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A Systematic Review of Curiosity and Wonder in Natural Science and Early Childhood Education Research

Anne-Line Bjerknes, Terese Wilhelmsen, and Emilie Foyn-Bruun

University of South-Eastern Norway, Drammen, Norway

ABSTRACT

Disagreement exists about how to best spark young children's motivation to learn natural science. Both curiosity and wonder are considered important motivational factors for learning during early childhood (0–8 years). This systematic literature review explores research about scientific curiosity and wonder in early childhood education and care published from 2010–2020. The review outlines the population of interest (participants in the study, age of children, study location), methodological trends, and how curiosity and/or wonder are included in the research. The search yielded 300 peer-reviewed articles, of which 33 were included for analysis based on eligibility criteria. The main results showed that: (a) the term "curiosity" was more commonly used than the term "wonder," (b) few studies elaborated on their understanding of the two terms beyond them being naturally present in children, and (c) curiosity and/or wonder were emphasized as means to learn natural science or considered as stimulated by it, although few studies discussed how children's curiosity and wonder can be observed and nurtured. With a better understanding of what defines the terms curiosity and wonder and how to foster these qualities in early childhood education and care, we can learn to better support children's intrinsic motivation for science learning.

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Curiosity; early childhood education; learning; natural science; wonder

Triggering curiosity and wonder is considered an important factor in early childhood education (ECE) to stimulate the motivation for learning natural science. However, there are differences in opinion on how these concepts are understood and how they play a role in children's learning (Jirout & Klahr, 2012). For example, in an ongoing debate on natural science learning in ECE, both Lindholm (2018) and Hadzigeorgiou and Schulz (2019) challenge the established view of natural science learning and suggest that learning should emphasize a romantic understanding (Egan, 1992), rather than only theoretical learning. To achieve a romantic view of science, wonder is invoked in the process to explore the extremes and limits of reality and human experience (Hadzigeorgiou & Schulz, 2019). For example, children are often surprised by the simple fact of seeing that things "exist." L'Ecuyer (2014) suggests that infants and children have a capacity for wondering that is much greater than that of adults, perhaps because children experience what is around them, again and again, as if it were for the first time. According to a wonder approach, the teacher facilitates the process of connecting the mind, the will, and the heart of the child with what is true, good, and beautiful, so that, when older, the child will eventually be able to identify and discover these things "by itself" (L'Ecuyer, 2014). The more traditional view of natural science learning argues that conceptual learning and understanding are important and applies several different teaching methods, such as play (e.g., Fleer, 2009, 2019), inquiry activities (Tytler & Peterson, 2003), reading literature (McLean et al., 2015; Sackes et al., 2009), and

CONTACT Anne-Line Bjerknes anne-line.bjerknes@usn.no University of South-Eastern Norway, Postbox 7053, 3007 Drammen, Norway

digital learning (Herodotou, 2018). A common factor for many of the studies on conceptual learning is an emphasis on children's curiosity via conversations and inquiry-based activities.

To discuss the role of curiosity and wonder in ECE, we need to first understand their difference and similarity in more detail. Being surprised seems to be an optimal starting point for both curiosity and wonder (Valdesolo et al., 2017). However, being surprised may promote different engagement by children, depending on whether the surprise derives from curiosity or wonder.

Curiosity often has been referred to as the desire for new experiences and learning, or the appetite for acquiring new knowledge (Kang et al., 2009; Kidd & Hayden, 2015; Loewenstein, 1994; Shin & Kim, 2019). From a biological perspective, curiosity in primates has been described as a basic biological drive that is an important motivational force for discovering new ways to solve problems and to adapt successfully and continually (Barto, 2013; Gazzaniga, 2005; Swan & Carmelli, 1996). One hypothesis regarding why curiosity is important for humans is that the brain generates intrinsic rewards that assign value to learning or information per se (Berlyne, 1960; Bromberg-Martin & Hikosaka, 2009), and that these rewards are activated by thought patterns that induce curiosity in humans (Jepma et al., 2012; Kang et al., 2009). The fact that curiosity also is found in several other species, such as dogs (Strandberg et al., 2005), elephants, and monkeys (Byrne, 2013), support two hypotheses: 1) curiosity has a genetic basis and 2) curiosity is supported by an intrinsic reward system shared among mammals, including primates.

The link between curiosity as a driving force in human exploration has been further elaborated in motivational theories, such as the self-determination theory (SDT; Ryan & Deci, 2000) and the growth mind-set (Dweck, 2006). From a motivational perspective, curiosity is often linked to related concepts such as intrinsic motivation, interests, and learning; however, relational assumptions between these concepts differ among perspectives. Silvia (2012) distinguishes between three main directions of motivational research on curiosity. The first direction proposes that curiosity is elicited by deficit motivation (i.e., people are motivated by filling knowledge gaps and by reducing uncertainty) (Silvia, 2012). One common theoretical perspective is the information gap theory (Loewenstein, 1994), and several studies have shown that partial knowledge induces curiosity and that curiosity is highest in people with intermediate confidence in their answer to a given question (Kang et al., 2009; Loewenstein, 1994). However, being confronted with a novel stimulus does not necessarily induce curiosity. To induce curiosity, a person must perceive the stimulus as interesting and worthy of attention (Kashdan et al., 2020), and the person must believe that s/he can cope sufficiently with the potential stress of exploring something new (Silvia, 2008). Research does not support educational methods, such as "pure discovery without guidance" (Honomichl & Chen, 2012). If a child does not encounter the to-be-learned principle, discovery will not be useful to make sense for the learner (Kirschner et al., 2006; Mayer, 2004) because all teaching is based on preexisting knowledge (Question 11 in Aquinas, 1953), which also resembles the zone of proximal development (Vygotski, 1978). For children, this suggests that to become curious about, for example, a natural phenomenon, they need to know something about this phenomenon in advance and it must not be too difficult to explore. Parents and ECE teachers may spark this awareness further, depending on how much knowledge they have on the topic of interest, or how well they can support children's exploration through curiosity and wonder.

Another strand emphasizes curiosity as motivation "for its own sake" (Silvia, 2012, p. 159). In this perspective, curiosity is an intrinsic drive for exploration, learning, and inquiry. This suggests young children will become curious about something if they already have some knowledge about it. If the aim is to improve children's motivation for learning about natural science through curiosity and they need to know something about it first, then we easily end up in the first strand where curiosity is driven by the lack of knowledge about something, thus the gap theory. In SDT, for example, intrinsic motivation is proposed as the optimal form of motivation in which people freely engage in activity out of personal interest (Ryan & Deci, 2017). Researchers have also attempted to distinguish between the different emotions curiosity experiences can evoke. A common scale used is the Five-Dimensional Curiosity Scale (5DC/5DCR), which distinguishes between joy explorations, deprivation sensitivity, stress tolerance, thrill seeking, and overt/covert social curiosity (for more information, see Kashdan et al., 2018, 2020). Others have explored how curiosity is linked to interests using a variety of measures of curiosity (Silvia, 2008; Wagstaff et al., 2021).

A third strand of research has focused on individual differences in curiosity. An example is the distinction between curiosity as a personality trait (i.e., the proneness to experience momentary curiosity frequently, in various conditions and over prolonged periods) and the more discrete and unstable state curiosity (Kashdan & Roberts, 2004). In children, this is perhaps a factor that can be manipulated, as we know children's brain structure and function is influenced by environmental influences, such as parenting (Miguel et al., 2019) or childcare in ECE. Hence, it is likely that children's upbringing may affect how curious they are or will be later in life. Curiosity research also differentiates between different facets of curiosity. A common distinction used is the difference between perceptual and epistemic curiosity (Berlyne, 1954). Perceptual curiosity describes the drive for increased perception of an object and can be defined as "the direct sensory motor exploration of objects and situations" (Stagl, 2012, p. 3); this is considered one of the most basic types of curiosity present in both humans and animals (Jepma et al., 2012). This form of curiosity can be easily observed in an infant attempting to grasp and taste everything within reach. Children's perceptual curiosity is also an important component of sensory play, whereby children actively use their senses (taste, touch, smell, sight, hearing, body awareness, and balance). On the other hand, epistemic curiosity relates to a search for knowledge and can be defined as "indirect exploration via asking of questions and direct thinking" (Stagl, 2012, p. 2). Epistemic curiosity can be both specific (i.e., being curious about a specific stimulus) and diverse referring to the personal trait of being prone to be motivated by curiosity (Litman & Spielberger, 2003). Even very young children might experience epistemic curiosity, but it may be difficult to observe as many children cannot explain it (Piotrowski et al., 2014).

