiosity as a way of promoting positive development in children, especially related to learning and building an understanding of their world, we define it in line with researchers who conceptualize curiosity as a positive epistemic emotion[32,35].

Despite the consistent support for interest curiosity and deprivation curiosity as distinct constructs, deprivation curiosity or curiosity motivated by discomfort or negative affect might conceptually conflict with the operationalization of curiosity we presented (as information-seeking that is intrinsically motivated and involves a specific desire for information). Specifically, we are interested in curiosity that leads to information gain, rather than a reduction in negative feelings of deprivation. Prior studies find that interest and deprivation curiosity relate to characteristics that can be maladaptive in the case of deprivation curiosity and productive in the case of interest curiosity. For example, deprivation curiosity has been positively related to a lack of intellectual humility and higher susceptibility to misinformation, errors and confusion, and indecisiveness and distractibility in adults[168,172]. These characteristics highlight reducing unpleasant feelings in shallow ways that do not lead to information gain, as opposed to the desire for truth and information. In another study, curiosity experienced in the more positive ways related to mastery-oriented children's learning, whereas curiosity experienced as deprivation was related to failure avoidance and success orientation[165]. Furthermore, when uncertainty is related to negative affect it is not associated with students' self-ratings of their curiosity in the moment, but enjoyment is generally related to both curiosity and situational interest[173].

into individuals' cognitive information search strategies[68] (Fig. 2d). These measures of curiosity can provide implicit assessments of cognitive processes separate from behaviour. Other related methods include wearable devices that measure the heart rate or electrodermal activity[69,70] and neuroimaging methods to track brain activity during tasks[67]. These methods try to differentiate between internal and external curiosity by detecting discrepancies between cognition and behaviour, such as biophysical signs of curiosity without observable information-seeking. However, just as more precise measures of information-seeking are needed to differentiate from non-curious exploration, more work is needed to validate biophysical markers as measuring curiosity.

More consistency in the operationalizations of curiosity across studies and the use of similar measurement methods will make it possible to better generalize across studies. Measurement work is needed to address challenges around understanding internal and external curiosity and understanding the interrelations across different related variables to better understand how curiosity develops in children. At the same time, it is important for these operationalizations and measures to be sensitive enough to explore the influences of contexts and culture on curiosity to build a more comprehensive understanding of it.

Variability in curiosity across childhood

Curiosity is present from infancy[7], yet there is a dearth of longitudinal and cross-sectional research examining its development. However, there is an amount of work that explores related cognitive processes, information-seeking and knowledge acquisition. In this section, we discuss how curiosity has been studied across development, beginning with infants (aged 0–11 months) and toddlers (aged 1–3 years) through to preschool children (aged 3–5 years) and older school-aged children (aged 5–12 years). We also address the issue of whether curiosity declines with age.

The development of children's curiosity coincides with their ability to recognize uncertainty and build knowledge representations that are accurate and complete. Infants and toddlers might not be explicitly aware of their knowledge gaps but can intentionally elicit information[71] from adults through gestures or eye gaze. These bids result in more effective learning than if the information was shared without a curiosity bid, which suggests that a bid might prime the infant to encode information[60]. Infants also have different expectations about who they can learn from: infants aged 11 months are more likely to anticipate learning, as evidenced by an increase in electroencephalography theta activity, from native speakers than from non-native speakers[72]. Looking behaviours are some of the earliest indices of curiosity, as they indicate where an infant is choosing to direct their attention. For instance, infants aged 7–8 months were more likely to look away from visual[73] and auditory[74] displays when the information they encountered there was predictable and therefore less likely to provide new information.

Pointing is another curiosity bid that infants use to elicit information from adults. There has been some debate on whether all pointing pertains to information-seeking, as a child can also point to elicit an adult's attention or gesture towards an object that they want[75]. However, infants can engage in 'imperative pointing' in which they purposely gesture towards an object they wish to know more about[76], which differs from other forms of pointing that infants might use to request something or show others an event or object. For instance, toddlers aged 16–18 months demonstrated enhanced learning of an object's name when they were informed of it after pointing at it, as opposed to after reaching for it or merely gazing at it[77,78].

