From Curiosity, to Wonder, to Creativity: a Cognitive Developmental Psychology Perspective

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Introduction

Playfulness, open-mindedness, thinking 'outside the box' describe a desirable and highly regarded state that children naturally engage in and most adults desperately crave. Across all aspects of modern life, we are constantly bombarded by pervasive powerful messages encouraging us to inquire and explore, discover and innovate. This desire is mirrored in public policies, education practices and business models, which emphasize the need for curiosity, innovation and creativity over the need for knowledge reproduction, imitation, and conformity (Cachia et al. 2010; Dede 2010; King and Rogers 2014; Trilling and Fadel 2009; OECD 2018; UNESCO International Bureau of Education 2014).

Among several positively valenced psychological terms often used interchangeably, curiosity, wonder and creativity hold a special place in the study of human development as core mechanisms behind knowledge acquisition and knowledge transformation. As such, curiosity drives information seeking, wonder expands and enriches the quest for knowledge to new dimensions, and creativity enables transformation of existing knowledge and generation of new, original knowledge about the world. These capacities are already present, albeit in rudimentary forms, and reliably observable in early childhood. However, the cognitive mechanisms underlying the processes of curiosity, wonder and creativity, the links between them, and their developmental trajectories are currently poorly understood.

Scholarly inquiries into curiosity, wonder and creativity abound in the fields of philosophy and education (Carlson 2008; Carson 2011; Engel 2015; Schinkel 2017; Starko 2013; Vasalou 2012, 2015; Verhoeven 1972). However, psychological research into exact links between these concepts is inconclusive, owing to vague conceptual definitions, lack of robust measures, and disregard of dynamics of developmental change. The goal of the present chapter is to review the existing psychological accounts of curiosity, wonder and creativity in early development and explore the conceptual links, unifying theoretical approaches and methodological considerations from a cognitive developmental perspective.

Cognitive developmental science aims to uncover the underlying cognitive mechanisms enabling psychological phenomena and explain their changes with development. From this perspective, methods such as brain scanning (EEG, fNIRS, fMRI), physiological response measuring (e.g., heart rate and skin conductance), facial electromyography (EMG), eye-tracking and pupil dilation response measuring, as well as monitoring explicit, reliably observable behaviour, may be powerful tools for understanding curiosity, wonder and creativity. The field is ripe for applying such methods to help theoretically and conceptually delineate the unique features of each of these psychological phenomena, enable development of age-appropriate measures for their rigorous experimental study, and investigate the links between them and their co-development.

In the present chapter, we review the state of the cognitive developmental research on these topics, with a special focus on successful methodological approaches, as well as challenges for the experimental study of their cognitive underpinnings. The chapter comprises four main sections: 1) Curiosity, where we focus on children's active exploration, information seeking, and question asking; 2) Wonder, where we emphasize affective response, reflection, and pursuit of further knowledge; 3) Creativity, where we discuss capacities such as generating ideas, original transformations, and novel combinations; and 4) Relationship between curiosity, wonder and creativity, where we propose that these links are complex and dynamic; concluding with suggestions for future research to understand their interrelations as they unfold developmentally.

Curiosity

Curiosity is broadly defined as an intrinsically motivated exploration with an information-seeking goal (Bazhydai, Twomey, and Westermann, 2020; Kidd and Hayden 2015). Crucially, in a curiosity-driven process, information is being sought for its own sake and not as a means of obtaining food or another kind of essentially non-epistemic reward. Curiosity is often described in terms of two distinct dimensions: perceptual vs. epistemic and specific vs. diversive (Berlyne 1950). Thus, a range of behaviours can be called curiosity, from momentarily picking up a random book from the library book shelf to reading an encyclopaedia chapter, and from locating a particular fact about the topic of interest to seeking an escape from boredom by browsing an online news website. In the past decades, cognitive scientists, employing a range of approaches from the fields of neuroscience, robotics and computational modelling, have started to develop better understanding of the cognitive origins of curiosity and its cognitive underpinnings in early childhood.

Several theoretical perspectives have been proposed to explain how curiosity arises. Among those are drive, incongruency, information gap and learning progress approaches (see Bazhydai et al., 2020, for a detailed review). Behaviourist approaches saw curiosity among other basic drives motivated by anticipated reward, similar to food and comfort seeking. Infants' attention in response to new and interesting stimuli was here explained in terms of mere orienting reflexes. While identifying the lower level components underlying curiosity-driven behaviour, largely from work on animal models, these approaches neglected more complex and cognitively rich mechanisms. In the wake of the cognitive revolution in psychological science in the 1950s-60s, curiosity received a fresh and more sophisticated look. A newly proposed way to explain the preference for novelty, surprise and complexity was to adopt an *incongruency detection* perspective. This approach postulates that upon detecting a mismatch between the existing state of knowledge and incoming information, a process of curiosity allows one to update one's existing knowledge. That is, a person is driven to achieve "a feeling of coherence and of necessity, the satisfaction of arriving at a system, which is both complete in itself and indefinitely extensible" (Piaget 1969, 139). Relatedly, the *information gap theory* (Loewenstein 1994) proposes that curiosity arises when an individual encounters a gap in their knowledge and is then motivated to fill it with new and relevant information. Here, curiosity cannot emerge if the level of prior knowledge is too low or too high in relation to the novel information, while an intermediate level of information familiarity and complexity is optimal for arousing curiosity (Kinney and Kagan 1976; Kidd, Piantadosi, and Aslin 2012, 2014). Finally, *learning progress theories* presume that curiosity's goal is to maximize information acquisition by minimizing uncertainty (Oudeyer, Gottlieb, and Lopes 2016; Twomey and Westermann 2018). Here, learning itself is an intrinsically motivating process, which in turn fuels a just as intrinsically motivated curiosity process, thus creating a positive, rewarding loop for driving knowledge acquisition.

This variety of theoretical approaches to curiosity has been instrumental in scientists' ability to formulate key questions to better understand how curiosity works. Whereas in Berlyne's classification, information novelty and complexity serve as determinants of curiosity, the information gap theory relies on reflective awareness of one's current knowledge in order to detect a gap, and the learning progress approaches place the greatest importance on the emerging, self-driven optimization of information intake to enable effective learning. Most contemporary approaches agree that the existing knowledge state and the ability to obtain new information dynamically interact to give rise to curiosity.

