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Young children's acceptance of within-species variation: Implications for essentialism and teaching evolution

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ABSTRACT

Neglecting within-species variation plays a crucial role in students' misconceptions about adaptation by natural selection. Prior research on the development of this propensity suggests that this neglect is due to a strong early-arising essentialist bias to treat species as invariant. Across two studies, we examined the strength of this bias by exploring 5- and 6-year-olds' and 7- and 8-year-olds' assumptions about variation in contexts similar to those used in a recent early educational intervention teaching adaptation. In Study 1, children heard about fictitious animals' physical and behavioral traits and their beneficial functions. They then judged whether all other species members would vary or be invariant on those traits. Across age groups, children showed a marginal essentialist tendency to reject variation. In Study 2, the same method was used, but all references to beneficial trait functions were removed. The 5- and 6-year-olds' responding did not differ from Study 1, but the 7- and 8-year-olds' acceptance of variation increased to above chance rates. Parental religious and evolution beliefs correlated with younger children's responses but not with older children's responses. Together, the findings suggest that under certain facilitative contexts children display greater abilities to represent variation than assumptions of a robust and inflexible essentialist bias would predict. By 7 to 8 years of age, children displayed autonomy from their parents' beliefs and tended to expect

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variation. However, priming their teleological intuitions undermined their non-essentialist expectations. Theoretical and educational implications are discussed.

Introduction

Adaptation by natural selection is central to the study of living organisms and fundamental to understanding why organisms possess functionally specialized traits. Despite its significance to biology and related fields, however, decades of research have shown that it is widely misunderstood (see Gregory, 2009, for review). This is in part because individuals fail to appreciate that adaptation involves a selectionist process in which species members with more beneficial traits out-live and out-reproduce other members with less beneficial traits—ultimately leading to a greater frequency of organisms with beneficial traits in the population. Instead, individuals tend to incorrectly reason that beneficial adaptations result from all species members undergoing heritable transformations in response to their survival needs (Gregory, 2009; Kelemen, 2012).

Although specific causal ideas about how individual species members transform can differ, incorrect beliefs about adaptation are largely resistant to instruction (Jensen & Finley, 1995; Shtulman & Calabi, 2013) and are observed among first-year medical students and science teachers with background training in biology (e.g., Brumby, 1984; Nehm, Kim, & Sheppard, 2009). One of the key reasons proposed for this learning challenge is that when reasoning about adaptation, students do not assume the critical feature of biological populations that allows the selectionist process of differential survival and reproduction to occur—within-species variation (Gregory, 2009; Shtulman & Calabi, 2012, 2013; Shtulman & Schulz, 2008). What, then, accounts for students' tendency to ignore within-species variation when reasoning about adaptation?

Recent developmental research gives good reasons to suppose the tendency to neglect variation may derive from cognitive biases present from early childhood, one of which is the essentialist bias (Rosengren, Brem, Evans, & Sinatra, 2012). Psychological essentialism is the implicit belief that categories such as animal species share underlying causal properties or "essences" that determine their identity (Gelman, 2003; Medin & Ortony, 1989). Although essences cannot be seen and their content may not be explicitly known, from young ages individuals make inferences indicating that they believe stable underlying essences exist and are responsible for species members' properties. For instance, 4-year-olds intuit that even if a rabbit is raised by monkeys, it will still have long ears and a preference for carrots because, despite its unusual rearing, its essential and inviolable rabbit nature remains intact (Gelman & Wellman, 1991). Importantly, essentialist assumptions displayed during early childhood, and arguably as early as infancy (Setoh, Wu, Baillargeon, & Gelman, 2013), endure into adulthood and continue to exert a strong influence on reasoning about biological categories.

If essentialist assumptions predispose individuals to represent all species members as intrinsically the same, then overt evidence of differences across individual species members (e.g., variable fur color) are likely to be overlooked in favor of noting similarities (Gelman & Rhodes, 2012; Shtulman & Calabi, 2012; Shtulman & Schulz, 2008). As a natural consequence of assuming trait homogeneity within species, the most intuitive way to think about adaptation seems to be in terms of beneficial transformational events that occur within the lifespans of individual organisms and not in terms of a population-based selectionist process dependent on within-species variation. Observations that animals undergo dramatic physical changes within their lifetimes (e.g., as a function of inevitable growth) without changing their identity (Rosengren, Gelman, Kalish, & McCormick, 1991) likely further promote transformationist views of adaptation.