By 3 years of age, children start to refer to their own knowledge states and differentiate between seeing and thinking[79], perhaps building off experiences of curiosity and information-seeking in earlier years. Preschool children can differentiate between individuals who know and do not know a piece of information and can recognize the sources of people's knowledge[80]. Also in the preschool years, children

develop a conceptualization of how learning takes place and are able to recognize that their information-seeking can have a direct impact on their knowledge acquisition[81].

Asking questions is a common form of information-seeking[82]. However, not all question-asking is asked as curiosity; for instance, asking what time dinner is or where a toy is located are requests for specific pieces of information that will not lead to further information-seeking or knowledge gains. Moreover, question-asking that is not effective, such as questions that do not take prior knowledge into account or request information relevant to the information gap, does not result in information gains[83]. Preschool children can recognize effective questions[84,85] and preschool children who generate questions more frequently in problem-solving contexts are better at identifying effective questions. Curiosity is positively correlated with the ability to recognize and generate effective questions in children aged 4–7 years[23]. Questioning changes as language skills develop[80], and non-verbal exploration is also likely to change as children's knowledge grows. For instance, children who have a foundation of knowledge about object properties do not need to continue exploring familiar perceptual elements.

Naturalistic observations of infants and children (such as from the CHILDES database[86]) demonstrate that verbal information-seeking is present across childhood[77]. However, longitudinal investigations of children's naturalistic non-verbal information-seeking is needed. All the examples we have discussed of information-seeking across childhood index external curiosity. It is harder to explore the internal processes of curiosity during childhood, although these are also likely to change across development.

There are individual differences in the development of curiosity. Malleable cognitive processes, such as executive function and vocabulary growth, might be associated with uncertainty monitoring, which might be an indicator of internal curiosity[15]. Uncertainty monitoring refers to a metacognitive awareness of uncertainty and is often measured using a perceptual task in which children are asked to identify degraded images and then rate their confidence in their answer[87]. Researchers measured children's uncertainty monitoring, executive function and vocabulary growth from preschool to kindergarten with children in a Head Start programme (a US government programme that provides early childhood education and other support to low-income families) and found that executive function and vocabulary growth were positively associated with uncertainty monitoring[88].

Although it has been suggested that curiosity declines with age[89], there is little longitudinal research that addresses this idea. However, there is increasing evidence of a developmental shift from exploration and seeking new knowledge to exploitation, using acquired knowledge, from childhood to adulthood[90], which could be interpreted as children becoming less curious as they get older. Exploration is considered the pursuit of information and willingness to encounter uncertainty, whereas exploitation refers to the implementation of prior knowledge towards a goal or reward[91]. Children often engage in exploratory play activities in which they encounter invented scenarios and problems, which enable them to generate and test hypotheses. These play activities often do not result in tangible learning or information gains, but they enable children to engage in thinking practices that support future curiosity[92].

Research on exploration–exploitation often uses a task with probabilistic distributions of external rewards known as the multi-armed bandit task, which is set up similar to a slot machine with multiple levers. In this task, exploring helps participants identify the probabilities of different choices, which can then be exploited to attain greater rewards. Compared with adults, children (aged 4 years[91], 7–11 years[93] and 5–12 years[94,95]) were more likely to engage in exploration even at the cost of rewards. One account of these findings is that children tend to engage in more exploration compared with adults because they have less background knowledge and experience more uncertainty, and therefore need to engage in more exploration to acquire relevant knowledge[90]. Increased exploration can make children less susceptible to falling into learning traps and lead them to discover information that adults might miss[90]. These findings should not be interpreted as adults becoming less curious or that children only engage in unfocused exploration: both children's and adults' curiosity can be driven by