Developmental psychologists often describe curiosity in conjunction with infants' exploratory activities. The image of the busy infant actively exploring its environment, approaching, touching, banging, mouthing and throwing toys, putting blocks on top of each other, constantly changing its position, crawling around, and engaging its caregivers in a rather demanding manner underpins this confluence of curiosity as a cognitive mechanism and curiosity as an exploratory behaviour. According to Piaget (1945), such active exploration enables infants to construct knowledge of the existing world.[1] Infants explore through visual scanning of their environment (as detected by eye movements tracking), object manipulation (grasping, throwing and mouthing them), preferentially approaching something that captured their interest (e.g., crawling towards a new toy), as well as querying others for information with all communicative tools available to them (Bazhydai, Westermann, and Parise, 2020; Begus and Southgate, 2018).

Infants' motivation to know how something works is sometimes proposed to explain the very process of curiosity-driven learning. A widely used metaphor presents young children as "little scientists", keen on discovering the world through optimized and adaptively rational learning mechanisms akin to the scientific process of knowledge discovery by trial-and-error. Recent research in cognitive developmental psychology highlights sophisticated information seeking strategies guiding infants' exploratory behaviours, such as active generation and testing of hypotheses about the world, attempts to understand the causal mechanisms of encountered events, and heightened interest in objects that violated their expectations (Bonawitz, van Schijndel, Friel, and Schulz 2012; Gopnik, Meltzoff, and Kuhl 1999). For example, infants who saw a surprising event, such as an object passing through a solid wall and emerging on the other side intact, looked at it longer and crawled toward such an object more often than with an event that was just novel (Sim and Xu 2017; Stahl and Feigenson 2017, 2019). These rudimentary behaviours can be interpreted at different levels. Either infants are merely interested in something unusual and therefore surprising, or, at a higher level, they are interested in resolving the uncertainty caused by the unusual event by seeking disambiguating or clarifying information about it. Studies with older children provided more context for the latter interpretation. For example, when the evidence presented to children was confounded (such as when two different explanations were possible for

[1] Furthermore, Piaget (1945) highlighted that it is through 'playful interactions' with the environment that the infant acquires knowledge, drawing a subtle link between learning what is known and creating something new through play – the argument we want to develop further in this paper.

what makes the funny noise in an exciting new toy), children explored the toy in a way that would allow them to understand the precise causal mechanism (Schulz and Bonawitz 2007). When information taught to them was insufficient (i.e., the teacher committed the 'sin of omission' by not relating all relevant information), primary school children's exploration was strategic to compensate for the missing knowledge (Gweon et al. 2014).

Curiosity-driven exploration in early childhood is evident in both independent and social processes. That is, encountering the need for information (either upon seeing a surprising event or when lacking information which they cannot obtain by themselves) may trigger infants' turning to others for help. Social partners are potent sources of information for young children, and the ability to interrogate them by asking questions and posing information-seeking requests develops in the first years of life (Begus and Southgate 2018; Ronfard et al. 2018; Southgate, Van Maanen, and Csibra 2007). Enabling such epistemic curiosity in social learning contexts, infants' early nonverbal communicative skills such as babbling, social referencing and pointing precede verbal question asking. Infants use them actively and selectively, paying attention to epistemic cues that available social partners exhibit (Harris and Lane 2014; Poulin-Dubouis and Brosseau-Liard 2016). They also strategically request pertinent information about the immediate environment from someone who can be regarded as knowledgeable about it as opposed to an ignorant person, and do so only when information (e.g., an unfamiliar object name or a hidden object location) was being asked for but not available to them (Bazhydai et al. 2020; Begus and Southgate 2012; Begus, Gliga, and Southgate 2016; Goupil, Romand-Monnier, and Kouider 2016; Kovács et al. 2014; Vaish, Demir, and Baldwin 2011). Thus, infants engage in curiosity-driven knowledge acquisition before they are even able to speak.

With development, deliberate question asking gives rise to more precise, sophisticated, and complex processes (Choinard 2007; see Ronfard et al. 2018 for a review). To seek knowledge from others, disambiguate unclear facts and confront counter-intuitive testimony, children pose 'why' questions, demand clarifying answers, solicit additional evidence, and question the reliability of information, actively engaging in critical thinking processes powered by intrinsic motivation (Frazier, Gelman, and Wellman 2009; Tizard and Hughes 1984). However, while social contexts may be conducive to the satisfaction of curiosity – if children seek information from social partners when in need – sometimes overly normative situations may inhibit curiosity. For example, when provided with a counter-intuitive testimony by an otherwise trustworthy adult, preschoolers endorsed the adult's judgment without skepticism or attempts to engage in independent verification even when given opportunity to do so (Ronfard, Chen, and Harris 2018; Ronfard et al. 2019). And when taught in a directive, explicitly pedagogical manner, children limited their further spontaneous exploration as if treating received evidence as exhaustive and normative (Bonawitz et al. 2011).

While actively engaging in strategic information seeking, infants are also known to constantly explore seemingly without an immediate perceivable goal. Given this sometimes aimless search for information, which is a hallmark of the diversive-perceptual kind of curiosity in contrast to the specific-epistemic kind (Berlyne 1950), infants' attention has been compared to a lantern, in comparison to adults' more focused spotlight (Gopnik 2009). Formalization of infants' behavioural exploration has led to the development of artificial intelligence models in robotics and computational modelling (Gottlieb and Oudeyer 2018; Oudeyer 2017). The main idea behind these approaches is that infants' exploration (active information sampling, in jargon terms) is not random but rather systematic and selective, thus enabling optimal and efficient learning (Smith et al. 2018). "Infants are curious learners who drive their own cognitive development by imposing structure on their learning environment as they explore", in the words of Twomey and Westermann (2018) who developed a neurocomputational model of infants' exploration as they learn object categories. This model, operating on the principle of the in-the-moment, step-wise maximization of learning opportunities, emphasized the importance of dynamic interaction between the properties of the available information, the environment, and the learner's current internal state. Given the freedom to select an object to learn from at each iterative step of the process, the model chose stimuli that took into account these interactions in order to optimize learning. In doing so the model generated exploratory sequences of overall intermediate complexity, echoing studies with infants as young as 7 months old showing that infants' visual attention to sequences of events that are either too simple (too familiar) or too complex (overly unpredictable and novel) is diminished while attention to events of intermediate complexity is enhanced. This preference for intermediate complexity (called the "Goldilocks Effect" of curiosity-driven exploration), supports the idea that infants implicitly seek information that they can reliably absorb and that is neither too boring nor too cognitively taxing (Kidd, Piantadosi, and Aslin 2012). An active and selective role played by a child in the learning process via discovery is key to "an increase in intellectual potency" understood as strategic deployment of cognitive resources (Bruner 1961).

