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Received: 1 February 2023 | Revised: 14 March 2024 | Accepted: 5 April 2024

DOI: 10.1002/sce.21873

RESEARCH ARTICLE

Science Education WILEY

About birds and bees, snails and trees: Children's ideas on animal and plant evolution

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Abstract

Evolution is the integrative framework of the life sciences. Even though the topic is often not formally introduced before high school, young children already have various ideas about evolutionary principles (variation, inheritance, and selection) and their underlying key concepts (e.g., differential fitness, reproduction, and speciation). Describing and refining those ideas has increasingly received attention over the last two decades. However, we see two scopes of improvement in the field: (1) There is a need to examine children's ideas about evolutionary concepts holistically rather than focusing at specific aspects. (2) Although research has shown that older students have different ideas about animal and plant evolution, there is little data on children's ideas about plant evolution to compare with their ideas about animal evolution. All of this results in an incomplete record of children's pre-existing ideas that would help to design assessments or interventions. Consequently, we developed a set of questions, about the evolutionary principles and interviewed 24 kindergarten children. Most children had basic ideas about individual variation in animals and plants but experienced a lack of knowledge about the origin of variation. Most children seemed to acknowledge plants as living beings and reasoned equally about animals and plants for most concepts. However, many children failed to reason about

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reproduction and inheritance in plants because they believed plants would not reproduce sexually. Confronted with a selection scenario, most children struggled applying concepts previously shown on an individual level to a population level. Considering our findings, we propose ideas about how to measure and foster children's pre-existing ideas about evolution.

KEYWORDS

animals and plants, children's ideas, early evolution education, elementary education, plant awareness disparity, plant blindness, science education

1 | INTRODUCTION

Intuitive theories that arise and establish in childhood through cognitive biases are recognized as being one of the major causes of why students struggle with learning about evolution. These theories are coherent, widespread, and robust (Shtulman, 2017). Consequently, a growing field of research addresses the question whether and how integrating the topic of evolution into early science education might enhance scientific thinking and decrease the negative effects of cognitive biases to facilitate later learning about evolution in school (Kelemen, 2019; Olson & Labov, 2012). We will refer to this area as early evolution education research. Studies in early evolution education research focus on collecting data about children's pre-existing ideas (e.g., Gormley et al., 2022), linking those ideas to psychological structures (e.g., Legare et al., 2013), or testing the effect of interventions on children's ideas (e.g., a storybook intervention; Ronfard et al., 2021; for a detailed review see Bruckermann et al., 2021). However, two issues exist that motivated us to undertake this study: First, previous work mostly concentrates on single concepts of evolution (i.e., individual variation, origin of species). Consequently, we find a mosaic of studies addressing different concepts connected to the evolutionary principles of variation, inheritance, and selection (see Section 1.1). Second, nearly all previous research focuses exclusively on animal evolution and evidence about children's ideas on plant evolution is lacking. Thus, our aim is (1) to offer a holistic look at children's ideas about evolution across the three principles of variation, inheritance, and selection, and (2) to counteract the establishment of plant awareness disparity in early evolution education and research by assessing children's ideas about both animals and plants. To do so, we interviewed kindergarten children at the age of 5–6 years old to answer the following research questions:

1. What ideas do children hold about variation, inheritance, and selection?
2. What context-dependent differences in their ideas do children show regarding these principles between animal and plant examples?

1.1 | Conceptual knowledge about evolution

One central goal of biology education is fostering conceptual knowledge of evolution, the integrative framework of the life sciences, that refers to the change of populations' properties over time (Mayr, 2001). Charles Darwin described the basic mechanism of evolution in terms of three principles: variation, inheritance, and selection. Variation refers to the differences that exist among individuals within a population. These differences can give

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individuals an advantage or disadvantage in a particular environment. Inheritance is the passing down of traits from parents to their offspring. The offspring inherits a combination of genetic information from both parents, which contributes to the diversity of traits within a population. Selection occurs when certain traits provide individuals with a better chance of survival and reproduction in a given environment, leading to greater representation of those traits in subsequent generations. Over time, this process can result in significant changes within a population. Given enough time and accumulation of changes, populations can diverge to the extent that they become distinct species.

Those principles (variation, inheritance, and selection) can be further characterized and amplified by associated biology-specific key concepts (e.g., Nehm & Reilly, 2007). Studies in evolution education research incorporate varying numbers of associated key concepts. In the context of this study, a framework comprising nine key concepts of the evolutionary principles is utilized (see Table 1). These key concepts are widely recognized and commonly employed in the field of evolution education research (e.g., Ha et al., 2015; Nehm et al., 2012; Opfer et al., 2012; Peel et al., 2019; Sá-Pinto et al., 2021; Tibell & Harms, 2017).

Depending on the key concept, learners may also demonstrate various misconceptions. Misconceptions are scientifically inaccurate ideas that most learners intuitively have about different science topics (Coley & Tanner, 2012). For example, in the context of mutations, there is the misconception of "one-gene-one-trait," incorrectly assuming that a single gene determines a specific trait. Similarly, in the case of speciation, misconceptions such as essentialism or transformationalism (i.e., change occurring without any underlying mechanisms) can arise. Many of those ideas are rooted in cognitive biases, which play a central role in human development and their basic understanding of the world (Evans et al., 2012). The most commonly discussed psychological biases in evolution education are essentialism, teleology, anthropocentrism, and anthropomorphism (Table 2).

TABLE 1 Overview of the evolutionary principles and nine associated key concepts.

Evol. principles	Key concepts	Explanation
Variation	Individual variation	Individuals of a species differ in phenotypes and genotypes.
	Origin of variation	Individual variation that occurs unlinked to the environment originates from mutations or in the case of sexual reproduction from an assortment of different chromosomes during meiosis and recombination.
	Differential fitness	Variants can be differently relevant depending on the environmental context.
Inheritance	Reproduction	Members of a population have a high fertility (sexually or asexually) and cause an overreproduction of offspring.
	Inherited variation	Organisms pass genetically encoded traits to their offspring by inheritance. The offspring shows variation (see Origin of Variation).
Selection	Limited resources	Resources available to species are limited.
	Differential survival & reproduction rate	Variants fortuitously better adapted to changing local environments are more likely successful in their survival and reproduction rate.
	Change in population	The relative frequency of variants in a population changes over time through different reproductive success and death rates.
	Speciation	New species arise from populations through limitations in gene flow leading to all existing species being related (i.e., having a common ancestor).

Note: See Darwin (1972), Futuyma (1979), Gould (2002), and Mayr (2001).

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TABLE 2 Overview of cognitive biases relevant for evolution education with examples taken from children's books about evolution.

Psychological bias	Explanation	Example
Essentialism	... describes the assumption individuals of the same categories would share an underlying nature that defines their identity and characteristics (Coley & Tanner, 2012; Gelman, 2004)	"But the world was not finished, because we grew bones. Suddenly we were all lizards."
Teleology	... describes the tendency to explain the occurrence phenomena by reference to their final cause (function or purpose) (Kampourakis, 2020; Kelemen, 2012)	"And then they grew lungs so they could breathe air."
Anthropocentrism	... describes the overestimation of humans' superiority over and importance for the biological world (Coley & Tanner, 2012; Mylius, 2018)	"Humans became the most powerful Earthlings of all, but they forgot that they are made out of Earth's air, water, and soil."
Anthropomorphism	... describes the over attribution of human characteristics to organisms, objects, or phenomena (Mylius, 2018)	"The dinosaur wanted to fly... and flying changed the dinosaur into a bird."

Through education, people encounter explanations that contradict their intuitive understanding yet enable them to provide more appropriate answers and draw accurate conclusions about certain phenomena (Gelman, 2004). Although adults continue to hold these cognitive biases, children are nonetheless more inclined to give responses shaped by these patterns because they yet lack knowledge about counterintuitive scientific concepts (Shtulman & Schulz, 2008; Shtulman, 2017).

1.2 | Children's ideas on the evolutionary principles

A large corpus of interview and intervention studies exists investigating how children think and learn about variation, inheritance, and selection. In the following, we will review this previous work in light of the three evolutionary principles.

1.2.1 | Variation

In the context of evolution, variation is considered an accessible topic for early education, as children seem comfortable discussing individual variation and differential fitness (Frejd, 2018, 2021; Tare et al., 2011). However, in children's books (Adler et al., 2022) as well as in parent-child conversations (Hohenstein & Tenenbaum, 2023), variation rarely appears in the context of evolution. Especially younger children might be prone to three cognitive biases: essentialist, anthropomorphic, and teleological reasoning (e.g., the assumption that variation in traits serves identification; Gormley et al., 2022; Legare et al., 2013). Within-species variation can also sometimes be mistaken for between-species variation or for a developmental stage (Allen, 2010; Ibourk et al., 2018). For instance, after hearing a story about natural selection younger children were less likely to recall within-species variation than between-species variation (Legare et al., 2013), and in a study about variation in animal breeding programmes, some students reduced variation to differences due to sex or age (Alred et al., 2019). Concerning individual variation, two studies report young children's (5–6 years) acceptance of variation in animal species to be around or below chance

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rates (Emmons & Kelemen, 2015; Shtulman & Schulz, 2008). In one of these studies, older children (7–8 years) showed slightly higher acceptance rates that increased when beneficial features of a trait were not mentioned beforehand (Emmons & Kelemen, 2015). In contrast to those findings, other studies have reported slightly more favorable outcomes, suggesting that children at the age of 5–11 years exhibit at least an isolated to advanced understanding of variation in animals, which appears to improve with age (Gormley et al., 2022; Ibourk et al., 2018). These divergent findings could be attributed to differences in assessment tasks, rating scales, as well as the specific nature of the examples used (fictional vs. real, beneficial traits vs. neutral traits). Comparatively, the origin of variation is more difficult for children to grasp (Ibourk et al., 2018) as it requires a basic understanding of genetics and inheritance.