Even though there is valid justification for proposing that an early arising essentialist bias may contribute to neglecting within-species variation, currently there is limited research directly examining the strength of this resistance early in development. Prior related work has explored young children's reasoning about different taxonomic families (e.g., cats, dogs) and classes (e.g., mammals, birds) and shown that young children struggle to spontaneously represent and make inferences based on biological variation at these category levels (e.g., Rhodes & Brickman, 2010; Rhodes, Gelman, & Brickman, 2010). However, to our knowledge only one study has directly focused on young children's intuitions about variation within species. In that study, Shtulman and Schulz (2008) asked 4- to 9-year-olds whether it was possible for members of familiar animal species (e.g., ants, giraffes) to differ on their internal, external, and behavioral traits. Using a generic statement, children were informed that the species under question had a certain trait (e.g., "Did you know that giraffes have spots on their coats?") and were told about the trait's survival-relevant function (e.g., "The spots help them blend into the surroundings."). Children were then asked whether the trait was common to all species members or just the majority (e.g., "Do all giraffes have spotted coats or just most giraffes?"). Children who denied variation on this question were then asked an additional forced-choice question to further gauge their assumptions about innate potential (e.g., "Could a giraffe be born with a different kind of coat?").

On the initial question, children largely rejected the notion of variation within a familiar species, endorsing it only 20% of the time on average. Furthermore, to the extent that they accepted variation at all, it was primarily for behavioral traits rather than internal or external physical traits, which were presumably understood as more clearly derived from a shared species essence. Children who denied variation on the first question sometimes then endorsed that animals could be born with a different version of the described trait (mean acceptance was approximately 55%). Unfortunately, this finding is difficult to interpret because the form of the question may have led children to misconstrue it.[1] Nevertheless, children's response to the initial and more direct assessment of their variation acceptance clearly suggests that, consistent with a strong essentialist bias, 4- to 9-year-olds are largely non-receptive to variation. By implication, then, young children should find it almost impossible to comprehend the mechanics of a selectionist explanation of adaptation and should be able to entertain only the types of transformationist explanations of species change widely observed among older students who are the usual targets of instruction on adaptation. Yet, results from recent research seem to contradict this expectation.

Specifically, Kelemen, Emmons, Seston Schillaci, and Ganea (2014) explored whether children as young as 5 to 8 years can learn and apply a basic but comprehensive explanation of adaptation by natural selection. This lab-based educational intervention centered on children hearing and self-explaining a factual picture storybook narrative that described adaptation within a fictional but realistic mammal species. Findings across two experiments showed that many 5- and 6-year-olds and a majority of 7- and 8-year-olds not only comprehended the basic logic of natural selection but also generalized it to a different fictional mammal species (see also Emmons, Smith, & Kelemen, 2015). Notably, whereas younger children gained much from the intervention, a comprehensive grasp of the selectionist logic of adaptation was particularly marked among the older age group.

These findings raise questions about whether an essentialist bias renders children as robustly and inflexibly resistant to the idea of variation as is often assumed (see also Rhodes & Brickman, 2010; Rhodes et al., 2010). In the current two studies, therefore, we sought to take a closer look at the strength of this resistance by employing a novel method that incorporated elements from Kelemen and colleagues' (2014) education intervention—features that likely facilitated children's abilities to represent variation and ultimately learn natural selection. Consistent with Kelemen and colleagues (2014), but in contrast to Shtulman and Schulz (2008), the current task deliberately employed novel animals and avoided generic language. In both studies, 5- to 8-year-olds were introduced to a set of fictional but realistic individual animals, each described as the only discovered members of a previously unknown species. Following Shtulman and Schulz (2008), children were told about each animal's physical and behavioral traits and, in Study 1, about the traits' survival-relevant functions.

[1] Rather than understanding the question as asking whether species members can be born with a different trait than their parents by virtue of the inherent variability within a population, children may have understood the question as asking whether immature animals can look different from mature animals due to factors related to maturation and growth. The latter is something that, like adults, children have been found to accept even in cases of dramatic physical transformations (e.g., caterpillar to moth transformations; Herrmann, French, DeHart, & Rosengren, 2013; Rosengren et al., 1991).

Children were then asked to make predictions about whether all species members shared the discovered animal's traits or if some members could have variants of its traits. In Study 2, we excluded references to the beneficial functions of animals' traits to examine whether the standard communicative practice and recommended educational approach of describing traits in functional terms (Achieve & partners that collaborated on the NGSS, 2013) heightens children's resistance to within-species variation.