The variety of approaches to the study of curiosity feature in turn in the variety of methods that may be successfully employed to uncover its mechanisms in early childhood. Viable measures include detection of visual and manual exploration, neural signals, physiological responses, and explicit behavioural choices. For example, the peak of the pupil dilation measured with eye-tracking equipment can be used to examine when infants are curious about what they are seeing. This measure has been successfully used with adults, correlating with self-reported curiosity (Kang et al. 2009), and with infants when they viewed sequences of images that were first scrambled and then unscrambled (Ackermann, Hepach, and Mani 2020). The amount of looking (allocation of attention) can be captured with fine-grained eye-tracking of infants' visual exploration of complex visual scenes, which has been shown in adults to correlate with their individual curiosity trait (Baranes, Oudeyer, and Gottlieb 2015; Risko et al. 2012). Similarly, suspending attention (looking away) may be a measure of curiosity's transience – determined by how rapidly curiosity subsides when a curiosity-inducing stimulus is removed. Physiological correlates of curiosity have been proposed as a decreased (decelerating) heart rate and increased skin conductance response (AlZoubi, D'Mello, and Calvo 2012; Berlyne, and Lewis 1963; Spinks and Siddle 1985), though these have to be carefully distinguished from general positive emotional arousal (Langsdorf et al. 1983; Hutt 1966; Hughes and Hutt 1979; Provost and Gouin-Dicarie 1979) and attention (de Barbaro, Clackson, and Wass 2017; Libby, Lacey, and Lacey 1973). Another implicit behaviour – facial displays of interest – can be measured in infants by coding their perplexed, puzzled, quizzical facial expressions (e.g., eyes widened and mouth slightly open, but with no smile) (Feinman et al. 1992; Hornik and Gunnar 1988; Reeve and Nix 1997). Finally, studying neural signatures is an exciting new avenue in infant curiosity research, with recent research associating theta band waves as curiosity's potential biomarker (Begus, Gliga, and Southgate 2016; Köster, Langeloh, and Hoehl 2019). Systematic and multi-faceted investigation into the cognitive correlates of curiosity is key to uncovering its mechanisms.

In sum, curiosity drives knowledge acquisition, with its mechanisms actively enabled from the first months of an infant's life and behavioural manifestations becoming more complex and sophisticated with the development of the child's cognitive capacities and communicative repertoire. Curiosity leads to the pursuit of knowledge, either specific to answer a pertinent question, or broad, to satisfy one's drive for exploring and generating information, and can manifest itself in various ways which are possible to capture using behavioural, physiological, and neural measures. What curiosity alone is not able to explain is the cognitive-affective state underlying the need to know commonly referred to as *wonder*. The next section will cover the variety of theoretical and empirical approaches specifically concerned with this state.

Wonder

Having reached the information-seeking goal of their curiosity-driven exploration, children may experience the state of wonder, understood as an emotionally laden, rewarding mental state of pondering upon their discoveries with astonishment and excitement about embarking on further deeper enquiry into the phenomenon. While 'burning with curiosity' made Alice follow the white rabbit in the first place, as her adventures unfold, she finds them 'curiouser and curiouser'.[2] In addressing how curiosity and wonder differ from each other, we emphasize affective response, reflection on obtained information, and seeking deeper and broader knowledge.

Scholars in philosophy and education disciplines have long debated about the nature of wonder (Schinkel 2020; Gallagher et al. 2015). Wonder has been defined as an astonishing, incomprehensible surprise, transcending the existing structures (Fingerhut and Prinz 2018), a combination of cognitive perplexity and intense perceptual engagement (Weger and Wagemann 2018), which is intricately linked to epistemic cognition. Two broad types of wonder have been proposed (Carlsen and Sandelands 2015; Parsons 1969; Schinkel 2017; Washington 2018): an active one (more akin to curiosity, 'wondering about') and the passive one, also called deep or contemplative wonder (more akin to awe, 'wondering at'), which "involves not knowing of a different kind – not a not-yet-knowing, but a fundamental, irresolvable not-knowing" (Schinkel 2017, 546). In this way, curiosity is a quest for knowledge that is already out there, while wonder is a quest for knowledge that may never be attainable. It is this propensity for posing essentially rhetorical, 'big questions', that may have led Socrates to famously propose that wisdom begins in wonder. Unlike curiosity, wonder can never be satisfied fully; it is not terminal as it would not disappear once relevant or missing information about the phenomenon has been discovered (Sinclair and Watson 2001). These conceptual distinctions date back to the Ancient Greek dichotomy: wonder is viewed as essentially a quest for truth, achieved by embracing holistic perception and remaining open to uncertainty, a valuable experience in itself regardless of the logical outcomes (Plato), while curiosity is a quest for information in order to fill epistemic gaps, reduce uncertainty, and deconstruct the phenomenon into parts in a rational, optimal way (Aristotle) (Schinkel 2017; Vasalou 2015). Centuries later, at the dawn of the cognitive revolution in psychological science, Bruner (1961) described a similar dichotomy in more contemporary terms: a "learning as a task of discovering" (curiosity) in comparison to "learning about" as a sought-after disposition which facilitates a deeper quest, accompanied by a sense of agency and mastery orientation (wonder).

While the contemporary field of education has been actively emphasizing the benefits of wonder for learning (Booker and Batt 2016; Jacobs and Crowley 2007; Edeiken 1992; Egan 2014; Opdal 2001) and the philosophical scholarship investigating wonder is thriving, the cognitive developmental research on this mental state is in its infancy. Below we review major advances in conceptualizing wonder – from an epistemic emotions view and a developmental perspective – and discuss the differences between wonder and related concepts such as curiosity and awe in light of these approaches.

Curiosity and similar states such as interest, surprise, wonder, astonishment, awe, doubt, uncertainty, boredom, feeling of knowing, fear of the unknown, to name a few, have been

[2] A set of cliché quotes from Alice in Wonderland is a must in a conversation about curiosity, wonder and creativity.

collectively referred to as 'epistemic emotions' (Carruthers 2017; Scheffler 1991; Vogl et al. 2019). According to these theories, affective and cognitive processes work in tandem, with epistemic emotions enriching purely cognitive activities related to the pursuit of knowledge and learning, such as information-seeking, explanation-seeking, belief formation and revision (Frijda, Manstead, and Bem 2000; Izard 1992). While other emotions, such as happiness, anger, or hatred may also affect epistemic processes under certain conditions, what makes epistemic emotions unique is their specialization in characterizing (either supporting or inhibiting) epistemic goals. Despite substantial advances in identifying a range of affective mental states that influence processes related to knowledge acquisition and revision, the nature of the relationships between some of the core emotions has not yet been clearly delineated. For instance, wonder has been included in composite measures of awe (Saroglou, Buxant, and Tilquin 2008; Shiota, Keltner, and Mossman 2007) but often used interchangeably with curiosity (e.g., "I am curious/wonder about"; Bijou 1998; Valdesolo, Shtulman, and Baron 2017) and surprise as a response to the unexpected (Frijda 1986). The causal links between concepts are also debated: according to one view, curiosity may arise from the feelings of awe or wonder and motivate exploration in order to resolve uncertainty (Frijda 1986; Izard 1977); on another view, wonder arises when curiosity-driven pursuits reach their limits (upon obtaining all pertinent information), by making one probe deeper (Opdal 2001). Despite these differences, both curiosity and wonder are agreed to be intrinsically rewarding emotional states promoting learning in the form of active explorative activities and constructive knowledge acquisition.