1.2.2 | Inheritance

Early ideas about reproduction are largely influenced by cognitive biases as well as cultural and social factors (Zogza & Christopoulou, 2005). For instance, kindergarten children struggle with causal and mechanistic explanations about reproduction (i.e., why do babies grow in the mothers' wombs?) and, not surprisingly, have not yet encountered the concept of genes (Williams & Smith, 2006; Zogza & Christopoulou, 2005). Instead of a baby emerging from a sexual relationship, young children emphasize intentional (i.e., wishing for a baby) or social factors (e.g., the father supports the mother) to play a key role in reproduction (Carey, 1985). In the case of plant reproduction, evidence suggests that children as well as older students reject plant reproduction (Banet & Ayuso, 2000; Okeke & Wood-Robinson, 1980; Stavy & Wax, 1989). This might be explained by the absence of visible mechanisms or movements (Lewis & Wood-Robinson, 2000). However, a more recent study indicates that even though older children did not reject that plants reproduced, they still lacked knowledge about the reproductive mechanisms (e.g., pollination and seed dispersal; Lampert et al., 2019). The disparities observed between these studies may be attributed to various factors, including potential variations in educational curricula across different nations (i.e., Austria, England, Israel, and Nigeria) and time periods (spanning over 40 years). Additionally, differences in the choice of terminology or phrasing could have played a role. For instance, in one of the earlier studies, students erroneously linked “reproduction” solely with mammalian copulation, resulting in a disregard for the concept of reproduction in plants (Okeke & Wood-Robinson, 1980).

Regarding inheritance, most kindergarteners believe that humans as well as nonhuman animals more strongly resemble their biological parents than their adoptive parents or friends (Ergazaki et al., 2014; Waxman et al., 2007; Williams & Smith, 2010). Some children, however, show a bias toward one parent being more strongly responsible for the offspring's traits and are still more susceptible to including information irrelevant for inheritance (Allen, 2010; Terwogt et al., 2003). As children grow older, their ability to reason about the inheritance of physical, behavioral, and personality traits improves enabling them, for instance, to distinguish between heritable traits (e.g., eye color) and nonheritable traits (e.g., beliefs) with greater accuracy (Solomon et al., 1996; Terwogt et al., 2003; Venville & Donovan, 2008; Venville et al., 2005; Waxman et al., 2007; Williams & Smith, 2006, 2010; Williams, 2012).

1.2.3 | Selection

Concerning selection, a considerable amount of research has investigated children's ideas about the origin of species (i.e., speciation) and the influence of cultural contexts regarding these ideas. For example, Samarapungavan and Wiers (1997) identified five different frameworks for children's ideas about the origins of animal species. Children who believed that all animal species were created by God as described in the Bible were considered creationists. However, most children showed to be non-creationists in that they did not believe in a Creator

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(Samarapungavan & Wiers, 1997). Instead, they assumed that all animal species had always lived on Earth (pure essentialists) or that dinosaurs had lived on Earth, which then somehow evolved into the current living species (dinosaur essentialists). Some children also assumed that animal species evolved from soil or seeds (spontaneous generationists), or that all animal species descended from a simpler ancestor that evolved by the use or disuse of organs (Lamarckians; Samarapungavan & Wiers, 1997). Following their work, other researchers came to conflicting conclusions, with some classifying children as predominantly creationists (Berti et al., 2010; Evans, 2000; Tenenbaum & Hohenstein, 2016) and others identifying them as mainly non-creationists but rather as transformationists (i.e., people assuming change without any underlying mechanisms) or spontaneous generationists (Berti et al., 2017; Shtulman & Checa, 2012).

Concerning the concept of change in populations, children also tend to use developmental (i.e., growth), transformationist, or teleological arguments (Berti & Barbetta, 2012; Emmons et al., 2017). However, there is ample evidence that children in second grade and higher are able to comprehend aspects of selection (Berti et al., 2017; Brown et al., 2020; Emmons et al., 2016, 2017; Legare et al., 2013; Metz et al., 2019; Ronfard et al., 2021; Shtulman et al., 2016). In a long-term intervention, Metz et al. (2019) showed how second graders developed the ability to reason about the relative frequency of certain traits over multiple generations. Yet, younger children seem to have more difficulties giving coherent explanations about the process of natural selection (Emmons et al., 2016; Kelemen et al., 2014) or imagining a time in which now living animals did not exist (Evans, 2000). However, studies show that young children can nonetheless benefit from interventions with simplified representations of selection concepts (Frejd, 2021; Nadelson et al., 2009). For instance, the concepts of extinction, homology, and adaptations (i.e., advantageous traits for certain environments) might be more accessible for children than changes in populations or common ancestry (Berti et al., 2010; Frejd et al., 2020; Grether, 2021; Nadelson et al., 2009; Shtulman & Checa, 2012; Shtulman et al., 2016).

There is conflicting evidence concerning younger children's ability to grasp adaptation as well as differential survival and reproduction (Frejd et al., 2020; Nadelson et al., 2009; Shtulman et al., 2016). One major difference contributing to this discrepancy might be the use of different task types, with interactive modeling tasks showing greater effects compared to receptive interventions (Frejd et al., 2020; Kelemen et al., 2014; Nadelson et al., 2009; Shtulman et al., 2016). Further, it shows that children appear very sensitive to speech when reasoning about selection. For example, young children who were told about a natural selection scenario were especially prone to anthropomorphic explanations (Legare et al., 2013). However, if the narrator used teleological explanations, they were more likely to refer to differential survival and differential reproduction (Legare et al., 2013).

1.3 | Blind spot: Children's ideas on plant evolution

This brief review demonstrates the imbalance we find in early evolution education research that favors the exploration of children's ideas about animals (Table 3).

This has led to a lack of data about children's ideas about plant evolution. Thus, there is insufficient evidence for comparing children's conception of animal and plant evolution. Studying children's ideas about plants is important for both research and education purposes (e.g., Jose et al., 2019; Lampert et al., 2019). First, anthropomorphic reasoning tends to be more common when reasoning about animals (Urquiza-Haas & Kotrschal, 2015). Thus, investigating children's ideas about plant evolution could also help determine if using plant examples could mitigate anthropomorphic misconceptions in the understanding of evolution. Second, plants hold immense ecological significance as the driving force of our ecosystem and the foundation of our food web (Vezzani et al., 2018). Omitting research on children's understanding of plants may result in a zoocentric output of educational materials and reinforce a biased (anthropocentric) worldview, potentially impacting students' behavior and attitudes (e.g., attitudes toward plant conservation; Balding & Williams, 2016; Martín-López et al., 2007).

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TABLE 3 Overview of studies about children's ideas/knowledge about variation, inheritance, and selection divided by organismal context since 2000 (sorted by participants' age).

	Animals		Humans		Plants	
Variation	Shtulman and Schulz (2008)	4–11 years				
	Emmons and Kelemen (2015)	5–8 years				
	Gormley et al. (2022)	5–11 years				
	Legare et al. (2013)	5–12 years				
	Frejd (2018)	6 years				
	Tare et al. (2011)	6–12 years				
	Ibourk et al. (2018)	g 5	Ibourk et al. (2018)	g 5	Ibourk et al. (2018)	g 5
	Alred et al. (2019)	g 6–16			Lehrer and Schauble (2004)	g 5
Inheritance	Waxman et al. (2007)	4–10 years	Ergazaki et al. (2014)	4–5 years		
	Solomon and Johnson (2000)	5–6 years	Terwogt et al. (2003)	4–10 years		
	Legare et al. (2013)	5–12 years	Williams and Smith (2006)	4–14 years		
	Frejd (2021)	6 years	Williams and Smith (2010)	4–14 years		
	Frejd (2018)	6 years	Williams (2012)	4–14 years		
	Tare et al. (2011)	6–12 years	Smith and Williams (2007)	4–15 years		
	Berti et al. (2010)	7–9 years	Zogza and Christopoulou (2005)	5 years		
	Venville and Donovan (2008)	g 2–12				
	Grether (2021)	8–12 years				
	Venville et al. (2005)	9–15 years	Venville et al. (2005)	9–15 years	Venville et al. (2005)	9–15 years
	Ibourk et al. (2018)	g 5	Ibourk et al. (2018)	g 5	Ibourk et al. (2018)	g 5
			Chin and Teou (2010)	10–11 years	Lampert et al. (2019)	10–18 years

(Continues)

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TABLE 3 (Continued)

	Animals		Humans		Plants	
Selection	Shtulman and Checa (2012)	4–12 years	Evans (2000)	5–13 years		
	Shtulman et al. (2016)	4–12 years				
	Legare et al. (2013)	5–12 years				
	Evans (2000)	5–12 years				
	Emmons et al. (2016)	5–8 years				
	Kelemen et al. (2014)	8–8 years				
	Nadelson et al. (2009)	k & g2				
	Frejd (2018)	6 years				
	Frejd (2021)	6 years				
	Frejd et al. (2020)	6–7 years				
	Emmons et al. (2017)	6–8 years				
	Hohenstein and Tenenbaum (2023)	6–11 years	Hohenstein and Tenenbaum (2023)	6–11 years	Hohenstein and Tenenbaum (2023)	6–11 years
	Tare et al. (2011)	6–12 years				
	Endreny (2006)	7–8 years				
	Tenenbaum and Hohenstein (2016)	7 and 10 years	Tenenbaum and Hohenstein (2016)	7 and 10 years	Tenenbaum and Hohenstein (2016)	7 and 10 years
	Ronfard et al. (2021)	g 2–3			Metz et al. (2019)	g 2–3
	Brown et al. (2020)	g 2–3				
	Metz et al. (2019)	g 2–3				
	Berti et al. (2017)	8–9 years				
	Grether (2021)	8–12 years				
	Berti and Barbetta (2012)	8–14 years				

Note: y = years, g = grade.