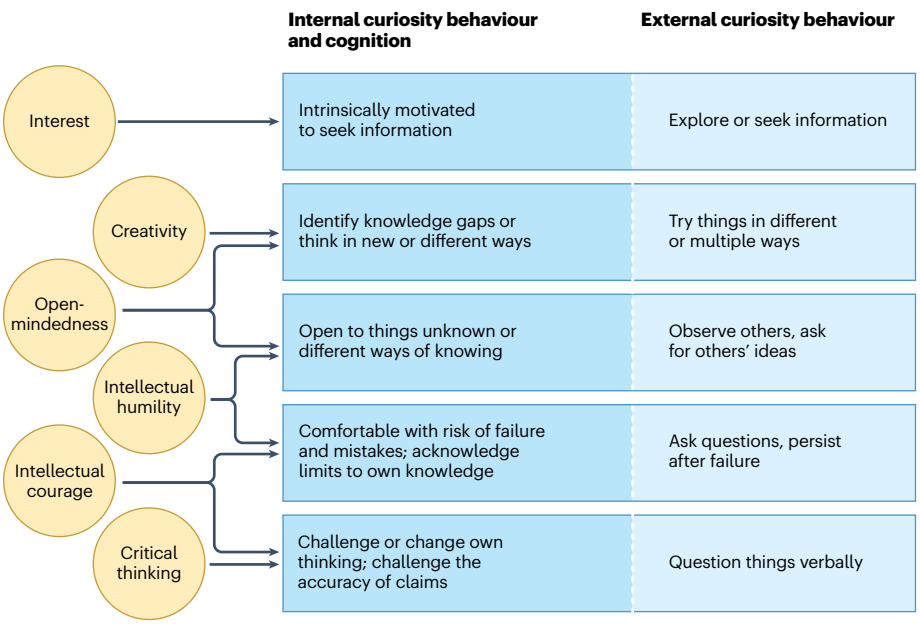

Fig. 1 | Overlap between curiosity and related constructs. One reason why curiosity is challenging to study is that it has many underlying processes in common with other constructs and involves similar behaviours as related factors[44].

Table 1 | Measures of curiosity

Type	Measure	Description	Benefits	Aspect of curiosity measured
Survey	Self-report	Children answer questions related to the frequency of their curiosity, wondering or thinking	Children know best what they think Requires few resources for administration and coding	Internal
	Parent report or teacher report	Adults answer questions about how often they observe children engaging in information-seeking	Requires few resources for administration and coding	External
Observational	Language corpus studies	Researchers document children's language	Data can be collected from naturalistic contexts	External
	Behavioural observation	Researchers document children's behaviour, language and social interactions	Data can be collected from naturalistic contexts	External
	Exploration tasks (open-ended or forced choice)	Children complete a structured activity and researchers document their behaviour	Enables control of activity across children	External
Biophysical	Gaze tracking	Measures where children look as an indicator of attention	Non-verbal	Internal
	Pupillometry	Measures the level of attention while children are visually attending to stimuli	Non-verbal	Internal
	Neuroimaging	Assesses neural activity during a task	Non-verbal	Internal
	Facial expressions	Measures facial features to assess affective responses	Non-verbal	Internal
	Heart rate	Measures heartbeats to assess physiological response	Non-verbal	Internal

expected learning[96]. Adults might be more likely to prioritize learning efficiency than children, whereas children are more likely to gather as much information as possible even when it is irrelevant[97]. Studies with adults also indicate that potential for learning gains is a key driver of exploration[98] and that curiosity can be driven by the perceived usefulness of the information that can be gained[99]. In studies with the multi-armed bandit task, adults are likely to perceive that earning rewards is the goal of the activity and therefore it is unsurprising that they exploit their knowledge to achieve that goal.

As children develop more complex knowledge systems, they might become more aware of specific knowledge gaps and focus their information-seeking on those gaps. It is also possible that domain-specific curiosities emerge as children's knowledge base grows and they become drawn to certain topics over others, leading to interests playing a greater role in curiosity or in motivation more generally[18,100]. Ultimately, the field should move away from viewing curiosity as something that increases linearly or looks the same across ages. It is more likely that, as children develop their knowledge representations and gain a more accurate and complete understanding of the world, they continue to experience curiosity as they encounter more uncertainty and their information-seeking reveals further questions (Fig. 3).

Rather than exploring how curiosity changes in frequency or intensity, researchers should explore what curiosity looks like and how it can be promoted across ages[101]. A key to advancing knowledge about these questions is understanding that curiosity is not a purely individual process, and that the ways it can be expressed and the ways it might be supported to foster learning are influenced by many factors, including context and culture.