A classical theory providing a valuable insight into the distinction between curiosity and wonder is the Piagetian theory of cognition (Piaget 1969), proposing that at first novel information is processed in order to be incorporated into the existing knowledge base through a process called assimilation. If successful, new information forms part of the ever-expanding knowledge repository in the mind. However, if the assimilation process fails, people either abandon the attempts to learn, or this novel information instead undergoes the process of accommodation – creating new knowledge structures to adopt the incoming information. In other words, assimilation incorporates new information into preexisting epistemic schemas, while accommodation changes the preexisting schemas to absorb new information. This latter property of the accommodation process is what links it to wonder as a qualitative and quantitative expansion of curiosity-driven information acquisition.

A combination of both the epistemic emotions view and the accommodation process of cognition lays a foundation for empirical study of the state of wonder and its cognitive origins. Schinkel (2018) urges psychologists (in addition to educators and philosophers) to dedicate more attention to wonder, especially as distinguished from curiosity and awe. We further propose that study of wonder would benefit from a cognitive development perspective, because understanding of early manifestations of any psychological phenomena may help explain complex cognitive mechanisms underlying these processes in adults.

Despite a well-developed theoretical base, empirical developmental research on wonder is lacking. One argument limiting research on wonder from a cognitive developmental perspective is that as a complex, reflective state requiring sophisticated metacognitive abilities, wonder may not be readily accessible to young children. Studies of metacognition generally conclude that children's ability to self-monitor their own affective and cognitive processing is not present until the preschool years (Sodian et al. 2012; Sobel and Letourneau 2018). Children's use of verbs related to epistemic states, such as 'know', 'guess', and 'remember' starts at around the age of three (Johnson and Wellman 1980), and children's explicit understanding of complex emotions not until the primary school years (Russell and Paris 1994). Counter to this view, rudimentary metacognitive processes have been shown as accessible to children even before they mastered language (Gliga and Southgate 2016; Goupil and Kouider 2019). Various proxies for implicit measurement of infants' awareness of their metacognitive states have been used, such as conceptualizing a state of epistemic uncertainty as a delay in making a choice or persistence in attempts to find reliable information. For example, preverbal infants, using social looks and pointing as communicative tools, are able to strategically request information from other people when they are aware of their ignorance; e.g., when they don't know where the toy was hidden but know that their parents can provide this information (Goupil et al, 2016) or when they don't know the label to a novel object but know who can provide it (Bazhydai et al, 2020). If we accept that wonder as a unique experiential state is indeed accessible to young children and even preverbal infants, just as curiosity or uncertainty which have been actively studied in this population, similar implicit measures can be employed to capture its cognitive origins.

What does wonder look like? A child experiencing wonder may be the one whose eyes are sparkling with excitement and amazement, one that pauses to think about the encountered phenomenon, one that persists in discovering more about the object that elicited wonder, or one that is not satisfied with the available answers. As we cannot rely on asking children what they think or feel, the use of objective rather than self-report measures becomes instrumental. Wonder may manifest itself neurally, physiologically and behaviourally in several ways. For example, we may record and analyse the overt observable behaviour, such as the kinds of questions that children may ask in wonder, as differentiated from other similar cognitive-affective states such as curiosity or awe. Such fine-grained behavioural analyses would allow disentangling the very conceptual uniqueness of wonder. Similarly, we may attempt to uncover the neural underpinnings of wonder by using techniques such as EEG or NIRS, or physiological signatures such as heart rate or skin conductance response, which, when compared with findings on other related states may pinpoint the exact biomarkers of wonder.

To develop such measures specifically, we need to adopt a working operational definition, for example one like this: an intense, emotionally uplifting experience whereby the person becomes aware of an expanded field of possibility for thought or action and engages in exploring this field (after Glăveanu 2017, 2). This definition is two-fold, invoking several specific measures as plausible candidates. For example, the intensity of an emotional state can be detected through implicit measures of physiological arousal (heart rate and skin conductance response), facial expressions via EMG or pupil dilation response. These measures may allow us to distinguish wonder as an intense, expansive experience following astonishing events (both external and internal) from curiosity as less emotional and more iterative, rational information acquisition. That is, a wonder response should extend beyond preferentially attending to, approaching and exploring the unexpected events (Sim and Xu 2017; Stahl and Feigenson 2017, 2019).

The second aspect of wonder according to the adopted operational definition – awareness of expanded possibilities and their passionate exploration – can be assessed both quantitatively and qualitatively. Children's desire for more knowledge may manifest itself in repeated searching for information, lack of satisfaction with immediately available evidence, seeking corroborative evidence, and returning to the topic that sparked their wonder even when all explanations have been received. Aimed at explanatory expansion upon witnessing anomalous or ambiguous facts, this 'wondering about' (Carlsen and Sandelands 2014) may prompt children to engage in the so-called 'passages of intellectual search' (Tizard and Hughes 1984) – a persistent stream of questions and explanations offered by children themselves as they strive to arrive at the truth about the phenomena of interest, above and beyond the routine 'why' questions (Chouinard, Harris, and Moratsos 2007; Frazier, Gelman, and Wellman 2009; Legare 2012; Ronfard et al. 2018). This may also manifest itself in the number of comments and emotional content in such remarks, connecting the topic of the wonder-inducing phenomenon to personal experiences, and posing rhetorical questions.[3] In preverbal infants, wonder can be measured as information seeking (e.g., through pointing or approaching objects) following reliable and timely attainment of key missing information (e.g., a novel label or demonstration of a toy's function). That is, upon satisfying the need for information through curiosity, wonder is likely to keep infants inquiring about the same object or event leaving them unsatisfied with the answers. The length of time dedicated to asking such questions and further exploration may serve as a proxy for the measure of wonder.

While given a lot of attention in philosophy and education, wonder remains an undeveloped psychological concept with its position in relation to similar terms unclear. To the best of our knowledge, no empirical work in cognitive development has investigated wonder as such. This may be due to young children's underdeveloped emotion and metacognitive skills and methodological challenges to detect the experience of wonder, which is among the "precious but elusive psychological states that are difficult to research experimentally" (Weger and Wagermann 2018). The study of wonder conceived as an epistemic emotion and a cognitive accommodation process is a promising avenue for future research, in combination with a range of cutting edge approaches to study complex cognition in early childhood.