While most of the research on curiosity has been conducted in the fields of biology and psychology, most of the research on wonder emerges from the field of philosophy. Schinkel (2018, p. 34) defined wonder as a "mode of consciousness in which we experience what we perceive or are contemplating as strange, beyond our powers of comprehension, yet worthy of our attention for its own sake." Both Schinkel (2017, 2018, 2019) and Hadzigeorgiou (2014) highlight the increased emphasis on wonder in the field of philosophy of education as a counterweight to an educational culture that favors specific ways of learning with an emphasis on coming up with the "correct" answer. According to Schinkel (2018), promoting wonder in education can be important, as it fosters children's empathy, imagination, and love of beings, nature, and the in which world we live. Similarly, Gilbert and Byers (2017) argued that wonder can be used as a pedagogical tool to overcome negative associations with natural science, as it triggers children's emotions and thus also creates a learning environment where teachers engage more with the children's emotions rather than with what they know. Hadzigeorgiou (2012) found that when teachers purposely evoked students' emotions and wonder in the beginning of science classes, students demonstrated increased content learning and retention as compared to a control group. Hence, emotional responses are possible consequences of wonder, but not wonder as such.

Within the educational literature on wonder, attempts have been made to distinguish between different facets of wonder, such as between "wonder at" and "wondering about" (inquisitive wonder), passive and active wonder, and deep or contemplative wonder (Wolbert & Schinkel, 2021). "Wonder at" is described by Wolbert and Schinkel (2021) as "the type of wonder we are 'struck' by, and that leaves us lost for words" (p. 441). This type of wonder leaves a person struck by the beauty or mystery of a phenomenon. "Wondering about" is inquisitive in nature and leads to an urge to explore explanations of a phenomenon. Wolbert and Schinkel (2021) describe this type of wonder as similar to curiosity, yet distinct, as the wonder about the nature of the phenomenon remains even if a plausible explanation is provided, urging us to seek a deeper understanding of a phenomenon. Common to both definitions of wonder is that it engages us not only intellectually, but also emotionally, aesthetically, and existentially (Schinkel, 2017; Wolbert & Schinkel, 2021). Because wonder connects more with feelings, especially good feelings, children are attracted to wonder (L'Ecuyer, 2014). Authors have argued for the importance of wonder to awaken ecological awareness in children (Carson & Lee, 1965) and as a pedagogical tool in classrooms (Egan et al., 2013; Lipman & Sharp, 1986).

Within the field of natural science, children are known to ask many questions that are both triggered by their curiosity and wonder. However, little research focuses on what curiosity and wonder means for children's learning. A literature review by Menning (2018) showed that only a limited number of studies in ECE literature focused on curiosity. The field of natural science education is an exception. Within natural science, Menning (2018) found curiosity to be central in Higgins and Moeed (2017), Jirout and Klahr (2012), Lloyd et al. (2017), and Spektor Levy et al. (2013). The commonality of these studies has been to answer the question of how to nurture curiosity in children, as this seems to increase the motivation for learning natural science. However, because there is a close link between wonder and emotions (Hadzigeorgiou, 2012; Valdesolo et al., 2017) and learning is positively connected with good emotions (Hinton et al., 2008), we would also like to know how wonder is included in ECE. Natural science is considered an important academic discipline, and it provides many work opportunities later in life. It is a subject that is often connected to facts and formulas that must be memorized. On the other hand, as pointed out by Menning (2018), it is a subject where curiosity is commonly used to motivate learning, and where teachers commonly struggle to motivate learning in older children. Many teachers and researchers assume that learning in young children depends on an enriched environment, whereas research asks questions about whether this behavioristic way of learning is limiting children's learning, as it removes them from good emotions they receive when wondering (L'Ecuyer, 2014).

To our knowledge, no review exists on curiosity and wonder within natural science in ECE. Here, we systematically review 10 years of ECE research within the field of natural science, as we believe that wonder can be an important tool in combination with curiosity to motivate children to learn more about natural science. The aim of this study is to compile, organize, and analyze the state-of-the-art ECE research on children's wonder and curiosity for natural science learning, published between January 2010 to January 2020. The research questions guiding this article were: 1) How do articles that focus on children and science in early childhood understand and include the concepts of curiosity and wonder? and 2) What population of interest, age of children, and methodological approach were salient in the research literature?

Methods

Search strategy and eligibility criteria

The literature search was performed on 28 February 2020, in Education Resources Information Center (ERIC) in EBSCO, Web of Science, and Proquest. We searched for peer-reviewed articles that were published in English between January 1, 2010 to January 1, 2020. To find articles that refer to science, curiosity, and wondering during early childhood (i.e., age 0–8 based on the UNESCO (2021) definition), we used the following search terms: (curio* OR wonder*) AND science AND (kinder* OR child* OR preschool). We kept the search broad by using "curio* and wonder*," as the aim was to include all articles on curiosity and wonder within this age group and the subject of natural science. Search terms were searched for in titles, abstracts, and key words. The eligibility and exclusion criteria are presented in Table 1.

The initial search yielded 300 articles. Following the guidelines for Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) (Moher et al., 2009), the evaluation of the eligibility of the identified articles followed four steps. First, the identified articles were entered in the bibliographic citation management tool EndNote 20 and duplicates were deleted ($n = 66$). Second, based on the eligibility criteria presented in Table 1, titles and abstracts were screened by at least two authors independently. Articles that did not meet the criteria were excluded ($n = 101$). In case of discrepancies regarding whether an article meets the eligibility criteria, the article was included in the next step for full screening. Third, remaining articles ($n = 133$) were divided between the authors to be fully screened by two authors. After the individual screening, the authors compared the results and

Table 1. Eligibility and exclusion criteria in the screening process.

Eligibility criteria	Exclusion criteria
To be included in this review, the research had to: 1) Focus on children in the age group 0–8 2) Mention science AND (curiosity AND/OR wonder) 3) Be published in English in peer-reviewed journals.	Based on eligibility criteria (1) Exclusion of research with only targeting children older that 8 years old (2) Exclusion of research did not combine science AND (curiosity AND/OR wonder) (3) Exclusion of book chapters, technical reports, unpublished dissertations, and master's thesis.

discussed articles with uncertain eligibility. In this process, 100 further articles were excluded. We did not include articles on children older than 8 years old or articles published in non-peer reviewed journals (Table 1). Overall, 33 articles were included in the final analysis (Table 2). See Figure 1 for a flowchart of the selection process.

Table 2. Description of articles included ($N = 33$) in the analysis. Sorted by first author, year it was published, country of study origin, educational level that was studied, participants studied, curiosity and/or wonder as a topic in the study, definition of curiosity and/or wonder included, and whether the study was weighted as score 1 or 2. Weighting score 1 includes studies that explore how to support children's curiosity and wonder. Weighting score 2 includes studies of how to support children's learning.