Variability in curiosity across contexts

Children develop within their environments, and their experiences are influenced by factors across levels, such as their family and broader society, the resources available and affordances of their environments, and how these influences interact and change with time[102]. Thus, although physical spaces are a part of context, context is much more complex than simply the location. Although the goal of curiosity research is to explain curiosity in real-world settings, most research takes place in a laboratory setting. For example, much curiosity research with children observes the questions they ask or how they explore a given task. However, there are many fewer constraints on children when they engage with tasks in their naturalistic environment or ask questions of familiar adults. Studying curiosity within children's typical childcare and school contexts would lead to the most relevant knowledge about the variability in curiosity across those contexts, and in particular the influence of other people[3]. In the realm of children's question-asking behaviour, parent language[80] and parent–child question-asking and question-answering norms[103] are rooted in cultural practices and can impact children's exploration and information-seeking behaviours[104]. In this section, we provide selected examples of research that examine how different contexts affect children's curiosity. We define context to include physical spaces, such as home, school and museum environments, social contexts, including different forms of adult–child interactions, and cultural and socio-economic background.

Physical contexts

Different contexts differ in how conducive they are to curiosity. These differences arise in the affordances for different ways curiosity can be expressed and in children's perceptions based on their past experiences, such as what they perceive as important or appropriate in one context compared with another. For example, when Dutch children aged 4–10 years were asked what they were curious about, responses related to school were trivial and infrequent, despite listing curiosities across many academic domains. When asked specifically about curiosity in school contexts, some children expressed surprise at the idea, with

responses such as 'No one is curious about what we learn in class. We just need to do whatever the teachers tell us to do'[28]. Another study found that 4-year-old British girls asked almost ten times more questions at home than in school, demonstrating the challenge in generalizing observations of curiosity across contexts[105]. Lower curiosity in school contexts could be based on the structure of educational systems as teacher-led and performance-oriented[2,37] or a poor fit between a child's learning approach or strengths and ideas about what is acceptable within the school structure[106]. It could also be possible that curiosity is expressed differently in schools to in other contexts and is therefore present but missed in research. For example, children in government-funded schools showed an unexpected advantage in creativity over those in privately funded schools in the United States. Researchers concluded that this difference was an effect of what was happening in the classroom on creativity measures conducted outside the classroom[107]. In a follow-up study in the privately funded school, when children were taken out of class to complete the study during activities that they rated 'uninteresting', their creativity was almost twice the level as when they were taken away from an 'interesting' activity[108]. Despite the challenges related to conducting research in schools, they are an important context in which to study curiosity, and further research is needed to better understand how to promote curiosity in schools.

In contrast to schools, museums can provide an open-ended opportunity for children to become curious and explore. Museum contexts might scaffold curiosity by giving information and interactive experiences that enable children to identify things they want to explore and figure out. However, even in this context there is variability in children's experiences related to their interactions with parents[109]. Numerous studies in the United States have shown that children explore in museums, and parents encourage this exploration and related learning[109,110], but the types of interaction between parents and children relate to factors such as parents' experience in museums and their schooling level. For example, in a California science museum, parents of Mexican heritage who have completed secondary school provided more explanations about science processes to their children (aged 4–6.5 years) than parents who had not completed as much formal schooling. There were no differences between the parental education groups in the number of conversations in which parents help children understand the relation between events or phenomena (causal conversations). A follow-up study found no differences between the education groups in the number of explanations or causal conversations between parents and children[111]. In another study, parents with fewer than 12 years of formal education asked more conceptual (why and how) questions of children compared with parents with higher schooling[112].

In summary, based on research in the United States and Europe, museums provide opportunities for children to be curious and engage with exhibits and materials they might not be exposed to at home and school, although less is known about the generalizability of these findings. Further, adults' own experiences and backgrounds shape how they interact with children in these settings.