To reiterate, wonder, and specifically its active, inquisitive type, just as curiosity, enables knowledge acquisition, but takes this process to a different level, a step forward towards knowledge transformation. In the range of 'playful interactions' with the environment (Piaget 1945), wonder underlies the desire to go further, deeper and broader than curiosity, the latter being transient and inherently terminal. In a quote brought up earlier in this chapter, Piaget (1969, 139) mentions that information acquisition allows the child to arrive at a state of mind that is both irreducible, in that the uncertainty has been resolved, but also 'indefinitely extensible'. This added value property, though not called wonder by Piaget explicitly, may refer to probing the field of knowledge further, allowing for multiple perspectives as a pathway to creative knowledge transformation (see Glăveanu 2017 for a proposed relationship between wonder and creativity).

Creativity

> *Sometimes I've believed as many as six impossible things before breakfast.*
>
> *"I see nobody on the road," said Alice.*
> *"I only wish I had such eyes," the King remarked in a fretful tone.*
> *"To be able to see Nobody! And at the distance too!*
> *Why, it's as much as I can do to see real people, by this light!"*
>
> Lewis Caroll, *Alice in Wonderland*

From a cognitive perspective, creativity includes a set of mental processes (rather than a particular personality or genetic predisposition) which manifest themselves in overt behavioural choices, such as coming up with multiple ideas (divergent thinking), forming unusual associations

[3] As an educationally minded side note, the beneficial role of the adults engaged in such passages is that in addition to resolving misunderstandings and presenting counterinformation if needed, they help children clarify and extend their own ideas and explanations. By questioning their ideas, adults facilitate the development of children's independent reasoning and intellectual growth.

(associative thinking), combining elements based on such remote, non-obvious associations (combinatory thinking), and transforming the existing structures in original ways (transformative thinking) (Guilford 1968; Finke, Ward, and Smith 1992; Mednick 1962; Rhodes 1961; Simonton 2010). Tolerance to ambiguity, flexible thinking, plasticity of mental structures, and openness to experience enable these processes. In contrast, functional fixedness, reliance on heuristics, context rigidity, hyper-precise prior probabilities as inability to update beliefs based on new incoming information, and general avoidance of new experiences are detrimental to creativity. Creativity thus can be conceptualized as a cognitive process leading to original modification of existing information and generation of new knowledge. We focus here on three core cognitive facets of creativity: idea generation or divergent thinking, novel combination, and original transformation.

Creativity manifestations in early childhood are difficult to pinpoint. One difficulty is lack of developmentally appropriate measures applicable to the very young population. Even with adults, measures of creativity lack consistency and vary greatly with the conceptual approach chosen by the researchers (Baptiste 2019; Said-Metwaly, Van den Noortgate, and Kyndt 2017). A second challenge comes from adherence to the argument that children simply do not exhibit creativity in its true, eminent, genius-type sense (Feldhusen 2002; Weisberg 1999), also called the 'Big C' (Kaufman and Beghetto 2009). This argument is dismissed by adopting a perspective of the so-called 'little c' creativity rooted in everyday playful imagination, undoubtedly accessible to young children (Amabile 2012; Bateson 1999; Craft 2001; Russ 2014). Accepting the premise that young children and even infants do not lack sufficient cognitive complexity to exhibit rudimentary creative behaviours (Glăveanu 2011; Engel 1993; Jalongo and Hirsch 2012), here we review how creativity manifests itself and how it can be measured in early childhood in order to better understand how these cognitive capacities develop.[4] The literature on children's creative *process* (as opposed to artistic outputs or other creative products; Rhodes 1961) is typically represented with several related but distinct strands: object play, imaginative play, and tool innovation. We review how the facets of idea generation, combination, and transformation are present in each of these strands and suggest ways to study these in young children.

Just as children actively seek information in curiosity-driven exploration, they actively engage in creative expression and experimentation with objects. While exploration and play are often discussed interchangeably in child development literature (Power 1999; Wohlwill 2018), the two are distinct. It has been suggested that children's play with objects is an early manifestation of creativity as only during play (but not exploration or other rational use of objects, such as construction) children create novel ways of using objects (Pellegrini and Hou 2011; Pellegrini 2013). Pointing to their unique role in cognition, exploration and play have been differentially linked to physiological arousal levels (Hutt 1966): exploration correlated with elevated heart rate, while play with lower heart rate. During object play, children go beyond the systematic acquisition of information afforded by the object (e.g., learning that it rotates or plays music when a button is pressed, etc.) and using the object properly (e.g., using a block to build a tower), to inventing novel ways to use the object (e.g., using unrelated, random objects to build a tower). Hence, they exhibit freedom from constraints of what is known and find creative opportunities where none existed. Both infants' and adults' playfulness have been shown to serve as a precursor to later creative outcomes (Howard-Jones, Taylor, and Sutton 2002; Lieberman 2014; Sutton-Smith 1967), and an

[4] In the words of Vygotsky: "One of the most important questions of child psychology and pedagogy is the question about creativity in children, its development and its significance for the general development of the child." (Vygotsky 1930/1967, cited in Smolucha 1992, 51).

evolutionary perspective highlighted the role of object play in cultural innovation (Riede et al. 2018).

Developing as early as eighteen months (Skolnick and Bloom 2006), a more cognitively complex process – pretend or imaginary play – has also been conceptualized as a manifestation of creative processes (Russ and Fiorelli 2010; Russ and Wallace 2013; Vygotsky 1967, 2004; Weisberg 2014). Imaginary play, similar to object play, is inventing novel ways of using an object, but here, it involves substitutions of functions of objects and creating new meaning (e.g., pretend that it can fly). During imaginative play, the child demonstrates remarkable tolerance to uncertainty, "not bothered by inconsistencies, departures from convention, nonliteralness (...) which often results in unusual and appealing juxtapositions and associations" (Gardner 1993, 228). This openness to new experiences and actively creating such experiences is possible due to a heightened alertness to opportunity – ability to notice relevance of available information (objects, people, situations) for potentially including it into the pretend play space. Inspired by this child-like capacity, Torrance (1988) trained adults who have performed poorly on standard creativity tasks to appreciate a cue-rich environment and take advantage of unrelated objects and concepts for creative recombination and transformation.