First Author	Year	Country	Study Design	Educational Level	Participants (age in years)	Curiosity and/or Wonder	Definition	Weighting Score*
Baruch	2016	Israel	Mixed	Preschool	Children (4–7)	Curiosity	Yes	1
Lindholm	2018	Norway	Theoretical	K-12	NA	Curiosity & Wonder	Yes	1
Mills	2019	USA	Quan	Primary school	Children (7–10)	Curiosity	Yes	1
Post	2018	Netherlands	Qual	Primary school	Children (4–9)	Curiosity & Wonder	Yes	1
Soydan	2013	Turkey	Qual	Preschool	Teachers	Curiosity & (Wonder)	Yes	1
van Schijndel	2018	Netherlands	Quan	Primary school	Children (7–9)	Curiosity	Yes	1
Bustamante	2018	USA	Theoretical	Preschool	NA	Curiosity	No	2
Bustamante	2017	USA	Quan	Preschool	Children (3–5)	Curiosity	No	2
Byrne	2016	UK	Mixed	Preschool	Parents and Children (5–7)	Curiosity	No	2
Cremin	2015	Several	Qual	Primary school	Children (3–8)	Curiosity	No	2
DeJarnette	2018	USA	Qual	Preschool	Teachers	Curiosity	No	2
Ferreira	2015	Portugal	Quan	Preschool	Children (5–6)	Curiosity	No	2
Fleer	2019	Australia	Quan	Preschool	Children (3–6)	(Curiosity) & Wonder	Yes	2
Fusaro	2018	USA	Mixed	Preschool	Children (4–5)	Curiosity	Yes	2
Heisey	2010	USA	Mixed	Primary school	Children	Wonder	No	2
Howitt	2011	Australia	Qual	Preschool	Children (4–5)	Curiosity & Wonder	No	2
John	2018	USA	Qual	Preschool	Teachers	Curiosity	No	2
Kanak	2018	Turkey	Qual	Preschool	Teachers	Curiosity	No	2
Kotaman	2017	Turkey	Mixed	Preschool	Children (4–5)	Curiosity	No	2
Lichene	2019	Italy	Qual	Preschool	Children (4–5)	Curiosity	No	2
Lloyd	2017	UK	Qual	Preschool	Parents and Children (0–3)	Curiosity	No	2
Marian	2017	UK	Theoretical	Preschool	NA	Curiosity	No	2
Menninga	2017	Netherlands	Quan	Preschool	Teachers and Children (4–6)	Curiosity	No	2
Merritt	2020	USA	Qual	K-12	NA	Curiosity	No	2
Nilsson	2015	Sweden	Qual	Preschool	Teachers	Curiosity	No	2
Nilsson	2017	Sweden	Qual	Preschool	Students	Curiosity	No	2
Rachman	2018	Indonesia	Qual	Preschool	Children (-)	Curiosity	No	2
Raven	2019	Australia	Mixed	K-12	Teachers	Curiosity	No	2
Salehjee	2020	Scotland	Theoretical	Preschool	Teachers	Curiosity	No	2
Siry	2013	Luxenbourg	Qual	Preschool	Children (4–6)	Wonder	No	2
Skarstein	2020	Norway	Mixed	Teacher education	Students	Curiosity & Wonder	No	2
van der Graf	2015	Netherlands	Quan	Preschool	Children (4–6)	Curiosity	No	2
van der Graf	2016	Netherlands	Quan	Preschool	Children (5–6)	Curiosity	No	2

*Analysis results. Weighting score 1 include studies that explore how to support children's curiosity and wonder. Weighting score 2 includes studies of how to support children's learning.

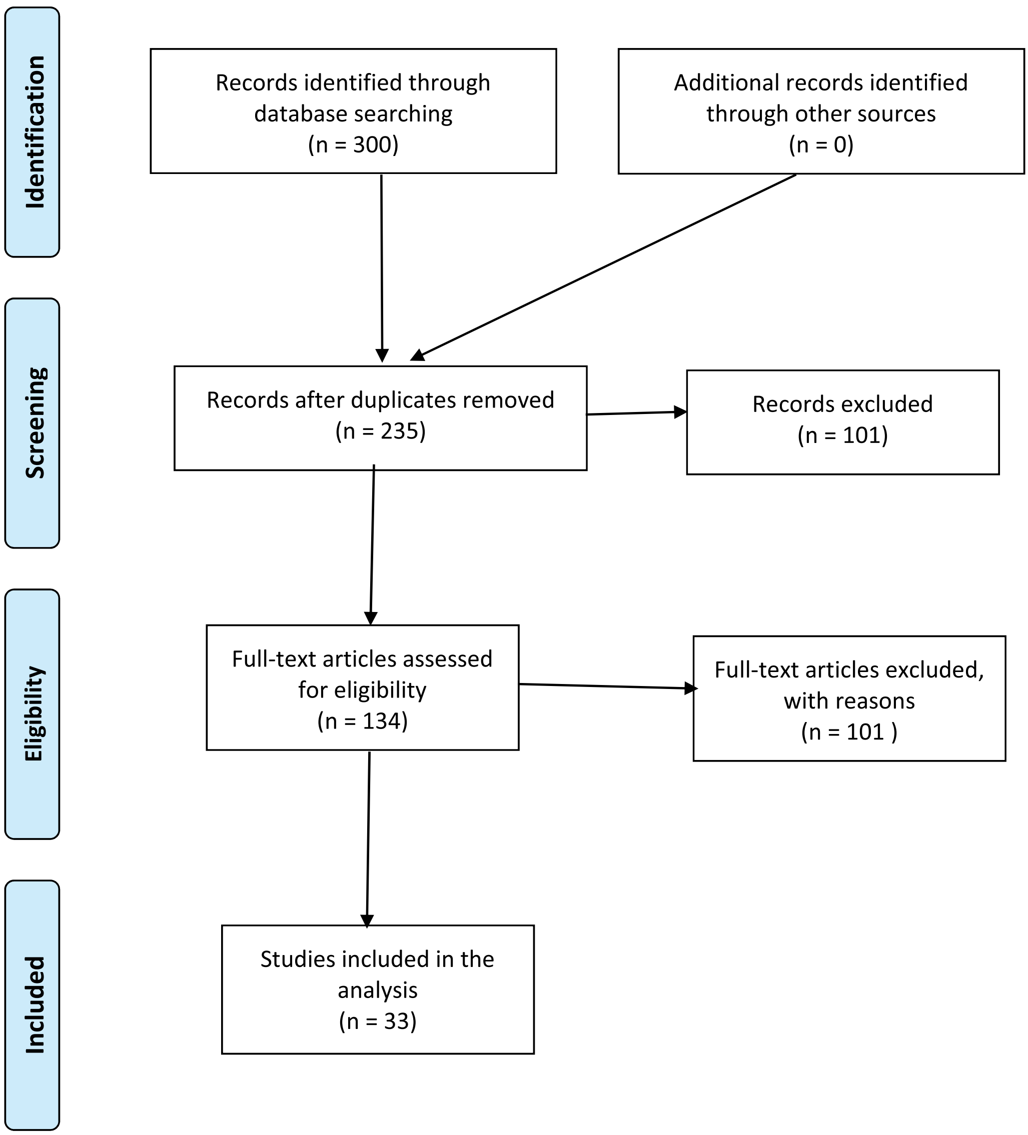

Figure 1. Prisma flow diagram of the literature search, screening and inclusion. *From:* Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & the PRISMA Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Med, 6* (7), e1000097. https://doi.orb/10.1371/journal.pmed1000097. For more information, visit www.prisma-statement.org.

Data analysis and representation

The main analysis was categorization of the 33 articles (Table 2), based on the name of the first author, year of publication, country of data collection or author affiliation, study design (i.e., qualitative, quantitative, mixed method, theoretical), educational level (e.g., kindergarten, preschool), participant group (and age of the children group, if applicable), and the use of curiosity and wonder (terms and definitions used and weighting of the terms). In the analysis of the weighting of curiosity and/or wonder in the articles, the first and third author categorized the articles into two categories: 1) exploration of how to support children's curiosity and/or wonder ($n = 6$), and 2) exploration of how to support children's learning ($n = 27$). The categories are outlined in Table 2 and described in detail in the result section.

Results

The first search resulted in 300 articles (Figure 1). After the selection process was finished, we ended up with a total of 33 articles that were reviewed in more detail. See Table 2 for descriptive information of the reviewed articles.

Most of the studies were research on children (60.6%, $n = 20$), and less on teachers (24.2%, $n = 8$) and parents (6.1%, $n = 2$) (Table 2). Of the studies that included children as participants, 15 studies included children in the age range 3–9, two studies included children in the age range 7–10, two studies did not indicate the age of the children, and only one study included children in the age range 0–3.

Among the 33 articles, 19 (57.6%) studies used qualitative design (observational studies ($n = 13$) and interview studies ($n = 6$)). A small number of studies used a quantitative design (18.2%, $n = 6$), of which five studies were cross-sectional and one was longitudinal. Seven studies (21.2%) used a mixed method design, and four of the studies (12%) were theoretical.

The weight of curiosity and wonder

Twenty-five (75.8%) of the articles only used the word curiosity, six articles (18.2%) used curiosity in combination with wonder, and two articles (6.1%) used only wonder. Most articles (75.8%, $n = 25$) did not define curiosity or wonder. A common jargon was "children's natural curiosity" without any definition of curiosity or citing literature with definitions, and no information about how curiosity can be observed, the role curiosity plays in exploring science, or how children's curiosity could be stimulated (e.g., "by eliciting children's natural curiosity about the world," Bustamante et al., 2018, p. 1).

