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The Relation Between Essentialist Beliefs and Evolutionary Reasoning

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Abstract

Historians of science have pointed to essentialist beliefs about species as major impediments to the discovery of natural selection. The present study investigated whether such beliefs are impediments to learning this concept as well. Participants (43 children aged 4–9 and 34 adults) were asked to judge the variability of various behavioral and anatomical properties across different members of the same species. Adults who accepted within-species variation—both actual and potential—were significantly more likely to demonstrate a selection-based understanding of evolution than adults who denied within-species variation. The latter demonstrated an alternative, incorrect understanding of evolution and produced response patterns that were both quantitatively and qualitatively similar to those produced by preschool-aged children. Overall, it is argued that psychological essentialism, although a useful bias for drawing species-wide inductions, leads individuals to devalue within-species variation and, consequently, to fail to understand natural selection.

Keywords: Conceptual development; Psychological essentialism; Intuitive theories; Folk biology; Science education

1. Introduction

If you ask students who have taken college-level physics to predict the trajectory of a moving object, most will produce trajectories more consistent with pre-Newtonian mechanics than post-Newtonian mechanics (Clement, 1982; Halloun & Hestenes, 1985; McCloskey, Caramazza, & Green, 1980). Likewise, if you ask students who have taken college-level biology to explain the origin of a particular trait, most will produce explanations more consistent with pre-Darwinian biology than post-Darwinian biology (Bishop & Anderson, 1990; Brumby, 1984; Shtulman, 2006). These findings, as well as many others (e.g., Springer & Keil, 1989; Vosniadou & Brewer, 1994; Wiser & Amin, 2001), suggest that conceptual development in the

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individual can parallel theory development in the history of science—that is, preinstructional conceptions of scientific phenomena often resemble theories of those phenomena previously articulated and debated within the scientific community.

What might lead today's science students down the same, erroneous paths as yesterday's science practitioners? In the domain of physics, the answer appears to be a commitment to the idea that motion implies a force (Clement, 1982; Halloun & Hestenes, 1985). In the domain of evolution—the focus of the present study—the answer is much less clear. One possibility, suggested by Shtulman (2006), is that learners are committed to the idea that the members of a species have an inner nature, or "essence," that determines the organisms' outward appearance and behavior. Evidence of such a commitment comes from at least three sources. First, children as young as 2 years old privilege species identity over perceptual similarity when reasoning about the properties of novel animals (Gelman & Coley, 1990; Gelman & Markman, 1987). Second, preschoolers assume that an animal will retain its species identify across surface-level changes in appearance, both natural (Gutheil & Rosengren, 1996; Rosengren, Gelman, Kalish, & McCormick, 1991) and artificial (Keil, 1989). Third, preschoolers assume that an animal will retain its species identity across changes in environment and upbringing (Gelman & Wellman, 1991; Johnson & Solomon, 1997; Springer, 1996; Waxman, Medin, & Ross, 2007).

Empirically, an organism's species identity is indeed a reliable predictor of its properties. Knowing what species an organism is (e.g., tiger) allows one to make accurate predictions about how that organism should look (e.g., striped), where that organism should live (e.g., the jungle), what that organism should have inside it (e.g., bones, muscles, etc.), and many other such properties. However, an organism's species identity is not a *perfect* predictor of its properties; not all members of a species are identical. In fact, variation within species is what allows evolution to occur. The primary mechanism of evolution—natural selection—operates over individual differences among members of the same species. Those members whose differences are advantageous to their survival tend to produce more offspring than those who do not, changing the frequency with which such differences are represented in the population as a whole.

Recognition of the importance of within-species variation to evolution was long in coming. Although Greek scholars formulated the concept of evolution as early as 600 BC, the mechanisms of evolution remained a mystery for nearly 25 centuries (Mayr, 1982). Many historians of science, including Gould (1996), Hull (1965), and Mayr (1982), have pointed to essentialist beliefs about species as a primary obstacle to the discovery of natural selection. According to these scholars, an essentialist construal of species led pre-Darwinian theorists to ignore or devalue within-species variation. Consequently, they formulated what Mayr (2001) characterized as "transformational" theories of evolution, or theories in which evolution is construed as the cross-generational transformation of a species' underlying essence, resulting in changes common to all members of the species. Darwin, on the other hand, formulated what Mayr (2001) characterized as a "variational" theory of evolution, or a theory in which evolution is construed as the selective propagation of within-species variation.

Recent work on evolutionary reasoning suggests that most modern-day students of evolution are covert transformationists (Shtulman, 2006). When asked to reason about either microevolutionary phenomena (i.e., variation, inheritance, and adaptation) or macroevolutionary phenomena (i.e., domestication, speciation, and extinction), many students appeal to the gradual transformation of an entire population (e.g., "The moths became darker over time") rather than the selective survival and reproduction of particular individuals within that population (e.g., "Darker moths were more likely to reproduce than the lighter moths"). Why do transformational misconceptions arise? The historical analyses suggest that they are the product of early developing essentialist biases, but this hypothesis has never been tested empirically. Here, we do so by asking participants to estimate the prevalence of within-species variation. We are interested in the extent to which both children and adults acknowledge that members of a species vary in their traits and whether adults' acceptance of variation correlates with their understanding of evolution.