Given our novel method and the limited prior research on children's expectations about within-species variation, some of our predictions were open. If young children have a strong and inflexible essentialist tendency to view animal species as homogeneous, then they should display low levels of variation acceptance regardless of how animals and their traits are described. If, however, children are receptive to variation when presented with materials designed to support non-essentialist thinking, then we might expect moderate to high levels of variation endorsement in Study 1 and potentially even higher levels of endorsement in Study 2. Because our method drew significantly from Kelemen and colleagues' (2014) intervention, where older children showed enhanced learning of the selectionist logic of natural selection, we expected 7- and 8-year-olds to be more receptive to variation than 5- and 6-year-olds in both studies (see also Legare, Lane, & Evans, 2013). Finally, we predicted that variation acceptance would be higher for behavioral traits than for physical traits (Shtulman & Schulz, 2008).

Study 1

Method

Participants

Twenty 5- and 6-year-olds (10 boys and 10 girls; M_{age} = 5 years 11 months, *SD* = 4 months) and 20 7- and 8-year-olds (11 boys and 9 girls; M_{age} = 8 years 1 month, *SD* = 8 months) were recruited from the northeastern United States and tested individually at the lab for approximately 30 minutes (52.5% White, 15% Multiracial, 12.5% Hispanic, 12.5% Asian, 5% Black, and 2.5% unreported). An additional 3 children who participated were excluded due to experimenter error. Most children were from middle and higher socioeconomic status (SES) backgrounds. Sample sizes, age groups, and demographics were aligned with Kelemen and colleagues (2014) and Shtulman and Schulz (2008).

In addition to demographic details, parent questionnaires solicited responses on parental religious beliefs and practices and acceptance of evolution given their potential influence on children's acceptance of variation (see Evans, 2000, 2001 for related findings). For brevity, we report these data together with Study 2 parent data at the end of Study 2 results.

Materials

As in Kelemen and colleagues (2014), all stimuli used in the study were fictional but realistically drawn animals. A total of four species were used: two mammals ("berpod" and "hergob"), one bird ("orina"), and one fish ("poltum"). For each species, children were asked about the variability of three novel traits: internal, external, and behavioral. The use of novel animals and traits was meant to reduce children's abilities to defer to prototypes and apply prior knowledge about familiar animals to inform their responses. This was an important consideration given that children have strong prototypes for familiar animals, leading to failures in recognizing and remembering atypical species members (Bjorklund & Thompson, 1983; Rosch, 1999) and increased rigidity when determining the shared traits among members (Farrar & Boyer-Pennington, 2011).

Children received a total of 12 forced-choice questions. For each question, forced-choice answer options were pictorially depicted in order to reduce the cognitive load associated with imagining different alternatives. The "essentialism option" showed a group of four animals that all had the same trait as the discovered animal; the "variation option" showed two animals with variants of the trait and two animals with the same trait. The drawings were carefully designed to not reveal any clues about traits discussed in other drawings (see Figs. 1 and 2).

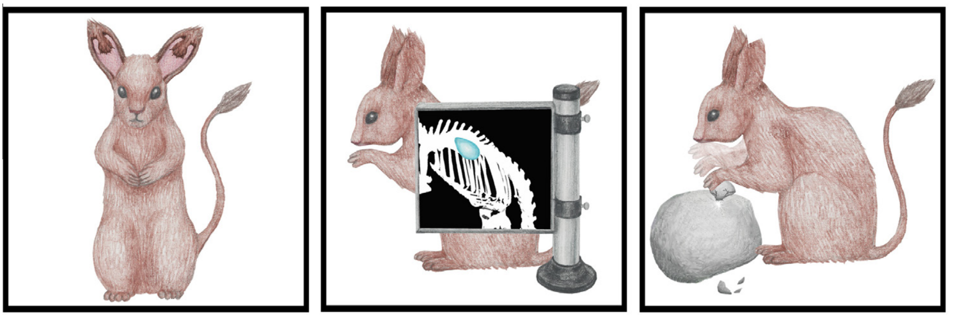

Fig. 1. Sample stimuli showing, from left to right, the discovered hergob's external, internal, and behavioral traits.