Group 1: Exploration of how to support children's curiosity and wonder

Of the six articles categorized in group 1, five were empirical studies (Baruch et al., 2016; Mills et al., 2019; Post & van der Molen, 2018; Soydan & Erbay, 2013; Van Schijndel et al., 2018) and one theoretical study (Lindholm, 2018). All articles showed an explicit understanding of curiosity by defining it, and two studies also defined wonder/wonderment (Lindholm, 2018; Post & van der Molen, 2018). Additionally, all studies aimed to explore how to support children's curiosity and wonder by nurturing a continued curiosity and/or wonder.

Of the empirical studies, Baruch et al. (2016) studied children's verbal and behavioral responses to scientific activities. They argued that both verbal and behavioral responses can be a way for children to express their curiosity, and that these responses can be observed to understand whether children are curious or not. Van Schijndel et al. (2018) measured children's curiosity to evaluate if curiosity was positively related to their exploration during inquiry-based learning. In comparison, Soydan and Erbay (2013) and Mills et al. (2019) focused more on methods to achieve curiosity used by staff working with children and science in ECE; however, they did not discuss how curiosity can be observed. Soydan and Erbay (2013) concluded that the teachers found it easier to promote curiosity in science compared to other topics, but that they lacked knowledge to promote curiosity in children. Soydan and Erbay (2013) further identified techniques used by teachers for promoting curiosity and suggested this be implemented in teacher training programs. Post and van der Molen (2018) studied children's scientific curiosity experiences (including wonderment) inside and outside of school and found that children were more curious of topics outside of school compared to in school. Interestingly, the topics outside of school were related to natural science, such as dinosaurs and planets. The findings by Post and van der Molen (2018) suggest that the lack of curiosity expressed by children in the classroom was not because the children's inquiry skills fell short, but rather because the norms, beliefs, reward systems, and pedagogy in schools insufficiently stimulate children's curious expressions in the classroom. In addition, the theoretical article by

Lindholm (2018) demonstrated an explicit understanding of wonder and curiosity in early childhood and suggested how these concepts should be understood and how and when they should be worked with in primary, junior high, and high school.

Group 2: Exploration of how to support children's learning

Articles in group 2 share an implicit understanding of what curiosity and/or wonder is, with the goal to achieve learning and not curiosity in children. Among the studies, curiosity was viewed as being naturally present in children if triggered the right way. Of the 27 articles, 22 (81.5%) included curiosity, two (7.4%) included wonder and curiosity, and three (11.1%) included wonder. Of all articles in group 2, only two articles defined curiosity (Fleer, 2019; Fusaro & Smith, 2018) and an explicit understanding of why and how curiosity is important in early childhood. Although children may have become curious during the studies in group 2, the researchers focused on what children learned and not on the questions children asked and whether the children were curious or wondered. This is, for example, shown in the conclusions by Fleer (2019): "This study sought to determine if and how imaginative play could promote scientific learning, as well as to identify the pedagogical strategies used by teachers to engage children in scientific play" (p. 1275). The conclusions by Fusaro and Smith (2018) are similar: "The findings of this study suggest that preschoolers, as 'little engineers' can use their emerging science content and reasoning skills to solve simple, hypothetical problems involving the physical and biological world" (p. 126). For many of the articles in group 2, the scope was more about how curiosity and wonder can be used to learn science through teaching methods such as conceptual learning through PlayWorld (Fleer, 2019), inquiry-based learning through experiments (Cremin et al., 2015; Siry & Max, 2013), problem-based learning (Fusaro & Smith, 2018), learning science through stories and mounting inquiry (Salehjee, 2020), or learning species' names (Skarstein & Skarstein, 2020). The research topics and results were relevant and important for science teaching in ECE. However, the scientific knowledge and/or understanding of the child or the student was the focus, and not whether the activities stimulated children's curiosity and wonder in the learning process. Other articles outlined how different teaching methods can spark curiosity and/or wonder through inquiry-based science (Byrne et al., 2016), read-alouds (Heisey & Kucan, 2010), solving mysteries (Howitt et al., 2011), acknowledging children's interest (Lichene, 2019), scientific activities (Lloyd et al., 2017), and catching the moments (Nilsson, 2015). All these methods are important and relevant for working with natural science in ECE; however, none of these methods measure whether curiosity or wonder occurred.

Furthermore, three studies in group 2 barely mentioned curiosity and/or wonder (Menninga et al., 2017; Raven & Whitman, 2019; van der Graaf et al., 2016). For example, the study by Menninga et al. (2017) was carried out in preschool within the field of natural science. However, the term "curious" was only included in the text in the project's title "Curious Minds." Furthermore, the study by van der Graaf et al. (2016) explored how children could discover the laws of physics through gaming in kindergarten. The study suggested further research to measure children's curiosity during the gaming process. However, there was no focus on how curiosity may drive the gaming process in this study.

Discussion

Through a systematic literature review of research published between January 2010 and January 2020, we investigated how ECE research in the field of natural science includes and discusses curiosity and wonder, if and how researchers included their understanding of curiosity and/or wonder, and why and how they believe it is important for children's learning and love for science. Our main findings show that: 1) the term curiosity is more commonly used in the research literature than the term wonder; 2) although many studies describe curiosity and/or wonder as important for children's learning of natural science, few studies show an explicit understanding of these terms; 3) most studies focus on children's natural science learning outcomes and not on what they wonder about or are curious about;

and 4) only one study observed children younger than 3 years. In other words, in most studies, curiosity and/or wonder are emphasized as important means to an end (i.e., children's learning), but not an end itself. Additionally, studies on curiosity and wonder in children younger than 3 years are scarce.

In the following, we first discuss the disparity in the emphasis on curiosity and/or wonder found in the studies and how these two terms have been defined. Second, we discuss how a change of focus from observing children's learning to observing children's learning process through their curiosity/wonder may impact our understanding of natural science education in ECE.

Ample curiosity, but what about wonder?

The results showed that most of the studies focused on curiosity and only a few studies explored how children's wonder may be appreciated or triggered as a part of learning natural science in early childhood. There are likely several reasons why wonder has received little attention in research so far. One reason might be the culture within natural science education. The education field has been governed by a culture that favors learning about species, facts about nature, and exploring questions in search of the "right" answer (Hadzigeorgiou, 2014). As Post and van der Molen (2018) point out, the education system implies that the norms, beliefs, reward systems, and pedagogy do not measure how well a teacher promotes curiosity or wonder, but rather measure what children learned from a lesson. Promoting wonder can be a counterweight in natural science learning, as it fosters children's empathy, imagination, and love of beings, nature, and the world we live in (Schinkel, 2018). L'Ecuyer (2014) argues that beauty is one of several properties of a phenomenon that might trigger wonder in children. In this sense, beauty is not a mere aesthetic value that depends on fashion and taste, but rather is a visible expression of truth and goodness. Aquinas (1965), as cited in L'Ecuyer (2014), says that "beauty can be found in all existing beings" because the properties of "being" is beauty (p. 3). L'Ecuyer (2014) argues that a beautiful environment is one that triggers wonder. Such an environment respects a child's pace and innocence, which goes beyond the rational and mechanical explanation of things, leaving space for mystery and silence. Neuroscientists also have begun to uncover the biological interdependence of learning and emotion (Hinton et al., 2008). In learning environments, high levels of stress disrupt learning (Bangasser & Shors, 2010), and children's emotional needs have been in focus to enhance intrinsic motivation and good learning environments (OECD, 2007; Reeve, 2016; Valdesolo et al., 2017). In addition to work on formative assessments where learning is nurtured rather than assessment, wonder may be used as a pedagogical tool for emotional and aesthetic engagement, where human experience is at the center, as opposed to the science content itself (Gilbert & Byers, 2017). While curiosity is the drive to investigate or study something, wonder is a state of mind or feeling with an aesthetic dimension (Hadzigeorgiou, 2012), and thus has the potential to touch our emotions. Hadzigeorgiou (2012) provided evidence that wonder may contribute to the learning process by achieving high involvement and conscious learning. Several studies have argued that allowing children to wonder about natural phenomena they encounter can foster their interest in natural science (e.g., Hadzigeorgiou, 2005; Milne, 2010).