Another way in which creativity manifests itself in early childhood is through spontaneous tool innovation (Beck et al. 2011; Carr, Kendal, and Flynn 2015; Cutting et al. 2014). Innovation along with imitation are considered the "dual engines of cultural learning" (Legare 2015), playing complementary roles in knowledge acquisition and transmission (Carr, Kendal, and Flynn 2016; Heyes 2012; Want and Harris 2002). Unlike imitation following a social demonstration, children's tool innovation in experimental tasks has been rarely observed (Chappell et al. 2013). This is typically explained by their propensity to learn socially and to conform in their tool use after observing someone else (Flynn, Turner, and Giraldeau 2018; Turner, Giraldeau, Flynn 2017), especially someone with a history of efficacious and reliable demonstrations (Carr, Kendal, and Flynn 2015). However, recent research suggests that children are more likely to use a tool in a novel way when its original purpose became clear rather than when it remained causally opaque (Neldner, Mushin, and Nielsen 2017) and when the efficacy of the adults' demonstration was low, leaving space for further experimentation (Carr, Kendal, and Flynn 2015). Furthermore, research with adults shows that other people's social performance cues may influence innovative choices (Toelch et al. 2011). In this vein, infants as young as 30 months of age have been shown to be able to achieve tool innovations when socially guided to do so, but not when left on their own (Hayne, Herbert, and Simcock 2003; Barr and Wyss 2008). Overall, the infrequency in reporting innovations in experimental studies may be the result of methodological shortcomings, where such behaviours may be discarded as anomalous findings rather than properly pursued (Carr, Kendal, and Flynn 2016). Despite these challenges, two kinds of spontaneous innovative behaviours in childhood have been identified: independent invention (such as creating a novel tool from scratch) and modification (such as adopting an existing tool for a new purpose) (Carr, Kendal, and Flynn 2016).

One of the core pillars of the creativity process is idea generation, or divergent thinking – an ability to come up with multiple ideas, alternative scenarios, thoughts and actions. In adults and older children, divergent thinking is tested using a variation of the classical Unusual Uses task (Torrance and Haensly 2003; Mouchiroud and Lubart 2001). Here, a person typically is asked to list as many uses for an everyday object, e.g. a paperclip, as they can (e.g., Alternative Uses Test: Guilford 1967; Torrance Test of Creative Thinking [TTCT]: Torrance 1974; Thinking Creatively in Action and Movement test [TCAM]: Torrance 1981; Wallach and Kogan tests of creativity: Wallach and Kogan 1965). The number and breadth of unusual uses are then scored to assess the level of creativity. Divergent thinking has been assessed in the verbal (report on various ideas), figural (drawing), kinaesthetic (movement) and manual (object use) domains. The latter is most useful from a cognitive developmental perspective since young children may not have yet developed language or drawing ability. In a recent demonstration of the applicability of the divergent thinking measure in preverbal infants, Hoicka and colleagues (Bijvoet-van den Berg and Hoicka 2014) used a colourful wooden box with several exciting features and five unrelated objects. Here, divergent thinking was coded as the number of different action-box area combinations infants applied during a free play episode (e.g., hitting the edge of the box and then guiding an object through the hole). Evidence also suggests that young children increase their action innovations following social modelling of divergent thinking behaviours by adults (Hoicka et al. 2016). While divergent thinking received the most attention in both adults' and children's creativity measures, it has been pointed out that over-reliance on this one measure is inappropriately reductionist as it misrepresents the dynamic, complex nature of creativity processes (Baptiste 2019; Baer 2016).

The second facet of creative cognition is the ability to come up with novel combinations. Here, unlike in divergent thinking where novel ideas depart from the known, the process is building heavily on the elements of existing knowledge, which are then combined in a novel way. At the core of this process lies the ability to re-imagine the existing structures – also called creative problem-finding (Runco 1994). In a seminal study with adult artists, Csikszentmihalyi and Getzels (1971) presented participants with a range of objects to use in a still-life drawing. The longer the artists spent choosing the objects, manipulating and rearranging them in several potential combinations, and the more objects they picked up, feeling their weights and textures and trying to work out their mechanical parts – in other words, time spent 'finding' a creative problem – the higher were their creativity scores received on the final drawings. Combinatory properties of creativity lie at the core of several major cognitive-based approaches, implicating the role of associative thinking, insight, mental imagery, conceptual combination, expansion and synthesis (Finke, Ward, and Smith 1992; Helie and Sun 2010; Mednick 1962; Simonton 2010; Thagart and Steward 2011). For example, in a creative synthesis task (Finke 1990), adults are tested on their ability to construct creative objects by mentally combining the components they are presented with into a potentially useful entity. The process of insight is understood here as an underlying cognitive restructuring of the problem that allows coming up with a sudden solution (Bowden et al. 2005; Gilhooly and Murphy 2005; Schooler and Melcher 1995).

The third core facet of creativity is the ability to make original transformations. Like with combinations, this process relies on some existing knowledge as a baseline structure, which is then modified in a novel way. For example, in a classical creativity task used with adults and children (TTCT; Torrance 1974), participants are asked to transform an incomplete figure by coming up with additional elements to complete the drawing. Similarly, the symbolical equivalence test (Barron 1988) measures the ability to make original transformations of objects or concepts, such as thinking of relevant metaphors or symbols. Such image transformation ability has been shown to correlate with performance on other creativity tasks in adults and predicted originality of their inventions (Palmiero et al. 2015). For young children, the process of pretend play serves as an excellent illustration, as children use existing objects but transform their meanings such that they depart from routine use (Russ 2013), transforming their imagination into reality (Vygotsky 2004). Thus, the ability to transform presents a viable line of research with young children.

How can divergent thinking, combinatory and transformative creative processes be measured in young children, keeping aside tasks that rely heavily on language or ability to draw or make other forms of art? Observational and behavioural experimental studies come to the forefront here, accompanied with fine-grained coding. Children may be observed while playing with a novel toy affording multiple actions and outcomes, just like the unusual box task (Bijvoet-van den Berg and Hoicka 2014). Measuring the number of unique actions performed is a clear proxy for divergent thinking, while the sequences of actions and specific action combinations can be coded as a proxy for combinatorial thinking. Here, the behaviour of interest is deviation from the typical use when two or more of such uses are combined. Transformation can be observed when children put together two unrelated objects in the process of play to create new meaning. A similar observation can be made when children engage with other elements which can be potentially combined or transformed, aside from toys or play objects. An example is providing children with a musical instrument like a piano or a xylophone, or a 'music wall' or 'music stairs' – an interactive sound sculpture of various shapes and colours – affording a range of musical keys. Creating novel musical sounds by combining them, transforming the sound of a single 'press' by adding other elements such as tapping or singing to them can be reliably coded by independent observers. Museums have long recognised the value of exhibits encouraging children's creativity and it is time that cognitive science learns from them (e.g., Association of Children's Museums 2015; Herz 2017; Luke et al. 2017). A variation of such tasks may capitalize on children's propensity to engage with mundane, everyday objects in an original way. A sample task to measure this process would be to offer them plain objects, such as wooden blocks or shipping cardboard boxes, and prompt their free play with them, subsequently coding how long and in what way they engage in the process, or even coding fluency, flexibility and originality of generated actions using the standard Consensual Assessment Technique (Amabile 1982).