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Research shows that children inherently hold different ideas and biases about the biology of plants and animals. For example, a variety of context-specific inaccurate ideas has been identified concerning taxonomy, nutrition, respiration, development, and response to stimuli (Allen, 2010; for an overview, see Wynn et al., 2017). There are several developmental and cultural factors that contribute to a phenomenon called *plant awareness disparity* (formerly referred to as plant blindness; Wandersee & Schussler, 1999). It manifests in people not aware of the plants in their environment, lacking knowledge and interest in botany, as well as underestimating the plants' value for our biosphere (Parsley, 2020; Wandersee & Schussler, 1999). During development, children first define living beings through self-generated movement (Margett & Witherington, 2011). Therefore, young children usually recognize humans and animals but not plants as being alive leading to different assumptions about individuals of the two kingdoms (e.g., Martínez-Losada et. al., 2014).

Adults continue to be biased by intuitive beliefs they had as children even after having acquired more accurate theories (Shtulman & Harrington, 2016). Consequently, students perform better on animals than on plants, for example, in reaction tests and memorization tasks (Balas & Momsen, 2014; Schussler & Olzak, 2008). However, unbalanced knowledge and misconceptions about plants can also be rooted in a lack of experience, education, interest (Uno, 2009; Wandersee & Schussler, 1999), or simply favoring the visibility of animals in media (Adler et al., 2022; Schussler et al., 2010). Plant awareness disparity can also be found in evolution education. Despite evolution being a universal phenomenon that applies to all living beings and viruses (Diamond & Zimmer, 2006), most learners show different ideas, conceptual knowledge, and misconceptions when reasoning about examples of evolution with different context factors (such as the biological kingdom; Heredia et al., 2016; Opfer et al., 2012). For example, students performed better on questions about animals than on plant evolution (i.e., chose more correct responses in a multiple-choice test; Heredia et al., 2016). Consequently, when trying to understand and shape children's first ideas about evolution, it is not trivial to consider their pre-existing ideas on plants.

2 | METHODS

2.1 | Interview questions

After defining the theoretical framework of this study (see Section 1.1, Table 1), we identified essential aspects of the nine evolutionary key concepts that we derived from the literature to obtain the most complete picture of natural selection. For instance, *Different age of death*, *Different reproductive rates*, and *Different preconditions connected to survival* were essential aspects assigned to the key concept Differential survival (see Table 4).

For each of these underlying aspects, we designed one question. The questions were either developed or adapted from prior studies that had assessed adults' (Anderson et al., 2002; Kalinowski et al., 2016; Nehm et al., 2012) or children's (Emmons & Kelemen, 2015; Ibourk et al., 2018; Samarapungavan & Wiers, 1997; Williams, 2012) knowledge or ideas on aspects of variation, inheritance, and selection by (1) adding or reducing aspects that were and were not in line with our research aim, respectively, (2) making the question applicable to different examples from the plant and animal kingdom, (3) simplifying the terminology and making them age-appropriate, and/or by (4) unifying the questions' layout (see Table 5).

Most questions started with a closed-ended question and were then followed by further clarification questions about the children's reasoning (e.g., "What do you think? Why is that?"). All questions were designed to be used similarly for animal and plant species by filling in the placeholders with the names, characteristics, and vital resources of the respective taxa.

We contextualized most of the selection items within a story about a small population that colonizes an island to depict the complexity of selection in a comprehensible manner (see Supporting Information M1—Interview Script). A research expert in child language development helped us adjust the language.

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TABLE 4 Aspects of variation, inheritance, and selection that the interview questions referred to.

Variation	Inheritance	Selection
Individual variation	**Reproduction**	**Limited resources**
1 *Individual variation in general*	1 *Coming to life*[a]	1 *Limited resources in environment*
2 *Variation in nonheritable traits*	2 *Biological parents*	2 *Different distribution of resources within a species*
3 *Variation in heritable traits*	3 *Superfecundity*	3 *Competition for resources*
4 *Variation in non-visible traits*	4 *Reproductive boundaries between species*	**Differential survival and reproduction rate**
Origin of variation	5 *Growth of populations under ideal conditions*	1 *Differences in reproduction rate in general*
1 *Origin of variation in general*	**Inherited variation**	2 *Survival depending on resources*
2 *Origin of heritable traits (by birth)*[b]	1 *Inheritance of traits – one parent*	3 *Different survival rate within a population due to different traits*
3 *Origin of variation in heritable traits*	2 *Inheritance of traits – two parents*	**Change in population**
4 *Origin of acquired traits (i.e., injury/environmental influence)*	3 *Resemblance in families*	1 *Change after obvious scarcity of resources*
5 *Anthropomorphistic explanation of variation*	4 *Anthropomorphistic explanation of inheritance*	2 *Change in morphology*
		3 *Type of change*
Differential Fitness		4 *Anthropomorphistic explanation of selection*
1 *Different age of death*		**Speciation**
2 *Different reproductive rates*		1 *Origin of species*
3 *Different preconditions connected to survival*		2 *Ancestry and phylogeny*
12 questions	9 questions	12 questions

[a]Translated from German: *auf die Welt kommen* [being born], which literally translates to "coming to the world."

[b]This question was excluded post hoc from the analysis because it did not lead the children to talk about the intended concept.

2.2 | Example species

We aimed to choose an equal amount of plant and animal species that were possibly diverse (i.e., belonging to different biological and folk biological categories such as herbaceous plant vs. tree). Even though many (especially psychological) studies use fictitious examples to ensure that possible prior knowledge does not interfere with the participants' conceptual ideas, we decided to use species that kindergarten children might be familiar with (i.e., species endemic to Europe that are not endangered). We wanted to keep the children from thinking of a fantasy creature that would not be bound to the laws of our world by asking for familiar real-world examples. We selected the brown-lipped snail, the hooded crow, the red fox, the eagle fern, the dandelion, and the apple tree (Table 6).

For the variation and inheritance questions, we used the brown-lipped snail, the red fox, the dandelion, and the apple tree. The hooded crow and the eagle fern were used for the selection scenarios.

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TABLE 5 Examples of adapted items that have previously been tested with children (variation example) or were designed to be used for older students (inheritance example).

Variation: Individual variation	
Original	Scientists have named one of the animals they recently discovered a [e.g., hergob]. There has only been one [hergob] found so far. […] I'm going to show you pictures of the [hergob] that was found and ask you some questions about what other [hergobs] could be like. Do you think all hergobs in the group could have fuzzier sprogs in their ears? – Emmons and Kelemen (2015)
Adapted version	Look, my friend John was walking in the forest the other day and he saw something. He's very good at drawing and when he got back home he tried to draw what he saw as neatly as he could. Do you have any idea what this is? […] Look. The [taxa] has [trait]. Picture John looking for more of these [taxa]. What do you think? Do all [taxa] have [trait]? … What do you think? Why is that? – Question V1_c
Inheritance: Reproduction	
Original	Assuming ideal conditions with abundant food and space and no predators, what would happen if a pair of guppies were placed in a large pond? – Anderson et al. (2002) (CINS, Item 11)
Adapted version	Now I would like to tell you a short story. There is an island in the middle of the sea. There is grass, and there are trees, bugs, worms, and lizards. But one day there is a heavy storm. A group of crows was flying over the sea when the storm carried them away and blew them to the island. Since then they live on the island and find a lot to eat. Now imagine that a lot of time has passed. How old are you now? … Okay. And think about it. From your x to your last birthday. That is a lot of time, right? … That was a year. And now imagine that one year passes. Then you are x years old. And another year. And one more. So a lot of time, right? What do you think? How many crows live on the island now? Are there as many as before? Or are there now more or less? … What do you think? Why are there more/less/did they stay the same? – Question I1_c

TABLE 6 Overview of the chosen examples.

	Animals			Plants		
Kingdom	**Invertebrates**	**Vertebrates**		**Polypodiophyta**	**Flowering plants**	
Categories	**Snail**	**Bird**	**Mammal**	**Fern**	**Herbaceous plant**	**Tree**
Species	**Brown-lipped snail**	**Hooded crow**	**Red fox**	**Eagle fern**	**Dandelion**	**Apple tree**
	Cepaea nemoralis	*Corvus cornix*	*Vulpes vulpes*	*Pteridium aquilinum*	*Taraxacum officinale*	*Malus domestica*

In collaboration with a graphical designer, we created images and prepared them in the form of small square-shaped cards as an opening and support for the interview questions. For each example, five images (six images for the selection scenarios) were designed that depicted variation (e.g., variation in height, fur color, or injuries).