Curiosity and wonder as means to an end or an end in itself?

Natural science is considered an important topic when preparing children for school (Bustamante et al., 2018; DeJarnette, 2018). Two claims in these studies are that young children are naturally curious (e.g., "by eliciting children's natural curiosity about the world," Bustamante et al., 2018, p. 1) or that children have a natural disposition toward science through their curiosity (e.g., "a natural disposition toward science with their sense of curiosity and creativity," DeJarnette, 2018, p. 1). This suggests that children are considered to have a natural curiosity about their world, including natural science, and that curiosity is necessary for the science learning process (Bustamante et al., 2018; Ferreira et al., 2015). This also has been suggested in earlier studies (Engel, 2011; Inhelder & Piaget, 1958). However, articles in group 2 did not explicitly explore the relationship between children's curiosity and their learning. Hence, many of the group 2 studies assume that all children are curious and/or become curious if they engage with natural science through different teaching methods (e.g., J. Byrne et al., 2016). Some of these teaching methods are well known in science teaching in school, such as inquiry-based learning within the topics of science, technology, engineering, and mathematics (STEM) (Bustamante et al., 2018; Byrne et al., 2016), while others have worked more with teaching methods common to ECE, such as reading books aloud (Heisey & Kucan, 2010) and play (Fleer, 2019). Hence, the focus in many of these studies is to explore what or if children learn by using different teaching methods.

While curiosity and wonder may serve as an intrinsic drive for scientific exploration and learning for some children in certain situations, children's learning also can be driven by external motivation, such as awards or grades (Ryan & Deci, 2017), without triggering children's curiosity or wonder. Students who are externally motivated to do well and to meet academic standards also may become less curious as a result (Jirout et al., 2018). In other words, while the studies in group 2 teach us something about how to support children's exploration and learning, they do not necessarily contribute to knowledge on how we support children's curiosity and/or wonder or children's intrinsic motivation to continue exploring and learning within natural science. This was not their intention. Articles in group 1 focused on children's curiosity and/or wonder as an end to itself, rather than the learning outcomes (e.g., Lindholm, 2018; Soydan & Erbay, 2013). For example, Lindholm (2018) suggested a framework for curiosity-based science education and explores options for how to implement the educational framework in preschool, preadolescence, and adolescence. In comparison, Soydan and Erbay (2013) were more occupied with how teachers can promote children's curiosity. Interestingly, they found that experienced teachers who love kids and their profession, and pay respect to the ideas, behaviors, and interest of children, are the ones who are most capable in promoting curiosity in children. They also found that teachers failed to promote curiosity in topics they themselves were not interested in, and that visual materials, tone of voice and body language, and question-asking methods were important for promoting curiosity. Considering a worldwide agreement that natural science skills are more important than ever in our technological society (Mullis & Martin, 2017), it is tempting to ask whether increased focus in teacher education on how to promote curiosity and wonder in children could bolster intrinsic motivation to learn natural science in early childhood.

The differences between group 1 and 2 suggest that they are related to two different approaches to ECE. One approach is social pedagogy, where concepts such as care, play, relationships, activity, and development are central, and where the children are seen as agents of their own learning. The other approach is more academically oriented and focuses on academic strategies aimed at teaching, learning, curriculum, content, and methodology, with a focus on emergent literacy and numeracy (Broström, 2017). As care, play, and activities that promote emotions, such as aesthetics and wonder, are fundamental for young children and their learning, there is a need to discuss and develop an understanding of how children's curiosity and wonder can be promoted to meet children's interest and needs in the best ways. Both curiosity and wonder are concepts often used by researchers and teachers, but this review shows differences in the way the concepts are understood, and how teachers and researchers choose to work with these concepts.

Why promote curiosity and wonder?

Soydan and Erbay (2013) highlighted that although preschool teachers find it easier to promote curiosity in natural science compared to other topics, they often feel that they lack knowledge on how to promote curiosity in children. They argued that if encouraged properly, children's curiosity can be a strong motivational factor in education. Much research shows that wonder and curiosity can be important, as it contributes not only to learning, but also to motivation for learning (Carson & Lee, 1965; Egan et al., 2013; Ryan & Deci, 2000, 2017; Silvia, 2012). Our results show that research on natural science learning in ECE focuses on learning as a goal, and not what children ask in their wondering or curiosity or how to promote this. Even less research considers the youngest children (0–3 years). As also emphasized by Sikder and Fleer (2015), the literature into infants and toddlers' scientific development is almost non-existent. The scarcity in research targeting the youngest children indicates a gap in knowledge about how to support this group of children's exploration of natural science phenomena. One way of moving forward with inquiry into the youngest children's exploration of natural science phenomena is to further explore how to support children in what Sikder and Fleer (2015) termed small science exploration or the small moments of everyday activity that occurs for infants/toddlers. Examples of small science moments include, for example, children's perceptual exploration of objects related to academic concepts, such as pressing hard, push, roll, and change of state of matter under force (Sikder & Fleer, 2015). By being observant of children's small science moments, teachers might be better equipped to provide ECE environments that stimulate children's perceptual curiosity and sensory play.

Interestingly, there are also studies indicating that children become less curious with increasing age. For example, Skalstad and Munkebye (2021) found that children in ECE (age 4–5) asked considerably more questions compared to school children (age 6–10). There may be different explanations for this development. Skalstad and Munkebye (2021) found that school children were given more specified tasks that required detailed knowledge and argue that this may cause fear of asking questions that may be considered "wrong" or "silly." This form of educational practice supports the widespread misconception that natural science is a topic focusing on facts that have either right or wrong answers, rather than a deliberative process (Öberg et al., 2022). When children experience learning expectations from teachers that focus on facts rather than process as the source of knowledge, they also learn that the process is not what is important in their learning process. An alternative explanation for changes in children's curiosity for learning science is children's implicit theories of learning. Beliefs about the capacity to grow one's abilities are called implicit theories or mind-sets (Haimovitz & Dweck, 2017). Children who believe they only have a certain amount of ability to change their mind-set have a fixed mind-set. This is typically seen in children when the focus on their learning is on results rather than on the process. In comparison, children who believe they can develop abilities through hard work, good strategies, and instruction from others have a growth mind-set (see Blackwell et al., 2007; Dweck & Leggett, 1988). Yet another explanation could be that children do not become less curious; rather, their curiosity changes from a more diverse curiosity to a more specific curiosity as they get older (Jirout et al., 2018). An example could be that a child is very curious about all that s/he finds in nature, but as time goes by s/he develops a more specific curiosity about butterflies.

Triggering children's emotions through their curiosity and wonder can help to overcome negative associations with science (Gilbert & Byers, 2017), and make it easier for teachers to support children's growth mind-sets (Jirout et al., 2018) and internal drive for learning science (Hadzigeorgiou, 2012). However, we need to better understand how teachers can support and sustain children's curiosity and wonder in ECE. Hopefully, emphasizing curiosity and wonder in ECE sparks school readiness and prolonged motivation for learning science later in school.

Limitations and avenues for further research

How to explore children's curiosity has been discussed in previous research (e.g., Baruch et al., 2016; Lindholm, 2018; Mills et al., 2019; Post & van der Molen, 2018; Soydan & Erbay, 2013; Van Schijndel et al., 2018). Despite the importance of curiosity and wonder as applications in education, studying these concepts empirically is challenging. Children's curiosity and wonder are difficult, if not impossible, to observe directly, as indicators that can be observed are needed, which so far do not give unitary constructs. Jirout and Klahr (2012) have analyzed two primary methods to study curiosity, through self-report questionnaires and behavioral measures. For young children, exploration and information-seeking behaviors were more suitable as measures for curiosity than questionnaires. Baruch et al. (2016) found that children expressed various emotional valences through figurative and verbal expressions, and by showing a desire to engage in sensorimotor interactions during scientific activities. They suggest that figurative and verbal expressions, as well as the desire to engage physically, should be indicators of curiosity attitudes when observing young children in science play and activities. However, children can engage in explorative behavior without being curious. An example is a child who is forced to finish a puzzle before going out to play. In other words, while curiosity, by definition, necessitates exploratory behavior, it is not a necessary nor sufficient explanation for exploratory behavior. Therefore, using explorative behavior as a measure for curiosity may be problematic. Further, to observe and measure wonder in preschoolers may be even more challenging as our wondering is often inner thoughts not necessarily expressed.