Social context

Children's exploration can also be influenced by interactions with adults, as shown in studies in the laboratory[113] and home[99] (with children

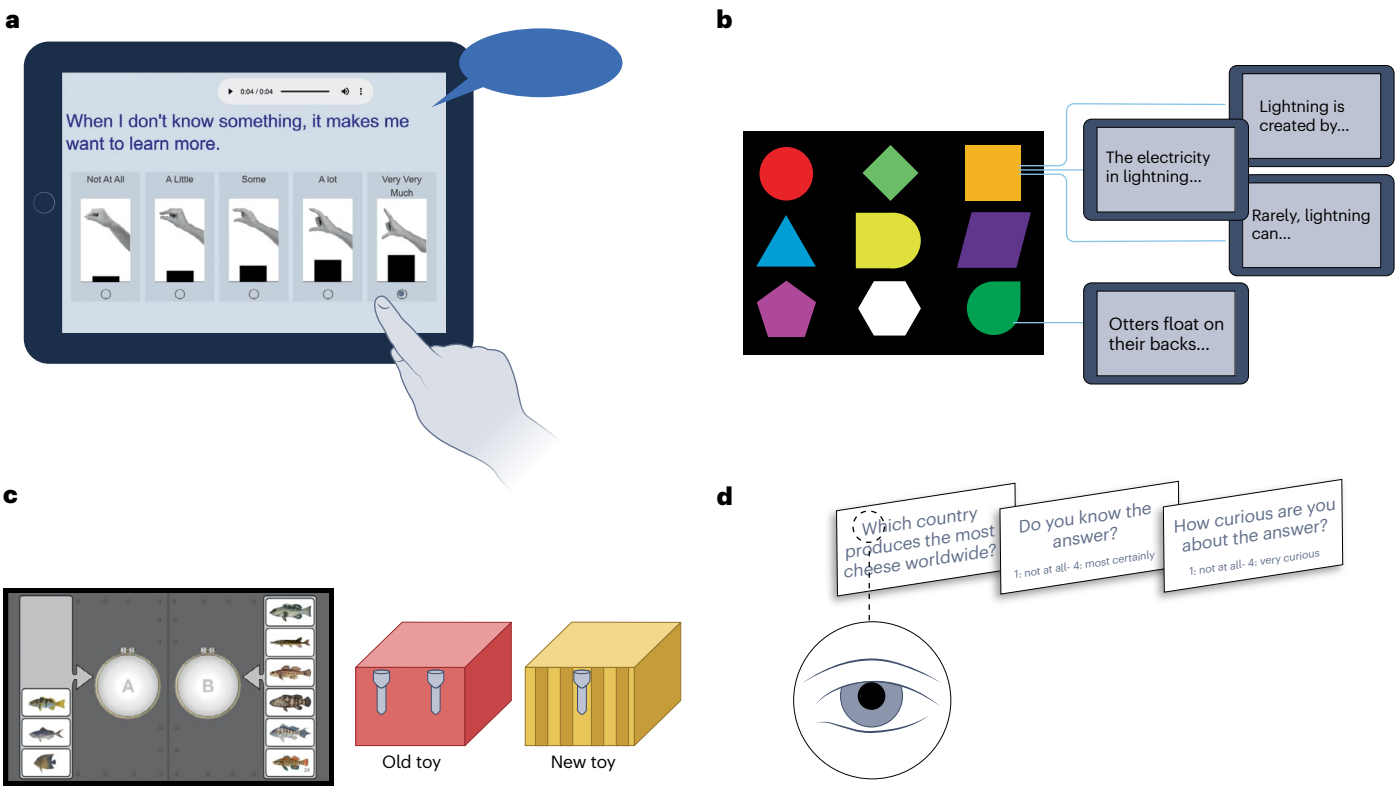

Fig. 2 | Methods and measures used in studies of children's curiosity. **a**–**d**, Example measures used to study children's curiosity by measuring internal curiosity: self-report surveys (panel **a**) and biophysical measures such as puillometry (panel **d**), and external curiosity: free exploration (panel **b**) and forced-choice paradigms (panel **c**).