2.3 | Sample

A total of 33 children were interviewed for this study. First, we conducted three rounds of pilot testing with a total of nine children (three children in each round) before the main data collection. Afterward, we collected the data of 24 children (63% read female) in German kindergartens. The children were between 5 ($n = 8$) and 6 ($n = 16$) years old. In Germany, there are no recommendations or curricula for early evolution education. Thus, the children had not previously encountered the topic of evolution, at least in the setting of their kindergarten education.

2.4 | Procedure

Each child was randomly assigned to a condition with one animal and one plant example treating questions about variation and inheritance as well as to one selection example (either animal or plant). Furthermore, the order in which the child was asked about the animal and plant examples was randomized. Some questions revealed information that could have influenced the children's answers for other questions. Therefore, we did not randomize but put the questions in a certain order (see Supporting Information: M1—Interview Script).

The interviews were carried out in a separate room within the children's kindergartens. Our team consisted of an interviewer and a research assistant who monitored the time and wrote down all inaudible actions (i.e., nodding, head shaking, shrugging, pointing) as well as deviations from the script. The interviewing person stayed the same, while the assistants changed between the interviews. The interviews were audio-recorded, transcribed verbatim, and the audio files deleted afterward due to data privacy rules. The sessions were scheduled for 1 h, including a break of at least 15 min, during which the children were invited to draw or play together with the interviewing team. The children were free to take breaks or stop the interview at any time. At the beginning of the interview, the children were told about their rights. They were reminded that it was not about saying the right thing, but that the team was interested in what they thought to be true. The interviewer also explained how the audio-recorder worked and for what the audio-recording would be used. The interviewer and the child then started the recording together when both agreed that they were ready and wanted to proceed. Additionally, the interviewer sought to monitor the children's motivation and well-being. The average time of the interviews was 36 min (min 9, max 56), with two children deciding to end the interview earlier.

The pictures were uncovered one by one during the interview. The interviewer followed the script as well as possible but tried to adapt to the vocabulary provided by the children. Also, the interviewer did not evaluate the children's answers, but showed interest and responded in a neutral yet affirmative manner. When a child gave a certain answer, the interviewer refrained from asking further questions that would have exposed the child's answer as incorrect.

2.5 | Validity considerations

To ensure the validity of the findings based on the interview guidelines and questions, we checked the validity evidence described by the Standards for Educational and Psychological Testing (see American Educational Research Association et al., 2014). In line with this guidance, we employed a well-established theoretical framework for item selection (see Section 1.1) and adapted questions from published instruments or interviews when available,

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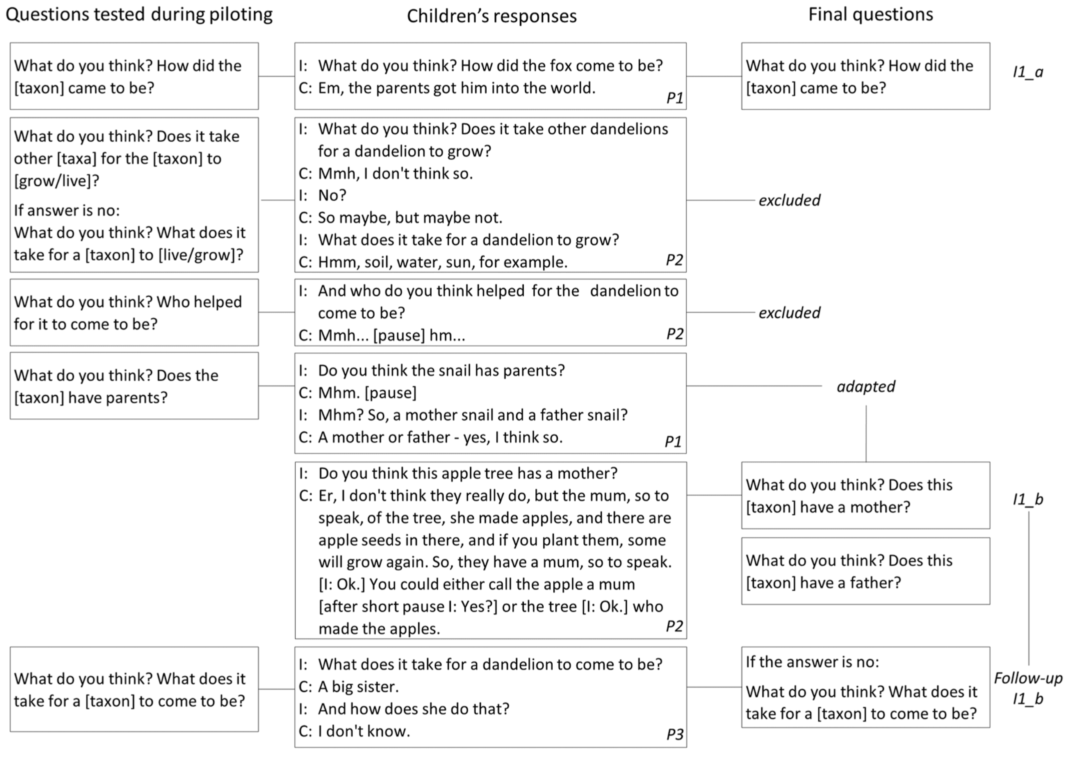

FIGURE 1 Excerpt of development process for the example of reproduction questions. The numbers P1 to P3 indicate the piloting phase.

increasing the likelihood of validity and reliability in our items (test content). Additionally, three pilot rounds helped identify and rectify flaws or limitations of the interview guideline, enhancing content validity (see Figure 1).

Evidence to determine whether the interpretation of the children's responses was valid came from (1) observations during the interview and (2) the analysis that was conducted in the process of the development of the category system. This was especially true for the questions not already been tested with children.

In the first two piloting stages, the interviewer used an observation sheet (taken from Werther, 2016) after each interview to notice any remarkable behavior or problems in understanding particular questions (e.g., hesitancy, confusion, or unusual responses) that then guided further improvements. In the last piloting phase, an additional observer was present to write a protocol of the session, noting again remarkable behavior, such as hesitancy, confusion, or unusual responses. Afterward, both filled out the observation sheet and discussed the interview protocol. Due to the target group being young children, we encountered limitations in gathering valid evidence related to the response process. The measure we implemented was to ask them to elaborate on their initial responses, seeking further explanations through questions like "What do you think?" and "Why is that?" (see Section 2.1). However, during the data collection process, we also tried to navigate the delicate balance of striving to extract meaningful insights while respecting the participants' autonomy, creating a comfortable environment for them to express their thoughts freely and avoiding any implication of their answers or ideas being insufficient. To achieve this, participants were explicitly informed that they had the option to decline answering questions, ensuring their voluntary participation but that responses such as "I don't know" or "next" were perfectly acceptable. This strategy was also implemented in previous studies (see, e.g., Halls et al., 2018). For this reason, we were especially cautious not to overwhelm or pressure the children into providing additional explanations when they indicated to had no idea concerning the question. Consequently, discerning the reason behind a child's response of having no

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idea (a genuine lack of knowledge, reluctance due to perceived inadequacy, or misunderstanding of the question) proved challenging in some instances.

To further refine the interview protocol and the category system, after each piloting round, the transcripts of the interviews were analyzed to see if the children's responses could be classified as fitting into one of the three intended categories (i.e., unscientific, intermediate, and advanced; see also next Section 2.6). If this was not the case, the category system was extended, or the questions were amplified to enhance the probability that the children would produce an answer that could be interpreted appropriately. Additionally, the interrater reliability of the interviewer with an independent rater was calculated to minimize the risk of a biased interpretation. It should be noted that the interview was used for formative purposes only, that is, to identify and analyze the first ideas of kindergarten-aged children about variation, inheritance, and selection in animal and plant examples. It was not intended to serve as a general summative evaluation tool.

2.6 | Data analysis

Based on the piloting data, we developed a category system to score the children's answers from 0 (unscientific) to 2 (advanced; see Supporting Information: M2—Coding Manual), similar to the approach of Shtulman (2006). We coded neutrally when the children indicated they had no idea, as this could not be used as an indicator of an unscientific idea.

We coded a total of 1100 answers. Interrating was conducted with six interviews (25% of the sample) including a total of 301 answers and reached an agreement of 84.1% and a Krippendorff's alpha of .79.

For a quantitative description, we calculated a mean score for every key concept (see Table 1) separated by the organismal context (plant or animal). Also, we conducted a Wilcoxon signed ranks test to assess whether there were significant differences in children's responses between animals and plants. For a qualitative description, we paraphrased the children's answers during the coding of the main sample and looked for patterns in their reasoning. Both, quantitative and qualitative findings, will be described in Section 3.

3 | RESULTS

Overall, the interviews revealed that most children had solid ideas (intermediate and advanced concepts) about variation (especially individual variation) and reproduction. Most children struggled with reasoning about inheritance and selection concepts. The mean score for plant examples was usually only slightly smaller, except for the reproduction and change in population questions (Figure 2). Statistical analysis revealed significant differences between the animal and plant conditions for the two reproduction questions I1_a and I1_b, that address how individuals come to life (I1_a; $V = 36.0$, $p = 0.012$) and if they (necessarily) have biological parents (I1_b; $V = 74$, $p = 0.005$; see also Supporting Information M3—Comparison of animal and plant examples).

In the following, we will give more insights into the children's answers.