Dewey (1910) believed curiosity is an essential component for learning science. We believe that both curiosity and wonder are essential science learning components. In order to be able to support children's curiosity and wonder better, teachers need to be able to learn what to recognize or look for in children. We believe that by focusing on the processes of curiosity and wonder rather than children's knowledge, learning will be stimulated and sustained through increased curiosity, wonder, and mind-set. We request more research on how to recognize and support children's curiosity and wonder in their learning processes. This may change the focus from measuring what young children in ECE know/can do to what they enjoy learning and doing it in a learning process.

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ORCID

Anne-Line Bjerknes http://orcid.org/0000-0002-7129-9789
Terese Wilhelmsen http://orcid.org/0000-0002-0062-2868
Emilie Foyn-Bruun http://orcid.org/0009-0004-4286-6694

References

Aquinas, T. (1953). *Questiones disputatae de veritate* (J. V. McGlynn, Trans.). Henry Regnery Company.

Aquinas, T. (1965). Quaestiones disputatae de virtutibus. *Quaestiones Disputatae*, *2*, 707–751.

Bangasser, D. A., & Shors, T. J. (2010). Critical brain circuits at the intersection between stress and learning. *Neuroscience & Biobehavioral Reviews*, *34*(8), 1223–1233. https://doi.org/10.1016/j.neubiorev.2010.02.002

Barto, A. G. (2013). Intrinsic motivation and reinforcement learning. In G. Baldassarre & M. Mirolli (Eds.), *Intrinsically motivated learning in natural and artificial systems* (pp. 17–47). Springer.

Baruch, Y. K., Spektor Levy, O., & Mashal, N. (2016). Pre-schoolers' verbal and behavioral responses as indicators of attitudes and scientific curiosity. *International Journal of Science and Mathematics Education*, *14*(1), 125–148. https://doi.org/10.1007/s10763-014-9573-6

Berlyne, D. E. (1954). A theory of human curiosity. *British Journal of Psychology*, *45*(3), 180–191. https://doi.org/10.1111/j.2044-8295.1954.tb01243.x

Berlyne, D. E. (1960). *Conflict, arousal, and curiosity*. McGraw-Hill Book Company.

Blackwell, L., Trzesniewski, K., & Dweck, C. S. (2007). Implicit theories of intelligence predict achievement across an adolescent transition: A longitudinal study and an intervention. *Child Development*, *78*(1), 246–263. https://doi.org/10.1111/j.1467-8624.2007.00995.x

Bromberg-Martin, E. S., & Hikosaka, O. (2009). Midbrain dopamine neurons signal preference for advance information about upcoming rewards. *Neuron*, *63*(1), 119–126. https://doi.org/10.1016/j.neuron.2009.06.009

Broström, S. (2017). A dynamic learning concept in early years' education: A possible way to prevent schoolification. *International Journal of Early Years Education*, *25*(1), 3–15. https://doi.org/10.1080/09669760.2016.1270196

Bustamante, A. S., Greenfield, D. B., & Nayfeld, I. (2018). Early childhood science and engineering: Engaging platforms for fostering domain-general learning skills. *Education Sciences*, *8*(3), 144. https://doi.org/10.3390/educsci8030144
Bustamante, A. S., White, L. J., & Greenfield, D. B. (2017). Approaches to learning and school readiness in Head Start: Applications to preschool science. *Learning and Individual Differences*, *56*, 112–118.
Byrne, J., Rietdijk, W., & Cheek, S. (2016). Enquiry-based science in the infant classroom: "Letting go." *International Journal of Early Years Education*, *24*(2), 206–223. https://doi.org/10.1080/09669760.2015.1135105
Byrne, R. W. (2013). Animal curiosity. *Current Biology*, *23*(11), 469–470. https://doi.org/10.1016/j.cub.2013.02.058
Carson, R., & Lee, K. (1965). *The sense of wonder*. HarperCollins.
Cremin, T., Glauert, E., Craft, A., Compton, A., & Stylianidou, F. (2015). Creative little scientists: Exploring pedagogical synergies between inquiry-based and creative approaches in early years science. *Education 3-13*, *43*(4), 404–419. https://doi.org/10.1080/03004279.2015.1020655
DeJarnette, N. K. (2018). Implementing STEAM in the early childhood classroom. *European Journal of STEM Education*, *3*(3), 18. https://doi.org/10.20897/ejsteme/3878
Dewey, J. (1910). Science as subject-matter and as method. *Science*, *31*(787), 121–127. https://doi.org/10.1126/science.31.787.121
Dweck, C. S. (2006). *Mindset: The new psychology of success*. Random House Publications.
Dweck, C. S., & Leggett, E. L. (1988). A social-cognitive approach to motivation and personality. *Psychological Review*, *95* (2), 256–273. https://doi.org/10.1037/0033-295X.95.2.256
Egan, K. (1992). *Imagination in teaching and learning: Ages 8 to 15* (1st ed.). Routledge. https://doi.org/10.4324/9781315887654
Egan, K., Cant, A. I., & Judson, G. (Eds.). (2013). *Wonder-full education: The centrality of wonder in teaching and learning across the curriculum*. Routledge.
Engel, S. (2011). Children's need to know: Curiosity in schools. *Harvard Educational Review*, *81*(4), 625–645. https://doi.org/10.17763/haer.81.4.h054131316473115
Ferreira, M. E., Claires, C., & Pitarma, R. (2015). Health and sustainable behaviours: Pedagogical and didactic experiment in preschool teaching. *International Journal of Knowledge and Learning*, *10*(3), 238–257. https://doi.org/10.1504/IJKL.2015.073462
Fleer, M. (2009). Understanding the dialectical relations between everyday concepts and scientific concepts within play-based programs. *Research in Science Education*, *39*(2), 281–306. https://doi.org/10.1007/s11165-008-9085-x
Fleer, M. (2019). Scientific playworlds: A model of teaching science in play-based settings. *Research in Science Education*, *49*(5), 1257–1278. https://doi.org/10.1007/s11165-017-9653-z
Fusaro, M., & Smith, M. C. (2018). Preschoolers' inquisitiveness and science-relevant problem solving. *Early Childhood Research Quarterly*, *42*(1), 119–127. https://doi.org/10.1016/j.ecresq.2017.09.002
Gazzaniga, M. S. (2005). *The ethical brain*. Dana Press.
Gilbert, A., & Byers, C. C. (2017). Wonder as a tool to engage preservice elementary teachers in science learning and teaching. *Science Education*, *101*(6), 907–928. https://doi.org/10.1002/sce.21300
Hadzigeorgiou, Y. (2005). Science, personal relevance and social responsibility: Integrating the liberal and the humanistic traditions of science education. *Educational Practice and Theory*, *27*(2), 87–103. https://doi.org/10.7459/ept/27.2.07
Hadzigeorgiou, Y. (2012). Fostering a sense of wonder in the science classroom. *Research in Science Education*, *42*(5), 985–1005. https://doi.org/10.1007/s11165-011-9225-6
Hadzigeorgiou, Y. (2014). Reclaiming the value of wonder in science education. In K. Egan, A. Cant, & G. Judson (Eds.), *Wonder-full education: The centrality of wonder in teaching and learning across the curriculum* (pp. 40–65). Routledge.
Hadzigeorgiou, Y., & Schulz, R. M. (2019). Engaging students in science: The potential role of "narrative thinking" and "romantic understanding. *Frontiers in Education*, *4*, 38. https://doi.org/10.3389/feduc.2019.00038
Haimovitz, K., & Dweck, C. S. (2017). What predicts children's fixed and growth intelligence mind-sets? Not their parents' views of intelligence but their parents' views of failure. *Psychological Science*, *27*(6), 859–869. https://doi.org/10.1177/0956797616639727
Heisey, N., & Kucan, L. (2010). Introducing science concepts to primary students through read-alouds: Interactions and multiple texts make the difference. *The Reading Teacher*, *63*(8), 666–676. https://doi.org/10.1598/RT.63.8.5
Herodotou, C. (2018). Young children and tablets: A systematic review of effects on learning and development. *Journal of Computer Assisted Learning*, *34*(1), 1–9. https://doi.org/10.1111/jcal.12220
Higgins, J., & Moeed, A. (2017). Fostering curiosity in science classrooms: Inquiring into practice using cogenerative dialoguing. *Science Education International*, *28*(3), 190–198. https://doi.org/10.33828/sei.v28.i3.2
Hinton, C., Miyamoto, K., & Della-chiesa, B. (2008). Brain research, learning and emotions: Implications for education research, policy and practice. *European Journal of Education*, *43*(1), 87–103. https://doi.org/10.1111/j.1465-3435.2007.00336.x
Honomichl, R. D., & Chen, Z. (2012). The role of guidance in children's discovery learning. *Cognitive Science*, *3*(6), 615–622. https://doi.org/10.1002/wcs.1199
Howitt, C., Lewis, S., & Upson, E. (2011). "It's a mystery": A case study of implementing forensic science in preschool as scientific inquiry. *Australasian Journal of Early Childhood*, *36*(3), 45–55. https://doi.org/10.1177/183693911103600307