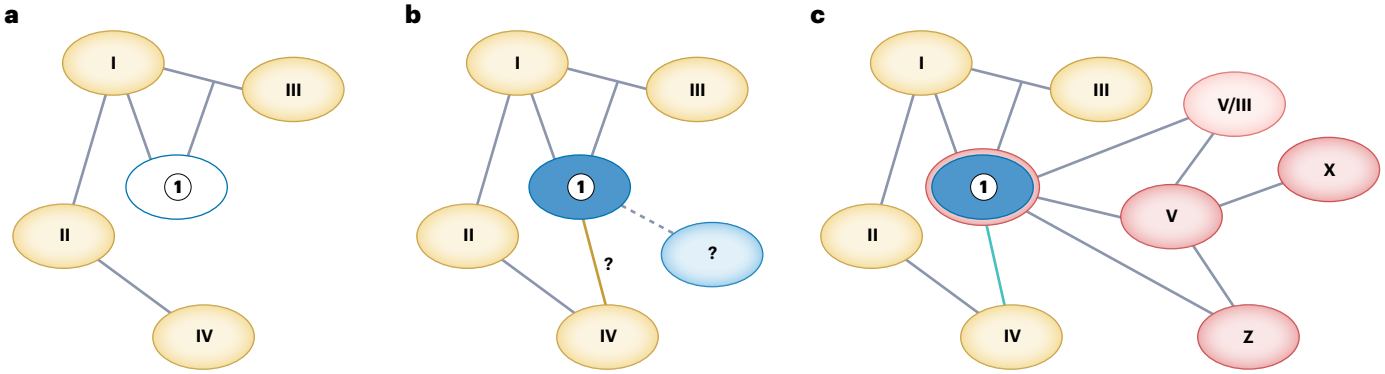

Fig. 3 | Curiosity in a network of knowledge. As knowledge representations become increasingly complex or new knowledge emerges, new opportunities for becoming curious are revealed. **a**, Initial curiosity involves identifying a gap in existing knowledge (denoted '1'). **b**, Filling that gap can lead to curiosity about further information or gaps to existing information (denoted '?'). **c**, Further learning can lead to additional curiosity across the network of knowledge and connections or new ways to understand existing information as children experience internal and external curiosity.

aged 3–6 years) and in informal learning spaces (with children aged 7–9 years)[63]. This influence occurs especially when the information children are learning is novel or potentially taxing on their cognitive resources[114]. Guided play, a joint activity in which a child initiates an activity and an adult provides scaffolding, can promote exploration and learning, particularly because children can take an agentic role in their learning[115,116]. Guided play is often contrasted with direct instruction. Although there is some evidence that adult-led direct instruction can make children aged 4–6 years less likely to engage in exploration[113,117,118], direct instruction can also help children aged 3–4 years learn more from exploration activities (such as discovering causal mechanism that makes a toy light up) than from free play[119]. However, it is not always clear whether the exploration observed during direct instruction is related to curiosity or to the extrinsically provided learning goals or task demands of the research study.

Several studies also demonstrate that small prompts or instructions to parents can influence how they interact with their children in museum settings and increase children's exploration[63,109,120]. One way caregivers interact with children is through guided play. In a museum study, children aged between 3 and 7 years whose parents interacted with them in a manner similar to guided play (jointly directed dyads) engaged in more exploration in museum exhibits than children whose parents directed them (parent-directed dyads)[121]. Across the three main ethnic groups that participated in the study, white or Caucasian and Hispanic or Latinx families were more likely to engage in jointly directed dyads, and Asian American families were more likely engage in parent-directed dyads. Although cultural differences sometimes underlie differences in curiosity-related social interactions, this cultural variation frequently involves different approaches that lead to similar results. For instance, a study with Yucatec Maya children in Mexico and children in a large US city aged 2–3 years found that both groups of children exhibit similar amounts of exploration even though there are substantial cultural differences in how they receive instruction from adults[122].

Children are also influenced by other people, such as siblings and peers, which can lead to nuanced effects on curiosity. For example, experiences of individual and group discrimination were associated with lower curiosity in African American adolescents, but racial socialization messages around self-worth and egalitarian beliefs were positively associated with curiosity[123]. Although interactions with siblings are challenging to separate from parent interactions, interactions between younger (aged 2–3 years) and older (aged 4–6 years) siblings can be mutually beneficial for learning academic and social skills[124]. Further work would benefit from considering more complex multi-person interactions, such as between children and their siblings and parents. A final point of consideration is that experiences are perceived differently by individuals and it might be especially challenging (but important) to understand children's lived experiences when exploring influences on their curiosity[125].