3.1 | Variation

3.1.1 | Individual variation

In general, children reached moderate rates in the case of within-species variation (on average 1.40, min = 0, max = 2). Seven children assumed that all individuals of animal and plant species vary (see Table 7), while another seven children said that individuals would partly show variation. Children rejected variation in general in only six cases (four in the animal,

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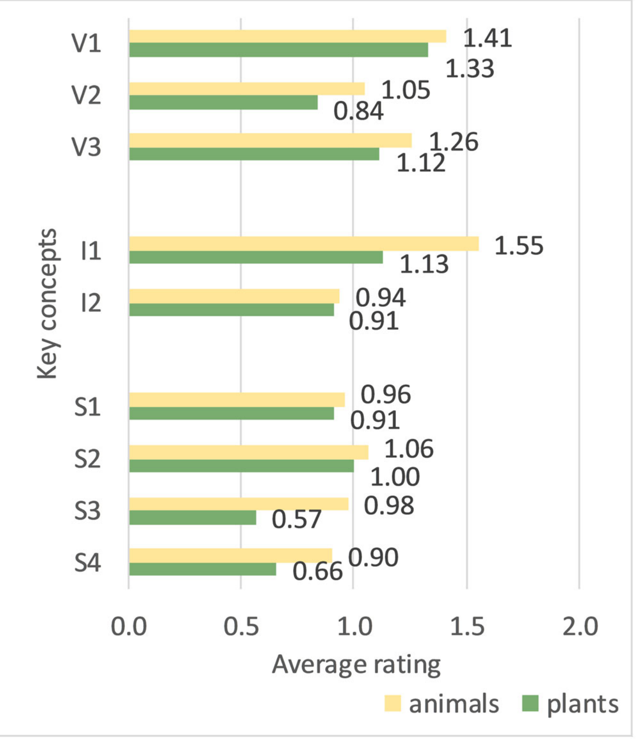

FIGURE 2 Average ratings the children showed for animal and plant examples for the nine key concepts* (*n* = 24). *V1 Individual variation, V2 Origin of variation, V3 Differential fitness, I1 Reproduction, I2 Inheritance, S1 Limited resources, S2 Differential survival & reproduction rate, S3 Change in population, S4 Speciation.

two in the plant condition). Children were more likely to assume variation in acquired/non-heritable traits (on average 1.88, min = 0, max = 2) and variation in general (on average 1.46) than variation in heritable traits (on average 1.02, min = 0, max = 2) and in non-visible traits (i.e., general variation in inner traits; on average 1.10; Figure 2). Most children (*n* = 17; 70.8%) also gave at least one essentialist answer. The children gave fewer essentialist answers concerning non-visible traits when it came to animals, and children gave no essentialist answers when it came to injuries in plants. When asked about variation in non-heritable traits (i.e., injuries, brown leaves), the children justified their answer by making hypotheses about the causal events (*n* = 13) or by relying on their own experiences (sightings of real animals [*n* = 4] or plushies [*n* = 1]). When asked about variation in heritable traits (i.e., coloring and leave shape), the children indicated that the trait was part of the species' nature (*n* = 7), justified their answer by relying on sightings in real life (*n* = 4), or also made hypotheses about an outer event that caused the heritable trait to emerge (*n* = 3). However, most of the children could not explain the reasoning behind their answers.

3.1.2 | Origin of variation

Two of the origin of variation items were those for which children most frequently claimed to have no idea (origin of variation in general (13 times for 8 children) and for heritable traits (18 times for 13 children). Another nine children failed to explain the origin of variation, for example, by using circular arguments (*n* = 5) or by solely describing the individuals (*n* = 4). One child identified variation to result from inter-parental variation and one child mentioned the plants' seeds

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TABLE 7 Definitions and examples of coding for unscientific, intermediate, and advanced responses to variation questions.

Category and definition		Example
Individual variation (V1)		
Unscientific	No variation/essentialist explanation (i.e., all individuals of a species are alike)	I[a] Imagine we could look inside such an apple tree. Do you think that all apple trees look the same from the inside or do they all look different? C Mh, the same. I Okay, why is that? C Because they all, every species looks the same. Child 118[b]
Intermediate	Variation occurs sometimes/between-species variation/variation occurs due to external or developmental factors	I Do you think that if Jan were to look for other dandelions, that they would all have such round leaves? C Nope. [...] They could also be pointed like tree leaves. I And how come that some dandelion leaves are pointed and others are round? If [... both are dandelions. C Maybe someone rounded them like that with a knife. Child 005
Advanced	Biological variation (i.e., individuals are unique)	I What do you think, if we could look inside the snail's body, would all the snails we are looking for look the same on the inside? Or would they look different? C M-m. [shakes head] I No? What do you think, why not? C Because every sn- we are different and then snails are also different. Child 003
Origin of variation (V2)		
Unscientific	No variation/unsuitable or anthropomorphic explanation	I Do you think that the snail was already born like that? C Uh, some snails pick up the snail shells just like that. Then they look for them, and then they just stick themselves into them. I They look for a new snail shell? C Yes, if it is too small, then they look for another one. But if there's a snail in it where another snail wants to get in, then it would be really slimy. Then the other snail would wake up and then like that, then they would get so

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TABLE 7 (Continued)

Category and definition		Example
		bent out of shape and wouldn't be able to get free. And then they would have to hop like this. Hop, hop. Child 121
Intermediate	Individuals occur randomly/variation occurs due to developmental stages	I What do you think, was he already born with the white tail tip? C I think it was brown first and then white. I Uh-huh, so that changed over time? C [nodds] I What do you think how did that happen? C Mh, I don't know right now. Child 103
Advanced	Variation occurs due to variation between parents (or eventually due to random factors (like mutations))	I And why do you think some are born with a yellow house and others with a brown house or a black house? C Because every um mother looks different, but snail babies can also look different than snail mothers. Child 003
Differential fitness (V3)		
Unscientific	All individuals die at the same age or do not die at all/have the same number of offspring/the same preconditions or skills	I Imagine we observe a group of foxes and we observe how fast they run. Do you think all foxes run the same speed? C [nods] I Yes? Or are there some that run faster? Or some that run slower? C No. Child 125
Intermediate	Individuals die at different ages/have different numbers of offspring (no or unsuitable explanation)//variation in preconditions or skills but those would not lead to advantages or disadvantages/variation in preconditions or skills occur due to developmental stages	I If you could now observe two foxes, a mother and a father, over their entire lives. What do you think? How many baby foxes do they give birth to? C I don't know. It could also happen that eight are born. I Aha, do you think there could be more than eight or less than eight? C More and less, I think. So, with less it could also be one, two, three, four, five, six, seven, and so on. And with more like twenty, forty. I Okay. How do you think it is that it varies so much among the foxes? C I don't know.

(Continues)

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TABLE 7 (Continued)

Category and definition		Example
		Child 127
Advanced	Individuals die at different ages/have different numbers of offspring due to internal or external factors/variation in preconditions or skills can lead to advantages or disadvantages	I What do you think? If we could observe two snails like this over their entire lives. What do you think? How many snails do they give birth to? C Hm… eighteen. I Mhm. Are there also some that give birth to more? Or some that give birth to fewer? C [nods] I Yes? How come some give birth to more and some give birth to less? C That the - the ones that give birth to uh less are just more threatening of extinction. I Ah, okay I see. C That they can die more easily. I Okay, how come they are threatened? Do you have an idea? C That they are noticed often. […] By the hedgehogs and birds. Child 118

[a]I = Interviewer, C = Child.

[b]The numbers refer to the children's IDs.

would be different from another. Even though most children did not come up with an explanation by themselves, most children rejected an anthropomorphic explanation for the origin of variation in plants ($n = 13$) or animals ($n = 12$).

3.1.3 | Differential fitness

Most children assumed that individuals of the same species would die at different ages ($n = 16$ for animals, $n = 18$ for plants) and produce different numbers of offspring ($n = 18$ for animals, $n = 8$ for plants). Seven of these children could explain why individuals had different survival rates (equally for animals and plants). Compared to that only four (for animals) and two (for plants) children could explain the variation in reproductive success. Also, half of the children agreed that individuals of animal ($n = 10$) and plant species ($n = 8$) would have different traits that could lead to advantages in the environment.

3.2 | Inheritance

3.2.1 | Reproduction

Most children agreed that animals would need two parents ($n = 17$) but that plants would have only one parent ($n = 11$) rather than no ($n = 6$) or two parents ($n = 4$; see Table 8). Regarding animals, two children said that the mother was needed more while fathers could be optional, and one child said that foxes could also have two

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TABLE 8 Definitions and examples of coding for unscientific, intermediate, and advanced responses to inheritance questions.

Category and definition		Example
Reproduction (I1)		
Unscientific	Individuals do not reproduce and have no biological parents	I What do you think? How did this dandelion come to be[a]? C I don't know. It just grew somewhere. Because it's a wild dandelion. We even have wild strawberries at home. I Wow, okay. Do you think the dandelion has a mother? C Nope. I Do you think it has a father? C Nope. [...] I And what do you think? What does it take for a dandelion to grow? C I don't know. Water, sun. Seeds? I Mhm. And where does the seed come from? C I don't know. Fell out of the factory somewhere. Child 127
Intermediate	Individuals come to life through other individuals of the same species but they cannot have more than one biological parent	I What do you think? How did this dandelion come to be? C It grew. I It grew? How did it grow? C Well, mmh, so then...mmh, I know! Because a dandelion grew somewhere else, which then became a blowball[b] and then someone blew it and it fell on the spot where this dandelion grew and then it grew. I Ah, okay, I see. C The dandelion umbrellas are the seeds of that. I Mh, do you think that a dandelion has a mother? C Yes. I Do you think that a dandelion has a father? C Mmh, well it only takes one dandelion. I Okay, I see. C That would be a mom or a dad. Child 112
Advanced	Individuals reproduce and have biological parents (of the same species)	I And what do you think? How did the fox come to be? C From the mommy.