2. Method

2.1. Participants

Forty-three children and 34 adults participated in the present study. The children ranged in age from 4;2 to 9;11 ($M = 6;10$) and were recruited from the Discovery Center at a large metropolitan science museum. The adults were recruited from the study pool of a large, northeastern university.

2.2. Materials

All participants assessed the variability of one behavioral property, one external anatomical property, and one internal anatomical property of six different animals (see Table 1). We predicted that participants would be more likely to accept variation in behavior than anatomy—particularly internal anatomy—given previous findings regarding the centrality of these properties to species identity (Gelman & Wellman, 1991; Simons & Keil, 1995; Solomon, Johnson, Zaitchik, & Carey, 1996). Three of the animals for which participants made variability judgments were mammals, and three were insects —a comparison designed to maximize the range of species included as stimuli (although it is possible that individuals essentialize animals to a greater degree than they essentialize nonanimals, like plants and fungi). The order of presentation for the three types of properties was randomized across animals, and the order of presentation for the two types of animals was randomized across participants.

After completing the variability-judgment task, adult participants completed a three-question version of the evolution comprehension assessment described in Shtulman (2006). All questions and coding categories can be found in the Appendix. The first question assessed whether participants interpreted changes to a species' environment as (a) a type of selection pressure or (b) an impetus for the adaptation of all species members; the second assessed whether participants interpreted individual differences between parents and their offspring as (a) random and unpredictable or (b) occurring in a direction beneficial to the offsprings' survival; the third assessed whether participants interpreted aggregate differences among successive generations of the same species as (a) the result of differential survival or (b) the accumulation of widespread (ontogenic) changes to individual organisms.

Table 1
The animals and their properties, organized by property type

Animal	Type	Description	Function
Giraffes	Behavioral	Sleep on their feet	To avoid being eaten
	External	Have spots on their coat	To blend into the savanna
	Internal	Have an extra neck joint	To reach hard-to-get leaves
Kangaroos	Behavioral	Hop on their back legs	To cover large distances
	External	Have pouches on their bellies	To carry their young
	Internal	Have two stomachs	To digest grass
Pandas	Behavioral	Live by themselves	To eat more food
	External	Have thumbs on their forepaws	To hold bamboo shoots
	Internal	Have thick, bumpy throats	To swallow bamboo shoots
Ants	Behavioral	Live in mounds of dirt	To stay dry when it rains
	External	Have feelers on their heads	To communicate by smell
	Internal	Have a tube-shaped heart	To pump blood
Bees	Behavioral	Make honey	To feed their young
	External	Have five eyes	To see in all directions
	Internal	Have poison in their stingers	To make their stings painful
Grasshoppers	Behavioral	Make chirping sounds	To attract other grasshoppers
	External	Have large hind legs	To jump great distances
	Internal	Have green blood	To stay healthy

Participants' responses to the comprehension assessment were scored +1 if they were consistent with variationism, –1 if they were consistent with transformationism, and 0 if they were consistent with both theories (this was possible because the assessment included both open-ended and closed-ended questions). Two coders classified all justifications independently. Intercoder agreement was high (Cohen's $k = 0.83$), and all disagreements were resolved via discussion.

2.3. Procedure

The task was administered as an interview for children and as a questionnaire for adults. The interview was structured around a picture book depicting a single member of each species. Properties were presented in the form of a generic question (e.g., "Did you know that giraffes have spots on their coat?"), followed by a description of the property's primary function (e.g., "The spots help them blend into their surroundings."). The decision to use generic language was motivated partly by previous research demonstrating that children as young as 4 years old understand that generic statements are distinct from logically necessary ones (Gelman, Star, & Flukes, 2002; Hollander, Gelman, & Star, 2002) and partly by considerations of ecological validity, for generic statements pervade everyday discourse about animals (Gelman, Coley, Rosengren, Hartman, & Pappas, 1998; Gelman & Tardif, 1998). The decision to include function information was motivated by the finding that children tend to believe that only functional properties are heritable (see Springer & Keil, 1989; Weissman & Kalish, 1999).

Participants were asked one to three questions for each property. First, they were asked whether that property was common to all members of the species (e.g., "Do all giraffes have spotted coats or just most giraffes?"). If they claimed the trait was common to all members, they were asked whether a species member could be born with a different version of that property (e.g., "Could a giraffe be born with a different kind of coat?"). If they claimed the trait could not vary, they were asked to justify their judgment (e.g., "Why couldn't a giraffe be born with a different kind of coat?"). Throughout, we refer to the first type of judgment as a judgment of *actual variability* and the second as a judgment of *potential variability*.