Inhelder, B., & Piaget, J. (1958). *The growth of logical thinking from childhood to adolescence: An essay on the construction of formal operational structures* (Vol. 22). Basic Books.

Jepma, M., Verdonschot, R. G., Van Steenbergen, H., Rombouts, S. A., & Nieuwenhuis, S. (2012). Neural mechanisms underlying the induction and relief of perceptual curiosity. *Frontiers in Behavioral Neuroscience*, *6*(5). https://doi.org/10.3389/fnbeh.2012.00005

Jirout, J., & Klahr, D. (2012). Children's scientific curiosity: In search of an operational definition of an elusive concept. *Developmental Review*, *32*(2), 125–160. https://doi.org/10.1016/j.dr.2012.04.002

Jirout, J. J., Vitiello, V. E., & Zumbrunn, S. K. (2018). Curiosity in schools. In G. Gordon (Ed.), *The new science of curiosity* (pp. 243–266). Nova Science Publishers.

John, M. S., Sibuma, B., Wunnava, S., Anggoro, F., & Dubosarsky, M. (2018). An iterative participatory approach to developing an early childhood problem-based STEM curriculum. *European Journal of STEM Education*, *Grantee Submission*, *3*(3). https://doi.org/10.20897/ejsteme/3867

Kanak, M., & Pekdogan, S. (2018). Examination of science and mathematics activities in pre-school education. *Research in Pedagogy*, *8*(1), 111–122. https://doi.org/10.17810/2015.75

Kang, M. J., Hsu, M., Krjbich, I. M., Lowenstein, G., McClure, S. M., Wang, J. T., & Camerer, C. F. (2009). The wick in the candle of learning: Epistemic curiosity activates reward circuitry and enhances memory. *Psychological Science*, *20*(8), 963–973. https://doi.org/10.1111/j.1467-9280.2009.02402.x

Kashdan, T. B., Disabato, D. J., Goodman, F. R., & McKnight, P. E. (2020). The Five-Dimensional Curiosity Scale Revised (5DCR): Briefer subscales while separating overt and covert social curiosity. *Personality and Individual Differences*, *157*, 109836. https://doi.org/10.1016/j.paid.2020.109836

Kashdan, T. B., & Roberts, J. E. (2004). Trait and state curiosity in the genesis of intimacy: Differentiation from related constructs. *Journal of Social and Clinical Psychology*, *23*(6), 792–816. https://doi.org/10.1521/jscp.23.6.792.54800

Kashdan, T. B., Stiksma, M. C., Disabato, D. J., McKnight, P. E., Bekier, J., Kaji, J., & Lazarus, R. (2018). The Five-Dimensional Curiosity Scale: Capturing the bandwidth of curiosity and identifying four unique subgroups of curious people. *Journal of Research in Personality*, *73*, 130–149. https://doi.org/10.1016/j.jrp.2017.11.011

Kidd, C., & Hayden, B. Y. J. N. (2015). The psychology and neuroscience of curiosity. *Neuron*, *88*(3), 449–460. https://doi.org/10.1016/j.neuron.2015.09.010

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychology*, *41*(2), 75–86. https://doi.org/10.1207/s15326985ep4102_1

Kotaman, H., & Tekin, A. K. (2017). Informational and fictional books: Young children's book preferences and teachers' perspectives. *Early Child Development and Care*, *187*(3–4), 600–614. https://doi.org/10.1080/03004430.2016.1236092

L'Ecuyer, C. (2014). The wonder approach to learning. *Frontiers in Human Neuroscience*, *8*, 764. https://doi.org/10.3389/fnhum.2014.00764

Lichene, C. (2019). Promoting science education in early childhood: A research in a nursery school. *European Early Childhood Education Research Journal*, *27*(3), 397–408. https://doi.org/10.1080/1350293X.2019.1600809

Lindholm, M. (2018). Promoting curiosity? *Science & Education*, *27*(9–10), 987–1002. https://doi.org/10.1007/s11191-018-0015-7

Lipman, M., & Sharp, A. M. (1986). *Wondering at the world: Instructional manual to accompany KIO and GUS*. Institute for the Advancement of Philosophy for Children (with University Press of America).

Litman, J. A., & Spielberger, C. D. (2003). Measuring epistemic curiosity and its diversive and specific components. *Journal of Personality Assessment*, *80*(1), 75–86. https://doi.org/10.1207/S15327752JPA8001_16

Lloyd, E., Edmonds, C., Downs, C., Crutchley, R., & Paffard, F. (2017). Talking everyday science to very young children: A study involving parents and practitioners within an early childhood centre. *Early Child Development and Care*, *187*(2), 244–260. https://doi.org/10.1080/03004430.2016.1226355

Loewenstein, G. (1994). The psychology of curiosity - a review and reinterpretation. *Psychological Bulletin*, *116*(1), 75–98. https://doi.org/10.1037/0033-2909.116.1.75

Marian, H., & Jackson, C. (2017). Inquiry based learning: A framework for assessing science in early years. *Early Child Development and Care*, *187*(2), 221–232. https://doi.org/10.1080/03004430.2016.1237563

Mayer, R. E. (2004). Should there be a three-strikes rule against pure discovery learning? *The American Psychologist*, *59*(1), 14–19. https://doi.org/10.1037/0003-066X.59.1.14

McLean, K., Jones, M., & Schaper, C. (2015). Children's literature as an invitation to science inquiry in early childhood education. *Australasian Journal of Early Childhood*, *40*(4), 49–56. https://doi.org/10.1177/183693911504000407

Menning, S. F. (2018). Mapping the dilemmatic space of early childhood education and care practitioners when challenged by children's curiosity. *Journal of Early Childhood Research*, *16*(4), 349–362. https://doi.org/10.1177/1476718X18775769

Menninga, A., van Dijk, M., Wetzels, A., Steenbeek, H., & van Geert, P. (2017). Language use in kindergarten science lessons: Language production and academic language during a video feedback coaching intervention in kindergarten science lessons. *Educational Research and Evaluation*, *23*(1–2), 26–51. https://doi.org/10.1080/13803611.2017.1292920