Implicit neural measures of the creative process are also possible with children with techniques such as fNIRS and EEG. Studies with adults have long implicated the brain's default mode network (Beaty et al. 2014; Immordino-Yang, Christodoulou, and Singh 2012), dynamic interactions between the large-scale brain networks (Beaty, Seli and Schacter 2019), and alpha and theta oscillations activity (Fink and Benedek 2014; Stevens and Zabelina 2019) as correlates of creative thinking. EEG has long been a staple neuroscience method for studying various aspects of infant cognition (Saby and Marshall 2012), and advances in fNIRS have brought it to the forefront of cognitive developmental scientists in recent years (Wilcox and Biondi 2015). Proving the utility of this method for studies of infants' developing default mode network as a signature of creative processes, a study using the fNIRS brain scanning technique was successful in capturing the default mode network activity in 18-month-olds (Bulgarelli et al. 2019). In sum, a combination of novel behavioural tasks and neural correlates capturing the facets of creative thinking in young children is necessary to move the cognitive developmental science of creativity forward.

Creativity as a cognitive process involves forming unusual associations, coming up with unconventional ideas, and making use of available resources and context in an original way. These novel ideas are possible due to a flexible attentional system, shifting perspective, noticing elements that were initially unnoticeable, and perceiving remote affordances in everyday objects and situations. Three core facets of creativity – divergent, combinatory and transformative thinking – are exhibited in children's object play, pretense and tool innovation activities, which form the base for experimental study of creativity process in childhood.

What is the relationship between curiosity, wonder and creativity?

We proposed that curiosity, wonder and creativity are complementary processes in cognitive development: curiosity drives exploration of the environment to gain new knowledge, wonder pushes the boundaries of acquired knowledge, and creativity enables active manipulation of the environment to generate new knowledge and encourage new opportunities for learning. How exactly are these processes related to each other?

Studies with adults have shown that curiosity, both specific and diversive (per Berlyne's typology, 1954), predicts creative problem solving and performance (Hagtvedt et al. 2019; Hardy, Ness, and Mecca 2017; Harrison 2016). Here, idea generation as a staple of the creativity process is fueled by either diversive thinking, desire for novelty such as a brainstorming session (Voss and Keller 1983), or the cognitive process of iterative, step-by-step idea linking (Hagtvedt et al., 2019). Curiosity and wonder as an intrinsic need for knowledge are proposed to be the means for reaching creative goals (Kashdan and Fincham 2002; Taylor 1964). On another account, an expansive state of wonder (the kind most similar to awe) affects creative thinking through modification of preexisting mental frames and openness to alternative perspectives (Chirico et al. 2018). However, the existing research is both limited, due to an overwhelming reliance on self-report measures (e.g., essentially asking adult participants: "Are you a curious/wondrous/creative person?" which is very prone to social desirability biases), and inconclusive, as it often does not take into account personality traits such as openness to experience, which is equally predictive of curiosity, wonder and creativity (Hunter et al. 2016; Silvia et al. 2015). Furthermore, curiosity conceptualized as a stable trait has been shown to form part of one's creative self-efficacy and creative personal identity (Karwowski 2012), thus reducing curiosity to an aspect of creativity and generally blending the distinctions between these concepts (Arasteh 1968; Maw and Maw 1965; Penney and McCann 1964). Nevertheless, research with adults firmly intertwined curiosity, wonder and creativity, although the causal direction and the nature of these links remain to be better understood. Several theoretical approaches are plausible.

One line of thinking proposes a linear relationship, in that curiosity and wonder are direct precursors to creativity: the generative power of curiosity may lead to a state of wonder, which may in turn lead to creative pursuits. In more detail, exploration of the environment leads to accumulation and integration of multiple experiences and perspectives through assimilation and accommodation of existing information. Creativity then follows as modification and transformation of this information in order to generate new knowledge. The traces of this idea are present in early cognitive developmental literature. Vygotsky (Ayman-Nolley 1992; Lindqvist 2003; Vygotsky 2004) proposed that accrual of experiences and a combinatorial process applied to what is known are the building blocks of creative thought.[5] Similarly, the Piagetian account of knowledge construction through playful interactions with the environment (Piaget 1945; 1969) posits the accumulation and accommodation of multiple scenarios and perspectives as a pathway to creativity. Hence, the richness of experience, both quantitatively and qualitatively, ultimately affects the richness of creative imagination.

The following two theoretical models specifically link wonder and creativity in this way and are ripe for empirical investigation. Glăveanu (2017) argues that a wondering person is able to entertain and adopt multiple perspectives, to engage with the possible and the impossible in novel ways, and to inhibit conventional schemas. Having opened up the possibility for multiple perspectives, a person can then explore those perspectives through creation. A pillar of creativity – divergent thinking – is rooted in engagement with the expanded space of the possible. Schinkel (2017) similarly suggests that wonder's openness to experience, eagerness to inquire, desire to understand, and willingness to suspend judgement and bracket existing – potentially limiting –

[5] "…the creative activity of the imagination depends directly on the richness and variety of a person's previous experience because this experience provides the material from which the products of fantasy are constructed." (Vygotsky 2004, 9).

ways of thinking, seeing, and categorizing, paves the way for creativity. On the one hand, wonder pushes the boundaries of what is known to the realm of the still mysterious phenomena; on the other hand, "wonder defamiliarizes the familiar, making it appear in a new light, as if seen for the first time" (Schinkel 2017, 543). Regardless of how familiar or novel the object of wonder is, it is the active act of wondering that makes subsequent divergent thinking possible.