(Continues)

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TABLE 8 (Continued)

Category and definition		Example
		I Aha. So, he has a mommy. Does he also have a dad? C [nods] Child 104
Inherited variation (I2)		
Unscientific	No inheritance (i.e., parents and offspring do not need to resemble each other)	I What do you think? Which ones could be the parents of the fox? C I think it's this one. That's the daddy. And this is the mommy. I And why would you say that this is the daddy? C Well, because he looks so manly. I What does a manly fox look like? C Well, he looks so mean. I Ah, okay. And this one? [points to the previously selected mother fox] C He looks so nice. I And therefore it is the mommy? C Yes. Child 001
Intermediate	Inheritance (i.e., parents and offspring share characteristics) but explanation does not follow the logic of inheritance (e.g., no differentiation between heritable and inheritable traits/one parent is considered as being more important than the other)	I What do you think? The apple trees that he brings into the world,[c] do they also have a hole in the trunk? C Mh, I think so. I [...] And do they also have a white flower? C I think so. Child 128 I Do you think the snails would then also be born with a crack in the house? C M-hm [agreeing]. I And do you think they would also have a blue body? C M-hm [agreeing] I Yes? Okay, what do you think? How come they are so similar to the snail then? [...] C I think because the, I think because that is inside the shell, and then they get the same body, I think. Child 128

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TABLE 8 (Continued)

Category and definition		Example
Advanced	Inheritance (i.e., parents and offspring share characteristics) and explanation follow the logic of inheritance	I Could the snail also come from this one? C [nods] I Yes, could be? Why? C Because he also has a yellow house. I Okay, could it also come from this snail? C No. [...] Because it's red. Child 117

[a]Translated from German: *auf die Welt kommen* [being born].
[b]Translated from German: Pusteblume [expression that refers to the mature stage of a dandelion].
[c]Translated from German: *zur Welt bringen* [to deliver].

mothers. The children were also more willing to use family terminology in the context of animals than plants. Children who located the origin of organisms in individuals of the same species would mostly refer to animals as to "come from mothers" ($n = 9$) and plants as to "come from other dandelions/apple trees" ($n = 8$). None of the children mentioned parents in combination with plants even though nine children agreed fully or partly when asked directly if plants had parents. Five children said those plants would come from another plant or fruit that could not be considered a parent. Three children considered the father, two children the mother to be essential for plants to come to life. Two children said that plants could not have parents because parents needed arms to hold children or feet to come to life. Fourteen children mentioned seeds ($n = 11$; $n = 6$ for dandelions; $n = 5$ for apples), pips ($n = 4$ for apples), or grains ($n = 3$ for apples) when asked about the origin of organisms. One child mentioned bees but could not explain how bees were involved in plant reproduction. Nine children mentioned the need for a human being for plants to come to life. They referred especially to humans' function of spreading or planting the seeds ($n = 9$) rather than buying, finding, sharing seeds ($n = 1$), watering ($n = 1$), or having a garden ($n = 1$). By comparison, the need of humans was not mentioned in any animal example. One child did not consider the need of anything else for a plant to start to grow and one child mentioned that plants would come from soil.

Concerning reproductive barriers, half of the children located reproduction only within the same species equally for animals ($n = 15$) and plant examples ($n = 10$). Some children considered species to be an important factor when reasoning about families or reproduction but assumed that some species might interbreed ($n = 5$ for animals and $n = 4$ for plants). This was especially true for species of the same family (e.g., two snail species or a fox and a dog).

Regarding superfecundity, half of the children assumed that animals ($n = 15$) and plants ($n = 10$) produced more offspring than required to maintain the population size (i.e., more than 2). Of those, most children chose numbers above 10. Additionally, when asked about a founder population that got to an island through a storm and further lives under ideal conditions, most children expected it to change in size over time ($n = 16$). However, most children assumed that a change in population size was caused by other factors than reproduction like another storm ($n = 4$), death ($n = 2$), or (in case of crows) migration (get their families, go back home; $n = 4$). Only three children mentioned reproduction as a factor for change in population size. Another three children expected the population size to stay constant over the years.

3.2.2 | Inherited variation

When asked to pick parents for a certain example, most children ($n = 15$) did not consider similarities in characteristics but mostly referred to the size of the individuals. When some of the children tried to determine the animals' sex (without being asked to do so), most of them referred to the size, mostly with the larger individuals being the male. In seven cases children considered similarities but claimed that both parents had to look similar or only chose one parent.

When asked about inheritance directly half of the children ($n = 11$) indicated that a parent would inherit traits to their offspring and most of those children differentiated correctly between heritable and non-heritable characteristics ($n = 8$ for animals, $n = 4$ for plants). However, the other half of the children ($n = 10$) rejected that offspring would resemble their parent, with six of them insisting that all individuals vary completely from each other. For example, one child said that offspring would resemble their parents just by accident. Further, three children explained the resemblance of parents and offspring through them belonging to the same species.

When asked about inheritance with two parents, most children assumed that offspring would somehow resemble their parents (animal condition: 14 out of 18, plant condition: 6 out of 8). Nine children agreed that parents or offspring could decide which characteristics the offspring would have. Seven children rejected anthropomorphic assumptions. Five children rejected parts of anthropomorphic explanations claiming that individuals could wish for it but that it would probably not come true.

Since we refrained from asking questions that would contradict former statements from the child, we skipped the inheritance questions in seven cases because the children had rejected reproduction of those species (six in the plant, one in the animal condition).

3.3 | Selection

3.3.1 | Limited resources

Most children assumed, at least for one of two examples, that resources in the environment would be unlimited ($n = 15$; $n = 10$ for animals, $n = 12$ for plants; see Table 9). However, most of the children also claimed in at least one example, that resources would not be distributed equally between individuals ($n = 18$). Comparing the different examples, it seems like the resource space was the context that the children struggled the most with (on average 0.59, min = 0, max = 2) compared to competition for prey (0.85, min = 0, max = 2), food (1.05, min = 0, max = 2), or water (1.19, min = 0, max = 2).

3.3.2 | Differential survival and reproduction rate

Even though most children agreed that individuals would die if they did not get enough resources ($n = 16$) they struggled imagining how a lack of resources would influence the reproduction rate and how to apply that concept on a population level: Out of 13 children in the animal condition, only four children assumed that the simulated lack of resources would lead to death of certain individuals. Two children assumed that the population would be affected by the environmental change but that this would lead to a change in their diet ($n = 2$). The other seven children assumed that the lack of resources would not affect the population.

3.3.3 | Change in population

Most of the children could not properly explain how traits within a population would change over time (on average 0.55). When no obvious selection pressure was given, six out of 18 children assumed an agent, like the wind ($n = 2$), water ($n = 1$), humans ($n = 1$), or nature ($n = 1$) to be responsible for the change.

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TABLE 9 Definitions and examples of coding for unscientific, intermediate, and advanced responses to selection questions.

Category and definition		Example
Limited resources (S1)		
Unscientific	Resources in the environment are not limited/ equally distributed	I No? What do you think? Does it happen sometimes that one fox has more food than another? C Mmh, no. I No? Do they all have the same? C I think so. Child 112
Intermediate	Resources in the environment are limited/not equally distributed (no or unsuitable explanation)	I Okay. What do you think? Is there always enough food for all the foxes? C Eheh [negating]. I No? How come? Why not? C I don't know. Child 127
Advanced	Resources in the environment are limited/not equally distributed due to biotic or abiotic factors	I And do you think it sometimes happens that one apple tree has more water than another? C [nods] I Yes? How come? C If he is simply in a place that has more space, if it is free, then he gets more. Child 118
Differences in reproduction and survival rate (S2)		
Unscientific intermediate	Selection pressure or a lack of resources could not affect individuals	I Could a fox also die if it does not get enough to eat? C No. Child 120
Intermediate advanced	Selection pressure or a lack of resources could affect (certain) individuals but they would not die/they would change	I Now imagine that one day there's a disaster and a big wave floods the part of the island where the beetles have their burrows. What do you think? What happens now? C Then those with long beaks have to eat worms. [...] And maggots. I Okay, so they eat other things then? C Yes, because they can't eat beetles anymore. Child 125 I What do you think? Could a snail die if it doesn't get enough to eat?