Socio-economic contexts

Family income (often operationalized as socio-economic status (SES)) has a complex relationship with development through its influences on the resources available in one's home and community, school quality and more. For example, one study found that 4-year-old girls in middle-class households asked more why questions — which are indicative of resolving larger knowledge gaps related to higher curiosity[1] — than their working-class counterparts[105]. However, both sets of children posed at least some 'why' questions and demonstrated an inclination for intellectual searching, which includes question-asking and seeking explanations[105]. Similarly, another observational study compared children's inquiries and parental responses within families from low-SES and mid-SES backgrounds and found that children from low-SES households posed fewer questions compared with their counterparts from mid-SES backgrounds[126]. However, the proportion of explanation-seeking questions (causal 'how' or 'why' questions) to fact-seeking questions ('what', 'when' or 'where' questions) among children from low-SES backgrounds was similar to that of children from mid-SES backgrounds. When examining parental follow-up to children's questions, the researchers found that parents from mid-SES backgrounds provided more explanations in response to their child's causal question than parents from low-SES backgrounds.

Curiosity can be demonstrated through verbal interactions other than questions, such as by talking through potential explanations or connections across knowledge structures, or non-verbal interactions such as observing. For instance, one study found that although children in preschool from low-SES backgrounds and from mid-SES backgrounds posed a comparable proportion of information-seeking

questions, the subsequent explanation patterns differed[127]. Although there were no distinctions in the quantity of explanatory responses children received from teachers, the teachers of students from low-SES backgrounds were significantly less likely to redirect the question than teachers of students from mid-SES backgrounds. At that point, children from low-SES backgrounds were more inclined to restate their initial question as a follow-up, whereas children from mid-SES backgrounds more often produced their own explanations. These findings underscore the importance of considering various factors, such as family income and in-home and community resources, in developing a comprehensive understanding of influences on how children's curiosity develops.

Cultural contexts

Examining information-seeking in different cultural contexts can illuminate different paths of how curiosity can develop. In doing so, researchers must avoid treating one cultural group as the default or adopting a deficit approach when comparing children from a non-Western Educated Industrialized, Rich, and Democratic (non-WEIRD) culture with children from a WEIRD culture[103,128]. In a study examining cultural differences, researchers found comparable quantities of information-seeking questions in naturalistic language data from 3-year-old and 5-year old children from the Logoli community in Kenya, Samoans in American Samoa, Newars in Nepal, and Garifuna in Belize and the United States (including four children sampled from different racial and SES backgrounds[82] from the CHILDES database[86])[129]. However, the proportion of explanation-seeking questions was notably lower in the non-US children than has been reported for the children from the United States in this study.

Contextual effects across many variables influence curiosity. The complexity of curiosity presents an exciting opportunity to explore and understand children's curiosity and other related motivational influences, and how these can be used to provide positive developmental experiences. The complexity also suggests that it is necessary to explore nuances and interactions across multiple aspects of context and backgrounds. Furthermore, the research presented here was predominantly conducted with neurotypical participants. Whereas there has been some work suggesting different patterns of exploration associated with autistic traits in young adults[130], there are few studies on curiosity specifically in neurodivergent children.

Summary and future directions

Research on children's curiosity is a quickly growing field with important implications for children's positive development. Here, we have focused on the state component of curiosity as a positive affective experience, defined by information-seeking behaviour that is internally motivated in response to a specific question or gap in knowledge. The research reviewed demonstrates different ways children express curiosity across ages, sometimes related to developing cognitive abilities. However, owing to different operationalizations and measures and a focus on external curiosity, there is insufficient evidence to know whether the level of curiosity changes with age. There are also different ways in which curiosity is expressed across physical spaces, such as occurring less frequently in schools and involving more social interactions in museums, and curiosity can be influenced by SES, culture and other factors of the broader social context.