Non-linear relationships between curiosity, wonder and creativity are also possible. First, the process may flow in the opposite direction depending on the stage: engaging in a creative act (e.g., playing a musical instrument) or witnessing it (e.g., attending a symphony concert) may put one in a state of wonder, and further prompt to search for specific information (e.g., what is the history of this symphony), which may in turn lead to more wonder (e.g., learning about a baffling fact), fueling another phase of creativity (e.g., writing a poem inspired by the unexpected fact). Second, the three states may be deeply interlinked so that dissociating them into curiosity, wonder and creativity at any particular moment may not only be impossible but would also be detrimental to properly accounting for complex dynamically evolving cognitive phenomena (see dynamic systems approaches for a similar argument, e.g., Smith and Thelen 2003). Third, the three states may be cross-fertilizing. Presenting a cyclical approach to creative cognition (Finke, Ward, and Smith 1992), the Geneplore model (made of verbs *generate* and *explore*), presents curiosity (pre-inventive exploration) and creativity (generation of pre-inventive structures) as a means to each other in a cognitive process. For example, in preparation for writing a book, a writer may gather information about the époque, traditions, and people in their story. This would be the curiosity or exploration stage. Upon obtaining this knowledge, rooted in already existing and now discovered information, they then transform the facts in an original way, eventually generating new knowledge. This would be the creativity or generation stage. Here, creativity follows curiosity, which in turn enables further transformations and modifications so that generative and exploratory phases work in tandem, enabling creative transformation both through conceptual change and focused decision making.

In sum, both linear and non-linear relationship models between curiosity, wonder and creativity are open for experimental investigation. Studies with adult participants, primarily in personality and social psychology research, have obtained mixed findings (see Loewenstein 2014 for a discussion; Voss and Keller 1983), which may reflect the lack of measurement validity, or alternatively, show that curiosity, wonder and creativity are not best measured as stable traits. The links between curiosity, wonder and creativity in childhood have been proposed but underspecified (Cecil et al. 1985), hence necessitating advancement in experimental research rooted in cognitive approaches in order to delineate their relationship and specify their developmental precursors.

Conclusions and further directions

> *"What is this?" he said at last.*
> *"This is a child!" Haigha replied eagerly, coming in front of Alice to introduce her (…).*
> *"We only found it today. It's as large as life, and twice as natural!"*
> *"I always thought they were fabulous monsters!" said the Unicorn. "Is it alive?"*
> *"It can talk," said Haigha solemnly.*
> *The Unicorn looked dreamily at Alice, and said "Talk, child."*
>
> Alice in Wonderland, Lewis Carroll

The intellectual fascination empowering every study designed by a cognitive developmental psychologist comes from the inability of young children to talk: if only these "fabulous monsters" could tell us all that we want to know about their curiosity, wonder, and creativity! In this chapter, we focused on these three concepts, intrinsically linked to each other but often used and researched without due attention to fine differences and causal links between them. Having developed clear operational definitions, the field of cognitive development would be able to undertake empirical investigations into these phenomena, which will in turn enable a better understanding transferrable to other scholarly fields.

We presented a range of theoretical models along with emerging evidence on how curiosity, wonder and creativity underlie knowledge acquisition and knowledge transformation in early childhood. Curiosity is an intrinsically motivated, deliberate form of information-seeking through independent exploration and active social learning. Wonder is conceptualized as an emotionally uplifting, expansive quest for more knowledge through questioning of existing frames. The transition from knowledge acquisition to its transformation begins with wonder, which expands the possibility space for knowledge beyond what already exists, motivating further discovery-oriented processes to search more broadly and inquire more meaningfully. Both curiosity and wonder seem to be useful prerequisites to creativity, understood as generation of novel ideas, original transformations and novel combinations of the existing structures. As both curiosity and wonder enable learning, knowledge acquisition as a goal in itself eventually extinguishes curiosity, while it does not detrimentally affect either wonder or creativity. Creativity allows to develop new knowledge regardless of what already exists or is potentially attainable. In a nutshell, curiosity is assimilation of information, intellectual activity in search of knowledge to achieve a reduction in uncertainty, whereas wonder pushes the door open to uncertainty, and creativity allows for modification and transformation of information and is only possible with a high threshold of tolerance to uncertainty.

It is premature to infer the causal links between these concepts. Cognitive processes may change dynamically from seeking specific information and engaging in broad exploration, to pondering upon discoveries and posing original questions, to generating novel ideas and transforming existing structures. Unanswered questions abound. Future research may ask whether curiosity and wonder differentially affect learning or creativity outcomes, or whether individual differences in trait curiosity remain stable across development and are retained in adulthood. To test the proposed linear relationship between these concepts, it may be asked if curiosity and wonder necessarily precede creative thinking; does one need to have satisfied one's curiosity about the topic before the creative process can start? While curiosity seeks out relevant, pertinent, and reliable information to satisfy its goal, what kind of information is suitable for wonder and creativity? While we know that curiosity subsides once the missing information has been obtained, wonder may be much more open-ended. What about creativity? Does one stop being creative upon believing to have found the most creative solution? Is it the abundance of cues and information or rather its scarcity that is conducive to creativity, given its reliance on perceiving non-obvious affordances in the environment? We hope to see future research engage with these and other fascinating questions.

Furthermore, essential both for enabling optimal experimental investigations and effective educational interventions is an answer to the question whether curiosity, wonder or creativity can reliably be induced. Some suggestions to facilitate curiosity are to encourage question-asking and critical thinking, expose children to counter-intuitive evidence, pose follow-up questions to probe further interest, encourage sharing interest with others, and create informationally rich environments. Wonder can be supported through exposure to various fascinating phenomena, dedicating time and space to experience and reflect upon them, access to a variety of information sources, promoting tolerance of uncertainty and complexity, and being open and welcoming to new experiences. Creativity thrives in judgement-free, playful environments, conducive to artistic and emotional expressivity, and benefits from the use of trainable cognitive skills such as divergent thinking, conceptual combination, associative thinking, and cognitive flexibility. A more fundamental question, however, is whether a generic approach fits every child (Parsons 1969). For instance, we may have assumed that seeing the northern lights for the first time is a likely generic candidate for inducing wonder and started to use this as an experimental induction in our study. But what about those children for whom encountering a challenging mathematical problem is most wondrous, while the wonders of nature leave them unaffected? We would be devastatingly wrong to conclude in our experiment that these children were unable to experience the state in principle or were less prone to wonder. Considering such inevitable individual differences, longitudinal methods may be most instrumental in detecting developmental change in the behavioural, neural and physiological manifestations of curiosity, wonder, and creativity. Finally, while in this article we chose to focus on the cognitive developmental approach to the study of curiosity, wonder and creativity, other fields of empirical inquiry, such as phenomenological research, embodied cognition, or psychoanalysis, among others, may also substantially contribute to our understanding of these phenomena.

The abundance of practical guidelines for parents, educators and psychologists urges them to foster curiosity, nurture wonder, and encourage creativity in children, often lacking supporting empirical data for the proposed interventions. Such evidence could be generated with the use of age-appropriate, interdisciplinary measures providing insight into underlying cognitive processes, asking feasible research questions, and conducting longitudinal studies marking individual trajectories in development of curiosity, wonder, and creativity.

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