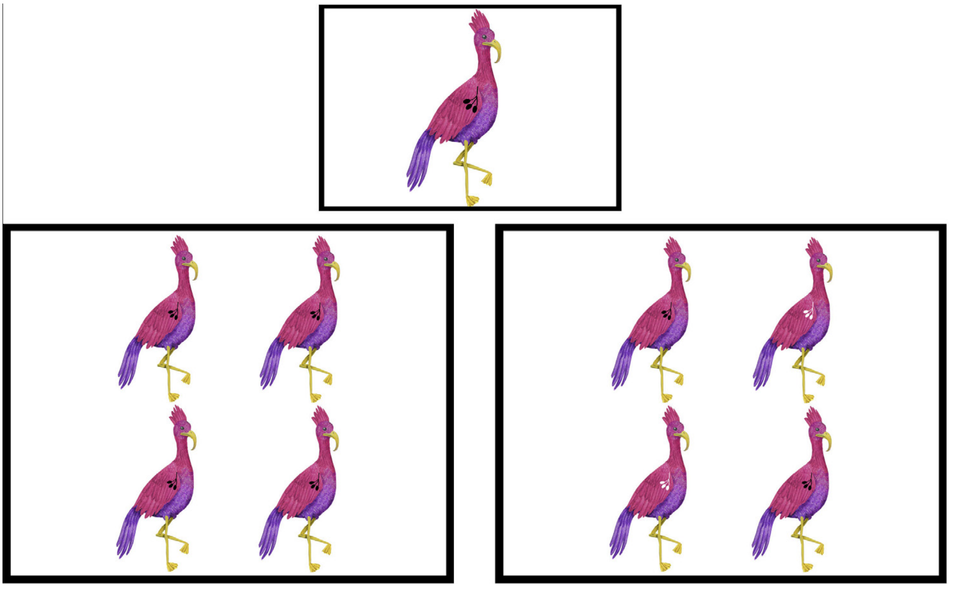

Fig. 2. Sample stimuli showing the discovered animal (upper), the essentialism option where all orinas have blacker plogs on their wings (lower left), and the variation option where some orinas have whiter plogs (lower right).

Procedure

To begin the task, children were told, "We're going to talk about some animals that scientists recently discovered in the wild. These are animals that most people have never seen or heard about before." Children were then introduced to each novel animal and told, "Scientists have named one of the animals they recently discovered a [e.g., hergob]. There has only been one [hergob] found so far. The scientists have studied it and know a lot about it. The scientists wonder what other [hergobs] in the group look like and how they act. Now, I want to hear your ideas about [hergobs]. So, 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." Combined with using unfamiliar animals, we expected that any tendency to treat the found animal as a representative prototype would be reduced by stating that only one member of the species had been discovered (Cimpian & Markman, 2009; Hollander, Gelman, & Raman, 2009; Hollander, Gelman, & Star, 2002).

Children then heard information about each animal's traits and their beneficial functions (e.g., "See this hergob's sprogs. The hergob that was found has fuzzier sprogs in its ears. Fuzzier sprogs make it

Table 1
Details provided about animals and their traits for Study 1.

Animal	Trait type	Trait description	Function	Trait variant
Hergob	Internal	Has a bluer alko inside its body	Helps pump more blood	Greener
	External	Has fuzzier sprogs in its ears	Make it easier to hear danger coming	Smoother
	Behavioral	Prooks more downward	Makes finding food easier	More upward
Poltum	Internal	Has a bumpier dorn inside its body	Helps digest food faster	Smoother
	External	Has redder apses near its eyes	Makes seeing in dark waters easier	Blacker
	Behavioral	Flisks more broad	Makes swimming fast easier	More narrow
Berpod	Internal	Has a purpler plork inside its body	Helps to fight more germs	Browner
	External	Has curlier quips on its nose	Makes smelling dangerous animals easier	Straighter
	Behavioral	Murls more to the back	Helps to hide food faster	More to the front
Orina	Internal	Has a crinklier tepin inside its body	Makes it easier to breathe	Firmer
	External	Has blacker plogs on its wings	Help to scare off more bugs	Whiter
	Behavioral	Gresses more side to side	Makes it easier to stay warm	More up and down

easier to hear danger coming."). Following each description (Table 1), children were asked whether all members of the group could share the same trait as the discovered animal (essentialism option: "Do you think all hergobs in the group could have fuzzier sprogs in their ears?") or whether some members could vary (variation option: "Do you think some hergobs in the group could have fuzzier sprogs in their ears and some could have smoother sprogs in their ears?"). The presentation of animals was divided into two counterbalanced sets—two animals per set that always included one mammal—separated by a 10-minute break during which time children played with the experimenter. The break was included to reduce the chances of response set or fatigue effects. The order in which each animal's three traits were presented was randomly determined, as was whether children received the essentialism or variation answer option first.

In contrast to prior work (Shtulman & Schulz, 2008) but following Kelemen and colleagues (2014), the current study deliberately avoided generic language when referring to species' traits. This is because generic noun statements (e.g., "Hergobs have sprogs.") imply a widely shared property and promote essentialist reasoning about animals (Cimpian & Markman, 2009; Hollander et al., 2002, 2009). Given that we showed children only one discovered member from each species, it was pragmatically and linguistically natural to avoid generic statements. Although we are not aware of any studies that have directly evaluated whether generic adjectives increase children's essentialist responding, following Kelemen and colleagues (2014, Experiment 2), the current method also employed relational adjectives to describe traits (e.g., "fuzzier" instead of "fuzzy") as a precautionary measure.