(Continues)

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TABLE 9 (Continued)

Category and definition		Example
		C [nods] I What do you think? Could it also be that a snail gives birth to fewer children if it has less to eat, or does it have nothing to do with that? C Nothing to do with that. Child 117
Advanced	Selection pressure or a lack of resources could affect (certain) individuals and they would be more likely to die/less likely to reproduce	I Imagine that these three and these three ferns are different. Namely, these three ferns have poison in the leaves. [...] When animals try to eat from the ferns, they get sick and then they stop eating from the ferns. And these ferns don't have poison in their leaves. [...] And now one day there is a plague of grasshoppers. Grasshoppers come over and spread all over the island. What do you think? What happens now? C The ferns get eaten up. These. [points at ferns without poison] Child 112
Change in population (S3)		
Unscientific intermediate	No change in population/unsuitable explanation	I When we return to the island a few years later, are there more of those [points to long beaked crows] or of those [points to short beaked crows], or are there as many as before? C As many as before. I Okay, how come? C Mh... that... that just happened. Child 118 I Okay, and if we look at them, you see [...] they have black and white feathers [...] But in the past, there were crows on the island, that were completely black and they didn't have white feathers. What do you think? How come they have white feathers these days? C [...] Probably, I think probably, because bird poop got on them. [both laugh] I I see, and so is there bird poop on every bird? C Yes. Child 103
Intermediate advanced	Populations change all at once or gradually but all at the same time/individuals with a certain trait are more likely to survive or die	I And if we take a closer look at the ferns, we see that all of them here have very smooth stems. [...] Now imagine that the ferns didn't

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TABLE 9 (Continued)

Category and definition		Example
	than others, but the (frequency of these traits within the) population would not change	have smooth stems in the past, but they had hairs on their stems. What do you think? How come that the ferns that live there have smooth stems now? C Mmh, nature. I Nature? What do you mean by that? C [...] Well, nature can choose how plants and crops are. I [...] Do you think they lost the hair all at once, or did they lose it bit by bit? C Bit by bit. Child 112
Advanced	The (frequency of certain traits within the) population changes because individuals with this trait would be more likely to survive or die than others/change in a population occurs over generations	I If time goes by and we wait a few years. What do you think? What will happen then? C Grasshopper. I Will there still be as many ferns as before or more or less? C None of those are there anymore [points to ferns without poison] and of those, all are there [points to ferns with poison]. Child 116
Speciation (S4)		
Unscientific	Now living species have always existed on Earth/individuals of closely related species look alike in certain features for no reason/(unsuitable explanation)	I What do you think? How come they look so much alike? C Because they're both dark green. Child 116 I What do you think, have there always been apple trees in the world or was there a time when there were no apple trees? C Um, so in the past, there were a few, but not as many as now. Child 121
Intermediate advanced	Now living species have not always existed on Earth (no or unsuitable explanation)/individuals of closely related species look alike in certain features because they are all of the same kind (e.g., they are all plants or all crows)	I What do you think? Have there always been apple trees in the world or was there also a time when there were no apple trees? C [nods] [...] With the dinos. I Ah, okay, and how come there are apple trees in the world now? C Because the dinos are no longer alive and some have been harvested.

(Continues)

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TABLE 9 (Continued)

Category and definition		Example
		I Okay, who harvested them? C Mh, a farmer. [...] First he had a seed and he planted it and then he dug up the apple tree. Child 118 I This is a hooded crow and then I have a raven here. And this is a carrion crow. What do you think? Why do these three animals look so much alike? C Because they're all one kind of crow. I Ah, okay I see. And what does that mean? C That they look alike. But they are still a different species. Child 118
Advanced	Now living species have not always existed on Earth but evolved from earlier species/individuals of closely related species who look alike in certain features due to their evolutionary relationship	I What do you think? Have there always been apple trees in the world, or was there also a time when there were no apple trees? C [unintelligible] a time when there were no apple trees I Aha, so why are there apple trees in the world now? C Because they have developed from other trees Child 116 I Look, this is one of the hooded crows. Then this is a carrion crow, and this is a raven. What do you think? Why do these three animals look so much alike? C Because of the black feathers, the feet and the beaks. [...] And the- and the two with the eyes. I Okay. And what do you think? Why do they have such similar feathers and feet and beaks? And such similar eyes? C Hmm, from of one of these animals, the other two have developed. Child 107

Two children traced the change to age. However, nearly all of the children (8 of 11) that got offered an explanation with an anthropomorphic reasoning rejected that explanation. Most children either assumed a sudden change of all population members (n = 6) or a gradual change of all individuals over time (n = 6). Only two children exclusively accepted that new traits appear and distribute within a population over time. In the selection scenario, where an obvious selection pressure was given, most children (n = 10) did not connect the environmental change to a change in the frequency of traits within the population.

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3.3.4 | Speciation

Most children ($n = 16$) assumed that there was a time before the example species lived on Earth. Of those children, four mentioned evolution or claimed that the species had developed from other species. Six children assumed that currently living species have always lived on Earth. Again, children who answered questions about both examples were mostly consistent in their reasoning between animal and plant species (i.e., scored equally for both examples) but sometimes deviated in their causal explanations. For example, when asked about plant examples, five children mentioned a human agent that brought the first individuals to life by planting or inventing them. Compared to that, a human agent was only mentioned by one child when asked about animals. Two children claimed that the first fox or snail was born from another fox or snail.

When asked about the resemblance of closely related species, most children ($n = 9$ out of 13) claimed to have no idea. Two children claimed that they were evolutionarily related. Another two children mentioned that they belonged to the same kind (crows/birds/ferns).

4 | DISCUSSION

Our study contributes to the need for a better understanding of the nature of children's pre-existing ideas about evolution (Bruckermann et al., 2021). The purpose of this study was to describe early ideas that kindergarten children have regarding the evolutionary principles of variation, inheritance, and selection and to analyze possible differences regarding ideas about animals and plants. The results showed that children hold a variety of ideas concerning the three principles, with a few children already having some advanced ideas. Surprisingly, we found no substantial differences between animal and plant examples except for the principle of inheritance. Furthermore, the present findings identify several courses of action for early science educators and researchers. In the following, we will discuss our findings as well as the limitations of this study and draw implications for education and research.

The interviewed children already had many accurate ideas about variation and we found much less evidence of young children rejecting within-species variation than reported by, for instance, Emmons and Kelemen (2015). Thus, our findings are in line with more recent evidence (Gormley et al., 2022). We even found that some children rejected inheritance due to a strong variationist bias. We hypothesize that the discrepancy between the three studies could be explained by the approach of using fictitious examples and simplified depictions (Emmons & Kelemen, 2015) versus using real and familiar examples with realistic, more detailed pictures (this study; Gormley et al., 2022). Even though research about plant awareness disparity describes that children, students, and adults perceive plants as a green mass (Parsley, 2020; Wandersee & Schussler, 1999), most of the children in our sample had a concept of within-species variation in plants.

Previous studies have shown that students who apply different ideas to plants or animals know more about animals than plants, or are better at remembering facts about animals (Heredia et al., 2016). Many misconceptions arise, because students transfer their understanding of animals onto plants (e.g., plants drink water, breathe air, or reproduce like animals, plants have 46 chromosomes like humans; Barman et al., 2006; Parker et al., 2012; see also Wynn et al., 2017). Other misconceptions may stem from students not perceiving motion in plants (e.g., plants do not compete for resources, light, or space; Wynn et al., 2017) and therefore young children show a delay in integrating plants into their concept of aliveness compared to animals (i.e., they initially do not consider them as being alive; Anderson et al., 2014; Barman et al., 2006; Margett & Witherington, 2011; Tao, 2016; Wynn et al., 2017). Based on these findings, we expected that children would show more advanced ideas regarding variation, inheritance, and selection in animals. However, our study surprisingly found that most children showed similar levels of ideas in both examples, except for the concept of reproduction. One interpretation of these findings is that the concept of aliveness alone may not be sufficient to explain the differences in children's reasoning about plants and animals when applied to other concepts. Although living things are typically characterized by certain

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properties such as growth, reproduction, metabolism, adaptation, response to stimuli, inheritance of genetic information, and evolution, children may not necessarily reject these properties when considering plants as not being alive. This discrepancy could be attributed to the limitations of previous studies on children's understanding of aliveness, as Leddon et al. (2008) point out. Ambiguous terminology used in these studies might have led to misinterpretation (for a discussion, see Leddon et al., 2008). Leddon et al. (2008) showed that, when children are asked about plants being living things rather than plants being alive, they demonstrate a different biological concept that encompasses both plants and animals. Another interpretation is that both the concept of aliveness and reproduction are influenced by their association with movement (i.e., children are more likely to consider things that move as being alive). The immobility of plants may have led the children in our sample to reject the idea of reproduction in plants because they associate reproduction with the social construct of families coming together and living as one. Previous findings also indicate that while children understand that plants grow from seeds, they struggle to explain sexual reproduction in plants (Lampert et al., 2019; Lewis & Wood-Robinson, 2000). This might be due to the assumption that fruits or seeds come from a single plant, leading to the misconception that plants reproduce asexually, which is also commonly found in high school students (Banet & Ayuso, 2000), similar to the mother bias observed in some children (Terwogt et al., 2003). On the other hand, the principles of variation and selection can be applied to both mobile and nonmobile entities. For example, dandelions vary but so do pebbles. Therefore, reasoning about these principles may not necessarily be tied to the concepts of motion or even aliveness. Consequently, children may not exhibit distinct differences in their reasoning between plants and animals.

Even though our study did not uncover statistically significant differences in the level of children's responses for most concepts, however, in some cases, we found some qualitative differences in the form of different reasoning patterns about plants and animals. For instance, the children showed a stronger anthropocentric bias toward plants by putting humans in the role of supporting their reproduction, evolution (i.e., change in population and speciation), and survival. This might come from the children's experience of gardening or keeping house plants. Consequently, they overestimate the role of humans as cultivators rather than as a dependent part within the biosphere or the food web (Allen, 2010). Other researchers also found similar anthropocentric explanations of children and students concerning plant evolution, development, and physiology (Christidou & Hatzinikita, 2006; Hohenstein & Tenenbaum, 2023). Based on our findings, we also hypothesize that the concept of reproduction might be linked to speciation (i.e., the origin of species). For instance, the children showed similar patterns in their ideas about these two concepts by stating that animals descended from other animals while assuming plants to have been introduced to Earth by humans. It would be interesting to investigate whether correcting children's anthropocentric view toward plant reproduction would influence their ideas concerning the origin of plant species.