Merritt, E. G., & Bowers, N. (2020). Missed opportunities for observation-based ecology in the Next Generation Science Standards. *Science Education*, *104*(4), 619–640. https://doi.org/10.1002/sce.21572
Miguel, P. M., Pereira, L. O., Silveira, P. P., & Meaney, M. J. (2019). Early environmental influences on the development of children's brain structure and function. *Developmental Medicine & Child Neurology*, *61*(10), 1127–1133. https://doi.org/10.1111/dmcn.14182
Mills, C. M., Sands, K. R., Rowles, S. P., & Campbell, I. L. (2019). "I want to know more!": Children are sensitive to explanation quality when exploring new information. *Cognitive Science*, *43*(1). https://doi.org/10.1111/cogs.12706
Milne, I. (2010). A sense of wonder, arising from aesthetic experiences, should be the starting point for inquiry in primary science. *Science Education International*, *21*(2), 102–115. https://files.eric.ed.gov/fulltext/EJ890665.pdf
Moher, D., Liberati, A., Tetzlaff, J., &, and Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement (Chinese edition). *Journal of Chinese Integrative Medicine*, *7*(9), 889–896. https://doi.org/10.3736/jcim20090918
Mullis, I. V., & Martin, M. O. (2017). *TIMSS 2019 assessment frameworks*. International Association for the Evaluation of Educational Achievement. https://files.eric.ed.gov/fulltext/ED596167.pdf
Nilsson, P. (2015). Catching the moments—coteaching to stimulate science in the preschool context. *Asia-Pacific Journal of Teacher Education*, *43*(4), 296–308. https://doi.org/10.1080/1359866X.2015.1060292
Nilsson, P., & Elm, A. (2017). Capturing and developing early childhood teachers' science pedagogical content knowledge through CoRes. *Journal of Science Teacher Education*, *28*(5), 406–424. https://doi.org/10.1080/1046560X.2017.1347980
Öberg, G., Campbell, A., Fox, J., Graves, M., Ivanochko, T., Matsuchi, L., Mouat, I., & Welsh, A. (2022). Teaching science as a process, not a set of facts. *Science & Education*, *31*(3), 787–817. https://doi.org/10.1007/s11191-021-00253-8
OECD. (2007) . *Understanding the brain: The birth of a learning science*. Author.
Piotrowski, J. T., Litman, J. A., & Valkenburg, P. (2014). Measuring epistemic curiosity in young children. *Infant and Child Development*, *23*(5), 542–553. https://doi.org/10.1002/icd.1847
Post, T., & van der Molen, J. H. W. (2018). Do children express curiosity at school? Exploring children's experiences of curiosity inside and outside the school context. *Learning, Culture and Social Interaction*, *18*, 60–71. https://doi.org/10.1016/j.lcsi.2018.03.005
Rachman, A. U. (2018). Alternative science game or increase cognitive ability of early age children. *Jurnal Indria (JIN)*, *3* (1), 1–12. https://doi.org/10.24269/jin.v3n1.2018.pp1-12
Raven, S., & Whitman, G. M. (2019). Science in silence: How educators of the deaf and hard-of-hearing teach science. *Research in Science Education*, *49*(4), 1001–1012. https://doi.org/10.1007/s11165-019-9847-7
Reeve, J. (2016). A grand theory of motivation: Why not? *Motivation and Emotion*, *40*(1), 31–35. https://doi.org/10.1007/s11031-015-9538-2
Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *The American Psychologist*, *55*(1), 68–78. https://doi.org/10.1037/0003-066X.55.1.68
Ryan, R. M., & Deci, E. L. (2017). *Self-determination theory: Basic psychological needs in motivation, development, and wellness*. The Guilford Press.
Sackes, M., Trundle, K. C., & Flevares, L. M. (2009). Using children's literature to teach standard-based science concepts in early years. *Early Childhood Education Journal*, *36*(5), 415–422. https://doi.org/10.1007/s10643-009-0304-5
Salehjee, S. (2020). Teaching science through stories: Mounting scientific enquiry. *Early Child Development and Care*, *190*(1), 79–90. https://doi.org/10.1080/03004430.2019.1653554
Schinkel, A. (2017). The educational importance of deep wonder. *Journal of Philosophy of Education*, *51*(2), 538–553. https://doi.org/10.1111/1467-9752.12233
Schinkel, A. (2018). Wonder and moral education. *Educational Theory*, *68*(1), 31–48. https://doi.org/10.1111/edth.12287
Schinkel, A. (2019). Wonder, mystery, and meaning. *Philosophical Papers*, *48*(2), 293–319. https://doi.org/10.1080/05568641.2018.1462667
Shin, D. D., & Kim, S. I. (2019). Homo curious: Curious or interested? *Educational Psychology Review*, *31*(4), 853–874. https://doi.org/10.1007/s10648-019-09497-x
Sikder, S., & Fleer, M. (2015). Small science: Infants and toddlers experiencing science in everyday family life. *Research in Science Education*, *45*(3), 445–464. https://doi.org/10.1007/s11165-014-9431-0
Silvia, P. J. (2008). Interest – the curious emotion. *Current Directions in Psychological Science*, *17*(1), 57–60. https://doi.org/10.1111/j.1467-8721.2008.00548.x
Silvia, P. J. (2012). Curiosity and motivation. In R. M. Ryan (Ed.), *The Oxford handbook of human motivation* (pp. 157–167). Oxford University Press.
Siry, C., & Max, C. (2013). The collective construction of a science unit: Framing curricula as emergent from kindergarteners' wonderings. *Science Education*, *97*(6), 878–902. https://doi.org/10.1002/sce.21076
Skalstad, I., & Munkebye, E. (2021). Young children's questions about science topics when situated in a natural outdoor environment: A qualitative study from kindergarten and primary school. *International Journal of Science Education*, *43*(7), 1017–1035. https://doi.org/10.1080/09500693.2021.1895451

Skarstein, T. H., & Skarstein, F. (2020). Curious children and knowledgeable adults – early childhood student-teachers' species identification skills and their views on the importance of species knowledge. *International Journal of Science Education*, *42*(2), 310–328. https://doi.org/10.1080/09500693.2019.1710782

Soydan, S. B., & Erbay, F. (2013). The methods applied by pre-school teachers to raise the curiosity of children and their views. *Educational Research and Reviews*, *8*(13), 997–1008. https://doi.org/10.5897/ERR12.213

Spektor Levy, O., Baruch, Y. K., & Mevarech, Z. (2013). Science and scientific curiosity in pre-school—The teacher's point of view. *International Journal of Science Education*, *35*(13), 2226–2253. https://doi.org/10.1080/09500693.2011.631608

Stagl, J. (2012). *A history of curiosity: The theory of travel 1550-1800*. Routledge.

Strandberg, E., Jacobsson, J., & Saetre, P. (2005). Direct genetic, maternal and litter effects on behaviour in German shepherd dogs in Sweden. *Livestock Production Science*, *93*(1), 33–42. https://doi.org/10.1016/j.livprodsci.2004.11.004

Swan, G. E., & Carmelli, D. (1996). Curiosity and mortality in aging adults: A 5-year follow-up of the Western Collaborative Group Study. *Psychology and Aging*, *11*(3), 449–453. https://doi.org/10.1037/0882-7974.11.3.449

Tytler, R., & Peterson, S. (2003). Tracing young children's scientific reasoning. *Research in Science Education*, *33*(4), 433–465. https://doi.org/10.1023/B:RISE.0000005250.04426.67

UNESCO. (2021). Retrieved November 16, 2021, from https://en.unesco.org/themes/early-childhood-care-and-education

Valdesolo, P., Shtulman, A., & Baron, A. S. (2017). Science is awe-some: The emotional antecedents of science learning. *Emotion Review*, *9*(3), 215–221. https://doi.org/10.1177/1754073916673212

van der Graaf, J., Segers, E., & Verhoeven, L. (2015). Scientific reasoning abilities in kindergarten: Dynamic assessment of the control of variables strategy. *Instructional Science*, *43*(3), 381–400. https://doi.org/10.1007/s11251-015-9344-y

van der Graaf, J., Segers, E., & Verhoeven, L. (2016). Discovering the laws of physics with a serious game in kindergarten. *Computers & Education*, *101*, 168–178. https://doi.org/10.1016/j.compedu.2016.06.006

Van Schijndel, T. J. P., Jansen, B. R. J., & Raijmakers, M. E. J. (2018). Do individual differences in children's curiosity relate to their inquiry-based learning? *International Journal of Science Education*, *40*(9), 996–1015. https://doi.org/10.1080/09500693.2018.1460772

Vygotski, L. S. (1978). *Mind in society: Development of higher psychological processes* (M. Cole, V. Jolm-Steiner, S. Scribner, & E. Souberman, Eds.). Harvard University Press. https://doi.org/10.2307/j.ctvjf9vz4

Wagstaff, M. F., Flores, G. L., Ahmed, R., & Villanueva, S. (2021). Measures of curiosity: A literature review. *Human Resource Development Quarterly*, *32*(3), 363–389. https://doi.org/10.1002/hrdq.21417

Wolbert, L., & Schinkel, A. (2021). What should schools to promtore wonder? *Oxford Review of Education*, *47*(4), 439–454. https://doi.org/10.1080/03054985.2020.1856648