Results

Children received a score of 1 each time they endorsed variation and a score of 0 each time they did not. Scores were averaged across all trials and are reported as mean percentages of within-species variation endorsement. Preliminary analyses revealed no main effects of gender or the order in which children received the two sets of animals and were collapsed in subsequent analyses. A 2 (Age Group: 5- and 6-year-olds or 7- and 8-year-olds) $\times$ 3 (Trait Type: internal, external, or behavioral) mixed analysis of variance (ANOVA) on children's variation responses revealed no main effects or interactions ($ps > .05$) (Fig. 3). Thus, counter to prediction, behavioral traits did not yield more variation responses than physical traits, and older children were not more receptive to variation than younger children.

More centrally, however, children did not demonstrate the pronounced essentialist bias found in prior work. On average, they accepted variation 41% (SE = 5%) of the time, which was only marginally

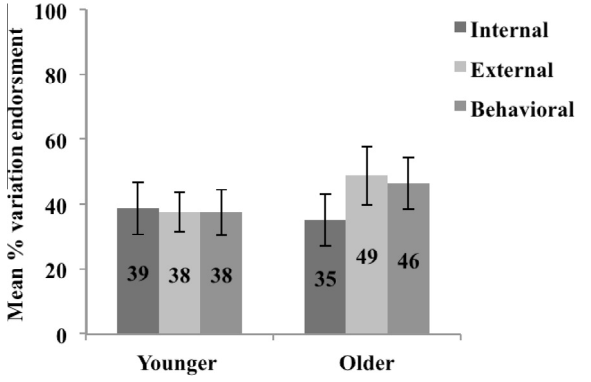

Fig. 3. Children's variation acceptance by age and trait in Study 1. Mean percentages are reflected within each bar, and error bars reflect standard errors of the means.

below chance rates, $t(39) = 1.95$, $p = .06$, and twice as high as the level found by Shtulman and Schulz (2008). Planned t-tests based on our age-related predictions showed that this marginal effect was primarily driven by the 5- and 6-year-olds, $t(19) = 1.87$, $p = .08$, rather than by the 7- and 8-year-olds, $t(19) = 0.92$, $p = .37$, whose responses did not differ from chance. Therefore, children did not appear to be deeply and inflexibly resistant to within-species variation.

To further explore children's potential resistance to variation, they were individually classified based on their overall response patterns. Children were categorized as *essentialists* if a third or fewer of their responses endorsed variation ($\leqslant$4 of 12), as *variationists* if two thirds or more of their responses endorsed variation ($\geqslant$8 of 12), and as *uncommitted reasoners* if there was no preference (i.e., all remaining children). This revealed that, in both age groups, 45% of children were essentialists, 25% were variationists, and 30% were uncommitted reasoners. A one-sample chi-square test confirmed that children were no more likely to be in one category than another, $p = .27$. The substantial proportion of uncommitted reasoners and variationists (55% in total) highlights that many children were open, rather than averse, to within-species variation.

Discussion

Study 1 revealed that when 5- to 8-year-olds were told about an unfamiliar species in a context involving beneficial trait function information but no generic language, they displayed a marginal tendency to assume trait homogeneity. This level of variation acceptance was notably higher than that found in prior research (Shtulman & Schulz, 2008), which used a method that revolved around familiar animals and used generic language in addition to providing information about trait functions. In combination with individual response patterns inconsistent with strong essentialist expectations, the current results suggest that in certain contexts many children can represent within-species variation. Thus, assumptions about variation appear to be flexible and context dependent rather than rigidly determined by a strongly marked essentialist bias.

However, despite the avoidance of familiar animals and generic language—features known to be detrimental to children's abilities to attend to variation (Bjorklund & Thompson, 1983; Cimpian & Markman, 2009; Farrar & Boyer-Pennington, 2011; Hollander et al., 2002, 2009; Rosch, 1999)—children in Study 1 did not actively assume variation. Therefore, it was possible that other contextual factors might have impeded their otherwise even stronger potential to represent within-species variation. In particular, in a departure from Kelemen and colleagues (2014), in Study 1 traits were described in relation to their survival-relevant functions. This potentially could have promoted a teleological (i.e., purpose-based) construal of traits as existing because of their functions and, therefore, ubiquitous in the population.