In summary, our findings propose that children are capable of learning about animals and plants on a comparable level, as they do not exhibit significantly different ideas about these two categories, except for the concept of reproduction. However, insufficient learning opportunities regarding plants (see Schussler et al., 2010) might result in the persistence of misconceptions (like the mother bias in the context of plant examples) and ultimately lead to an imbalanced understanding of animals and plants. Consequently, it is still necessary to investigate context-specific differences in children's ideas to provide learning opportunities that connect with their pre-existing ideas.

Even though our study did focus more explicitly on context-dependency regarding animals and plants rather than spatial scales (i.e., levels of organization; see Ross et al., 2010; Tibell & Harms, 2017), our results still indicate that kindergarten children struggle with transferring conceptual knowledge from the individual to the population level. For example, most children assumed that plants and animals would reproduce. However, most of these children did not expect populations to grow as a result of reproduction. Although, most children knew that an individual would die without nutrition resources (i.e., water or food), only few children concluded that the selection pressure would lead to death of the affected individuals in the population-based selection scenario. Previous findings indicate that children have difficulties thinking of complex ecosystems that contain more than one living organism, for example, because they do not consider that other organisms are critical as a food source

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(Endreny, 2006). Furthermore, the selection scenario also required the ability to reason about time (another threshold concept) and hypothesize about the future of a population. Children begin to make predictions at an early stage (e.g., Baillargeon, 2004). However, the ability to make predictions based on temporal and causal information probably does not emerge until the age of 4 and develops until the age of 6 (Lohse et al., 2015). In contrast, children's ability to recall temporal and causal events, known as temporal updating, is developed much earlier (McCormack & Hoerl, 2005, 2007). This suggests that interventions designed to convey more complex scenarios, such as natural selection, should rely on detailed visual representations, but will likely generate responses that rely more on the children's memorization than on their causal understanding (see Kelemen et al., 2014).

4.1 | Implications

Our findings reemphasize conclusions from previous studies suggesting that early evolution education could start with learning about variation and inheritance because they are observable in children's environment (see Adler et al., 2022; Frejd, 2018; Ibourk et al., 2018; Tare et al., 2011). A solid conception of individual variation is known to correlate with more accurate ideas about evolution (Shtulman & Schulz, 2008). By strengthening children's variation concept, educators might be able to counteract unscientific ideas about evolution (e.g., essentialist reasoning). Purposefully designed interventions could provide them with fruitful experiences that might lead to the development of more accurate ideas about evolutionary principles. For instance, outdoor activities, children's literature, or conversations could be used to discover and discuss within-species variation or to explain how plants reproduce sexually and do not depend on human support. It is true that many plants can reproduce asexually. However, rejecting sexual reproduction in plants could lead to severe misconceptions about the inheritance and evolution of plants. Even though we are not aware of books that focus on variation in plant and animal species, books exist that depict diversity (explicitly or implicitly) in humans which aim to teach children about tolerance (e.g., Feder, 2021; Madison et al., 2021). Those could offer a good starting point to show that variation is not unique to humankind but part of the biological world.

Interventions introducing a simplified gene concept (as a place-holder for a scientific gene-concept) possibly have a strong sense-making impact on children's reasoning about biological concepts origin of variation and inheritance (see Ergazaki et al., 2014). Children are receptive to satisfying explanations (Frazier et al., 2016). Thus, it might be especially useful for children to introduce first ideas about underlying mechanisms (i.e., the molecular scale) that help them explain more accurately the ideas that they already have. For example, nearly all of the interviewed children differentiated between heritable and non-heritable traits. However, compared to the origin of non-heritable traits, the children had no or only unscientific ideas about why individuals would be born with certain traits and why they would vary in those traits. The origin of variation might be the most abstract variation concept due to aspects on the molecular level. Further studies could investigate whether a simplified gene concept might not only help children to learn about inheritance (see Ergazaki et al., 2014) but also about the origin of variation. Thus, interventions about the origin of variation could strengthen the conception of inter-parental variation and the role of randomness as a placeholder for genetic concept (such as recombination and mutation).

The concept of death seemed to be more accessible for children than reproduction. For instance, children inferred how individual's survival rate is impacted by access to resources in general or by certain traits that help individuals accessing resources, but they struggled drawing conclusions about their reproductive success. To design first easy scenarios for teaching selection, educators might choose a context that lead to death, explaining how death leads to changes in populations, without covering differences in reproductive success, or connecting reproductive success explicitly to survival or death rates.

In sum, our research can serve as a base for future studies, for instance, on how children can be supported to apply their knowledge about individuals on a population level. We also propose that further research should be undertaken concerning children's biological ideas about plants.

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4.2 | Limitations

This study provides first insights into children's ideas about plant evolution and how these ideas differ from their ideas about animal evolution. However, during data collection and analyses, we realized that one question did not lead to our intended outcome. We asked if individuals would already possess their heritable traits when born to investigate whether children think that heritable traits are deterministic (i.e., genetic) or caused through development. In retrospect, we realized the question did not fit the aim because plants in contrast to our animal examples only show the most heritable traits that affect their physical aspect later in development. Therefore, we excluded that item from the analysis. Further, we tried to avoid a floor effect (i.e., design questions too difficult for kindergarten children). Thus, children performing well in this interview do not equal a scientific understanding but might be an indicator for advanced conceptual pre-knowledge. This is especially true for the concepts change in populations and speciation. In our qualitative approach, however, we were not interested in diagnosing the children, but rather in describing their ideas.

We tried not to exceed 45 min per interview. This resulted in more missing data toward the last questions covering the selection scenario (i.e., differential survival and reproduction rate and change in population). We also refrained from asking questions revealing flaws in the children's reasoning. For instance, many children rejecting plant reproduction, so we did not ask these children the questions of the inheritance set resulting in several missing data for this particular set. Other missings were products of poor audio quality or deviations from the script. Due to these missing data the numbers are not always comparable among each other.

Furthermore, we identified issues in terminology use. For the sake of comparison, we designed the questions in a way that they could be applied to animal and plant examples and used familiar nonscientific terminology. In some cases, this might have caused problems. For example, we asked for mothers, fathers, and siblings of animals or plants. However, the intended biological concept could be easily mistaken for the social construct of a family. This was a clear trade-off. We tried to control this by asking further clarification questions to get to the root of the children's ideas. Still, we think that using family terminology can help ask about reproduction and inheritance without using scientific or sexual terms. Furthermore, family terminology is also frequently used in phylogeny (e.g., Diamond & Zimmer, 2006).

5 | CONCLUSION

Implementing evolution education earlier in the curriculum is believed crucial for facilitating and improving learning about evolution in school. Yet, we still lack knowledge about children's preliminary ideas about evolution so as to plan and evaluate interventions and educational activities at the elementary and primary levels. For example, a neglected topic in the field of science education research is what children think about variation, inheritance, and selection of plants compared to animals (see also Table 1). By exploring this question, our findings add to a growing body of literature on how children think and learn about evolution. We found that the interviewed children largely accepted variation in plants and animals. However, they had difficulties explaining how variation emerges. Most children had difficulties applying inheritance, which would comprise concepts on the molecular level (i.e., genetic knowledge), and hypothesizing about the potential development of populations, which would comprise inferences involving concepts such as probability, space, and time. Concerning the differences between animals and plants, surprisingly, the children showed only marginal differences for most key concepts. However, the children often lacked knowledge about reproduction in plants (i.e., children describe that only one plant is involved in the process of reproduction), which might also interfere with their ability to reason about inheritance and selection within the dynamic of a population. Also, the children overestimated the importance of humans for plant life, reproduction, and evolution. These observations led to the conclusion that inheritance (possibly including a simplified gene concept, as suggested by Ergazaki et al., 2014) and plant reproduction could be promising starting points to enrich children's ideas about basic evolutionary concepts while further consolidating children's ideas about variation.

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One objection to studying kindergartners' ideas about evolution is that even older students still struggle with comprehending evolutionary biology. We would like to take the position that our findings indicate children already inherently have various ideas about basic evolutionary concepts, which could be supported by learning opportunities to enhance scientific thinking and mitigate the establishment of misconceptions. Previous research also showed that age-appropriate speech can sometimes be the limiting factor in why children and researchers fail to understand each other (Greif et al., 2006; Kelemen et al., 2014; Margett & Witherington, 2011). We as researchers might help them shape their ideas toward a scientific concept by providing adequate learning opportunities and crucial information, they can understand but would not intuitively know only through their experiences.

This study is a first step toward a more holistic approach regarding our understanding of children's ideas about biological concepts relevant to their notion of evolution. Even though our study provides a small sample, we are confident that our results may improve knowledge about children's pre-instructional ideas regarding evolution and provide educators with ideas on how to further improve science education for children.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support during the data collection provided by our research assistants Felix Müller (data collection, transcription, and interrating), Laura Callsen (transcription), Linn Krackow (transcription), Johannes Poser (data collection), and Leah Skrzynski-Fox (data collection). The authors also thank Occidental College and Andrew Shtulman for providing a workspace and professional input during the preparation of this paper. Finally, special thanks are due to the kindergarten directors and educators who opened their doors to our projects, together with the parents who gave their consent to have their children interviewed. And last but not least, the authors would like to thank all the brave children who participated in our study. Open Access funding enabled and organized by Projekt DEAL.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

This study was granted ethics approval by the IPN Ethics Board (Reference No. 2021_AD54), with all kindergarten principals, parents, and children providing informed consent.

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