Although it is clear that curiosity is a universal characteristic of childhood that can motivate and direct attention during information-seeking to support knowledge development, there is a need to understand curiosity more thoroughly across ages and contexts. Research with children has been limited by focusing on measures of external curiosity, and more investigation of internal curiosity can inform practical applications to create curiosity-supporting contexts for children to learn and develop. A key to generalizing knowledge beyond controlled research studies is to consider the various ways in which curiosity can be expressed and that its promotion and influence on learning are affected by many internal and external factors. Factors including physical and social contexts, and how these are influenced by children's socio-economic and cultural backgrounds, need to be included in future research. There are large gaps in what is known about children's curiosity, and researchers should keep in mind key methodological issues, consider diversity, equity and inclusion, and evaluate the generalizability of results based on the methods chosen when exploring ways to promote curiosity. We have three primary suggestions for research needed to address these gaps in the literature.

First, research should explore internal curiosity, either on its own (perhaps as a type of metacognition) or along with external curiosity. Research should address the factors that influence the spark of internal curiosity and what leads to engaging in external curiosity and the respective potential benefits of both internal and external curiosity. Past research and practice (including parenting and educational practice) have focused on promoting observable external curiosity, but internal curiosity is essential as a first stage of curiosity. Internal curiosity can also be beneficial on its own through mental connection-making and information-seeking[101,131,132], so more basic and applied research is needed on this aspect to promote curiosity more generally.

Second, studies should explore curiosity in the physical and social contexts related to their specific research questions. Ideally, children should be studied in the environments in which researchers want to promote curiosity. Future research should aim to better understand the ways in which curiosity can be expressed, both internally and externally, and to develop psychometrically sound measures of curiosity in children. Within this work, longitudinal research is key to understanding the nature and development of curiosity across ages and contexts. Measurement work should be sure to address past challenges related to structured activities and cognitive demands, such as introducing extrinsic goals, tasks that are overly complicated for younger children, or using question-asking as a main measure (which relies on language ability). These challenges might limit expressions that could provide insight into children's curiosity or lead to behaviours that are motivated by something other than curiosity. Another important consideration for further research is to examine how social influences and interactions, as well as changing contexts, such as increasing technology use in children's homes and schools, might influence curiosity[133]. Consideration of the social influences and interactions and other characteristics of the contexts studied are important when planning research and interpreting research results.

Last, researchers should examine how curiosity is expressed across cultural backgrounds to be inclusive of all children and their experiences. With some exceptions, most studies include a single population of children with low representation of children from minoritized racial and ethnic groups. A failure to consider children's varying cultural backgrounds sustains the persistent issue of centring the behaviour and cognition of a single majority population as the default, expected or, even, 'ideal'. Curiosity is a strength of children that is often ignored, and ignoring or failing to capture differences in expressions (such as asking family members questions instead of seeking out information independently or the type of information children might become curious

about) of curiosity in children from varying cultural backgrounds further undermines the understanding of this ability. Researchers need to consider whether and how internal and external curiosity are expressed in different ways across cultures. There is a need for more work to determine whether measures are invariant — consistent and comparable across different groups (such as younger and older children) and contexts (such as home and school environments) — to adapt measures to the population studied, and to use qualitative approaches to better understanding the variation in curiosity and its expression. Beyond the ethical issues with centring research and knowledge around a limited population and the limitations this poses for a broad understanding of curiosity in children, even more problematic ethical concerns arise from using research for applications to populations or contexts not represented in the research. With increasing focus on the importance of curiosity and other twenty-first-century skills in schooling[134], such as research on how to promote curiosity in classrooms[135,136], understanding curiosity as it varies across contexts and cultures will enable the development of inclusive practices that will be effective for all children[137] and create equitable opportunities for children across all backgrounds.

Much more work is needed to understand curiosity in children, and researchers can benefit from exploring what has been learned across different fields and in the study of related constructs. Research will be most beneficial if completed using a range of methods and with clear operationalizations of curiosity. Both qualitative and quantitative methods are needed to understand developmental trajectories over time and the nuances in curiosity and the expressions and role of curiosity across cultures. Research is needed to explore whether measures assess the same things in the same ways across different subgroups (including by age and culture) and to consider alternative measures or indicators of curiosity. This work will provide the knowledge needed to inform policies and practices to create curiosity-supportive environments that can promote learning and positive development for all children.

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