Specifically, young children display marked tendencies to explain natural phenomena—including biological traits—in teleological terms (e.g., Keil, 1992; Kelemen, 1999a, 1999b). For instance, they view physical traits as existing in order to fulfill survival-relevant goals. Furthermore, they regard beneficial traits as more heritable than non-beneficial traits (Springer & Keil, 1989; Ware & Gelman, 2014). This suggests that they expect beneficial traits to be uniformly shared. Children's teleological beliefs about traits seem to be related to older students' teleologically based misconception about adaptation that individual species members transform to acquire a beneficial trait by virtue of the trait's survival-relevant function (Gregory, 2009; Kampourakis & Zogza, 2009; Kelemen, 2012; see also Järnefelt, Canfield, & Kelemen, 2015). Transformationist misconceptions about adaptation derive from beliefs that species did not vary in the past and adapt such that all species members come to invariantly possess those traits that aid in survival. Thus, it seems possible that notions about shared species-wide needs and how traits function to fulfill those needs are linked to assumptions of within-species homogeneity. If so, priming children's teleological beliefs with trait function information in Study 1 could have promoted the inference that all species members need the trait and, thus, uniformly possess it.

In Study 2, we explored children's assumptions about variation in a context identical to Study 1 but in which no information about trait functions was provided. Although we suspected that omitting trait function information had the potential to increase children's variation acceptance at both ages, we again predicted that 7- and 8-year-olds would benefit more than younger children. Indeed, based on their enhanced performance in Kelemen and colleagues (2014), their response patterns in Study 1, and other prior work (Legare et al., 2013), we anticipated that under the highly facilitative context of Study 2 older children would display a marked tendency to expect biological variation.

Study 2

Method

Participants

Twenty 5- and 6-year-olds (10 boys and 10 girls; M_{age} = 5 years 11 months, *SD* = 7 months) and 20 7- and 8-year-olds (12 boys and 8 girls; M_{age} = 8 years 0 months, *SD* = 6 months) were recruited from the northeastern United States and tested individually at the lab for approximately 30 minutes (67.5% White, 15% Multiracial, 7.5% Hispanic, 7.5% Black, and 2.5% Asian). Most children were from middle and higher SES backgrounds. As in Study 1, parent questionnaires solicited responses on parental religious beliefs and practices and acceptance of evolution.

Materials and procedure

The materials and procedure were identical to Study 1 except that information about the survival-relevant functions of animal traits was excluded.

Results

Scoring was identical to Study 1. Preliminary analyses revealed no main effects of gender or the order in which children received the two sets of animals and were collapsed in subsequent analyses. A 2 (Age Group: 5- and 6-year-olds or 7- and 8-year-olds) × 3 (Trait Type: internal, external, or behavioral) mixed ANOVA of children's variation responses revealed a main effect of age group only, $F(1,38) = 4.94$, $p = .03$, $\eta_p^2 = .12$. Consistent with prediction, when trait function information was omitted, 7- and 8-year-olds (*M* = 60%, *SE* = 5%) accepted variation more than 5- and 6-year-olds (*M* = 41%, *SE* = 7%) (Fig. 4). As in Study 1, children's variation acceptance for physical and behavioral traits was similar.

To further examine reasoning, we compared children's responses with chance levels of variation endorsement. The 5- and 6-year-olds' variation acceptance did not significantly differ from chance rates, $t(19) = 1.33$, $p = .20$, a pattern largely consistent with Study 1 findings. By contrast, and consistent with prediction, when trait function information was omitted, the 7- and 8-year-olds endorsed

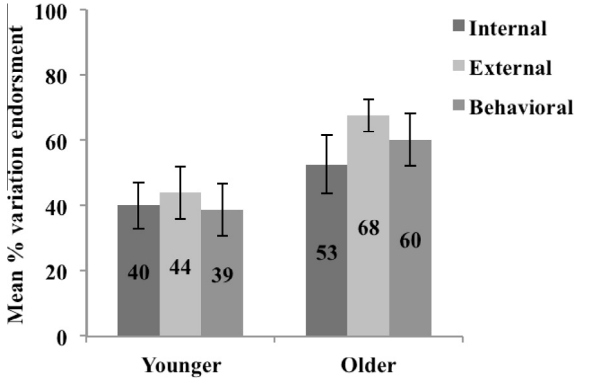

Fig. 4. Children's variation acceptance by age and trait in Study 2. Mean percentages are reflected within each bar, and error bars reflect standard errors of the means.

variation at above chance rates ($M = 60\%$), $t(19) = 1.93$, $p = .03$, one-tailed. This shift from chance ($M = 43\%$ in Study 1) to above chance rates of variation acceptance was driven by responses to external physical traits. With an average of 68% endorsement, older children's variation acceptance for external traits was pronounced, $t(19) = 3.39$, $p = .002$, one-tailed (Fig. 4).

Individual patterns were again explored by classifying children as essentialists, variationists, or uncommitted reasoners. This revealed that 45% of 5- and 6-year-olds were essentialists, 20% were variationists, and 35% were uncommitted reasoners, consistent with Study 1 results. By contrast, only 15% of 7- and 8-year-olds were essentialists, whereas 45% were variationists and another 40% were uncommitted reasoners. One-sample chi-square tests revealed that both younger ($p = .39$) and older ($p = .21$) children were no more likely to be in one category than another, again demonstrating that neither age group was strongly essentialist. Among older children, essentialists dropped from 45% in Study 1 to 15% in Study 2, whereas variationists increased from 25% to 45%. A chi-square analysis confirmed that this change was significant, $\chi^2(1, N = 26) = 4.01$, $p = .045$. This finding, together with 85% of older children classified as uncommitted reasoners or variationists, highlights that 7- and 8-year-olds' abilities to entertain variation were enhanced when beneficial trait functions were omitted.

Social influences on children's variation acceptance

Prior work has shown a relationship between parents' beliefs and children's macro-evolutionary concepts (Evans, 2000, 2001). Therefore, we conducted a set of correlational analyses to evaluate whether parents' religious beliefs and practices and evolution acceptance had any relation to children's variation judgments across Studies 1 and 2. We expected that parents' stronger religious commitments might relate to increased essentialist responding among their children, whereas stronger evolution acceptance might relate to decreased essentialist responding.

Preliminary analyses revealed no differences in parental responses on self-reported measures between Studies 1 and 2 or by age group. Nevertheless, we controlled for any potential effects of study version given that 7- and 8-year-olds performed differently in the two studies. Partial correlations revealed that 5- and 6-year-olds were less likely to accept variation if their parents reported greater religiosity, more strongly believed in God, and more strongly endorsed that God created all biological organisms ($rs \geqslant -.372$, $ps \leqslant .05$). Those whose parents more strongly endorsed that evolution explains the origins of all biological organisms were more likely to accept variation ($r = .374$, $ps \leqslant .05$). By contrast, there were no significant correlations between any parent-reported measures and variation acceptance among 7- and 8-year-olds ($rs \leqslant .204$, $ps \geqslant .25$). This suggests that older children's judgments were largely independent of their parents' religious and evolutionary beliefs and mediated by other factors. Further details on measures and analyses are provided in the online Supplementary Material.

Discussion

Findings from Study 2 extend Study 1's findings by demonstrating that in addition to other contextual factors (e.g., species familiarity, generic language), the presence of beneficial trait function information can affect children's thinking about within-species variation. Namely, when trait function information was omitted in Study 2, older children were more likely to accept variation. This is consistent with the notion that identifying traits in terms of their functions promotes teleological and essentialist reasoning about animals, at least by 7 to 8 years of age.

Notably, however, younger children's judgments were unaffected by the omission of beneficial trait function information. Their beliefs were also closely tied to their parents' religious and evolutionary beliefs, which was not the case for older children. Older children's greater capacities to expect variation under certain contexts may be partially explained by children of this age having had sufficient opportunities to observe and learn about variation among people and non-human animals (e.g., by observing differences in eye, hair/fur, and skin color). In turn, these experiences may promote more autonomous reasoning and less reliance on parental beliefs. However, recognition of variation alone was not by itself sufficient to lead these children to consistently expect within-species variation. Rather, their judgments seemed to be significantly influenced by what they perceived to be relevant contextual information such as the presence of trait function information.

General discussion

Taken together, the current results suggest that given certain descriptive contexts, young children are not as rigidly resistant to the notion of within-species variation as prior work has shown (Shtulman & Schulz, 2008). Study 1 revealed that when children were presented with unfamiliar species in a context that avoided generic language but provided details about beneficial trait functions, 5- to 8-year-olds collectively showed a marginal, rather than robust, essentialist preference. This degree of acceptance occurred not only when children were asked about behavioral traits but also, unexpectedly, when they were asked about physical traits that seemed particularly likely to be essentialized.

Study 2 then showed that older children were even more open to the possibility of within-species variation when overt statements about beneficial trait function were removed. In contrast to younger children who were unaffected by the omission of this information, older children endorsed variation at above chance levels under these conditions. Children's recognition of variation among physical traits was again higher than expected based on prior work (Shtulman & Schulz, 2008), with older children displaying the highest level of acceptance for external physical traits. Developmental differences in variation acceptance seem to be at least partially explained by younger children's greater deference to parental religious and evolution beliefs and by older children's greater theoretical autonomy and sensitivity to the presence of trait function information. Although older children's abilities to take trait function information into account when determining whether a population is variable may be perfectly reasonable and even helpful in some settings, it is also the case that their sensitivity and autonomous patterns of theorizing about such functional cues may work against ultimately acquiring a correct selectionist understanding of adaptation.

Implications for evolution education

The current results not only highlight that children, and in particular older children, have better abilities to represent variation than was previously assumed but also that cognitive biases that are frequently treated as independent (Rosengren et al., 2012) may increasingly interact over development to produce theoretical ideas that are deleterious to science learning (Kelemen et al. 2014). Specifically, they suggest that by 7 to 8 years of age, priming children's teleological beliefs that traits exist to fulfill survival needs by overtly stating their survival-relevant functions enhances children's essentialist tendencies to assume within-species uniformity. As a consequence of derailing emerging expectations about within-species variation, this may ultimately create challenges for learning natural selection.

In light of this possibility, the current findings along with others have implications for pedagogical practices aimed at fostering an understanding of within-species variation and for the design of coherent and developmentally informed learning progressions for teaching evolution. First, they are consistent with prior work (e.g., Bjorklund & Thompson, 1983; Cimpian & Markman, 2009; Farrar & Boyer-Pennington, 2011; Hollander et al., 2002, 2009; Rhodes & Brickman, 2010; Rosch, 1999) showing that children's ideas about biological variation are influenced by contextual factors like species familiarity and the presence of generic language. Educators and educational tools, therefore, should be mindful of these contexts when introducing evolutionary concepts and developing evolution instruction. Second, and although yet tentative, they also offer reasons for caution about recent proposals advocating the value of teleology in ultimately promoting an accurate scientific understanding of evolution (Evans, Legare, & Rosengren, 2011; Legare et al., 2013; Spiegel et al., 2012; Zohar & Ginossar, 1998).

The rationale behind such proposals has been that accepting the idea that animals acquire traits because they are useful for survival promotes acceptance of the idea that species are mutable. It has been further argued that teleological need-based reasoning about adaptation represents an intermediary biological form of reasoning that is conceptually autonomous from psychologically based explanations of species origins that invoke intentional design (Evans et al., 2011; Legare et al., 2013; Spiegel et al., 2012; but see Kelemen, 2012). However, the current findings tentatively imply that, rather than serving as a useful conceptual bridge en route to acquiring an accurate understanding of adaptation, a focus on trait functions may have the unintended long-term consequence of suppressing individuals' abilities to represent the variation-based process of adaptation. This, in turn, may further promote misconceptions that adaptations arise through need-driven transformations (Gregory, 2009). In addition, findings from Kelemen and colleagues (2014) suggest that an incomplete teleologically based conceptual bridge may be unnecessary given young children's capacities to learn the selectionist mechanism of natural selection (see also Emmons et al., 2015). Future research should aim to directly evaluate whether a focus on trait functions relates to misconceptions about adaptation.

In terms of considering learning progressions on teaching evolution, the current findings in combination with others speak to the content and timing of current education guidelines (e.g., Achieve & partners that collaborated on the NGSS, 2013; National Research Council, 2012). In particular, science standards have long recommended that children should first receive instruction on how animals possess functional body parts that aid in their survival and only later receive instruction on within-species variation, with comprehensive instruction on adaptation by natural selection being delayed until junior high or high school. The current findings along with evidence of young children's abilities to learn natural selection from explanation-rich narratives (Emmons et al., 2015; Kelemen et al., 2014) suggest that this kind separation and piecemeal sequence may be inadvisable. Rather, children would likely benefit from cohesive discussions about the functions of animal traits in the context of learning about the naturally occurring variability of those traits. The implementation of more nuanced and comprehensive conversations about biological traits from early on would likely leverage children's emerging sensitivity to within-species variation and the functional qualities of traits in ways that could successfully counteract the entrenchment of inaccurate transformationist theories of adaptation. This could ultimately provide a beneficial foundation for children's introduction to an accurate and comprehensive selectionist explanation of adaptation.

Conclusion

Results from the current investigation highlight that young children are not fundamentally resistant to the idea of within-species variation. In particular, children's abilities to expect within-species variation can be facilitated by certain contextual factors. Future work should seek to identify other factors that might influence children's and older students' abilities to represent variation and explore the impact of survival-relevant trait function information on students' teleological reasoning and understanding of evolutionary processes. It is our hope that interdisciplinary approaches that integrate methods and findings from cognitive development and education continue to address current challenges in science education by informing our understanding of children's biological reasoning and the best ways children can be taught about highly counterintuitive processes.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jecp.2015.05.011.

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