3. Results

3.1. Overall pattern of judgments

On the whole, most participants denied the variability of most properties (details follow). Our primary prediction was that there would be a correlation between adults' acceptance of within-species variation and their understanding of evolution by natural selection. Consistent with this prediction, there were significant correlations between the number of properties an adult judged as variable and his or her evolution comprehension score, both for judgments of actual variability ($r = .53$, $p < .01$) and judgments of potential variability ($r = .64$, $p < .001$). For ease of presentation, we divided the adults into quartiles, the bottom 25% being those least likely to accept variability (actual or potential) and the top 25% being those most likely to accept variability. Figure 1 displays the average evolution comprehension score for

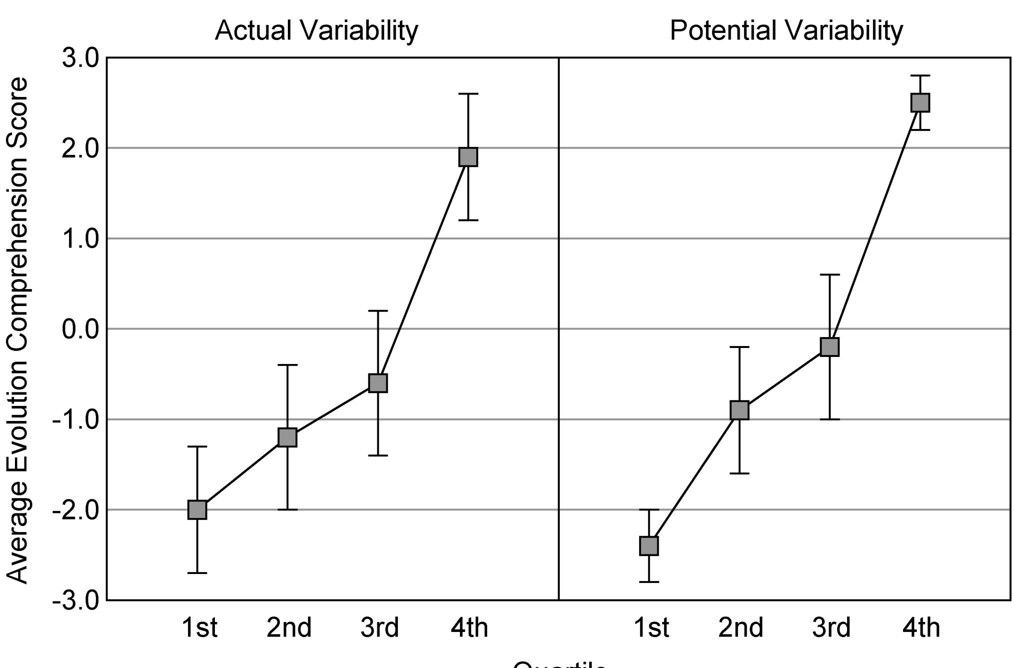

Fig. 1. The average evolution comprehension score for adults in each quartile of each distribution of variability judgments.

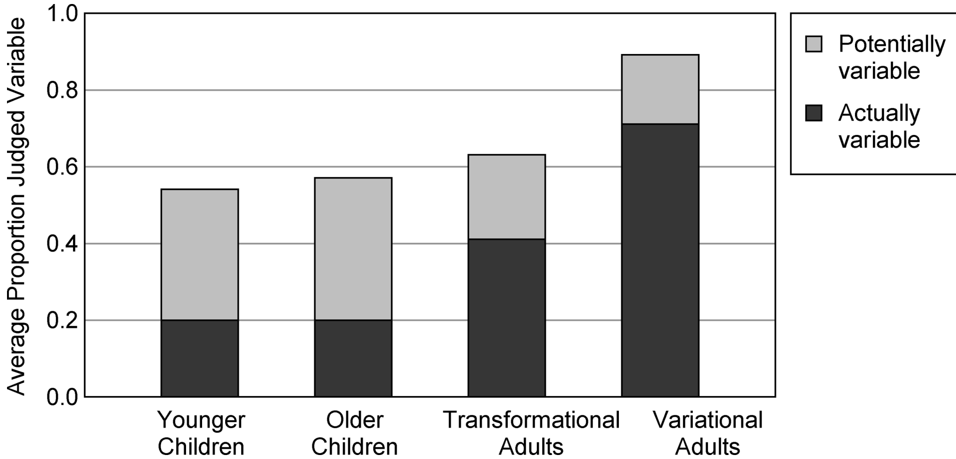

Fig. 2. The average proportion of properties judged (a) actually variable and (b) potentially variable by each group of participants.

adults in each quartile. Only adults in the top quartile of each distribution earned evolution comprehension scores above zero (actual variability: $t[8] = 2.88$, $p < .05$; potential variability: $t[8] = 9.35$, $p < .001$), indicating that those who were most likely to accept within-species variation were also those who were most likely to understand natural selection.

To facilitate the comparison of children to adults, we divided children on the basis of their age into "younger children" ($n = 22$; mean age = 6;6; age range = 4;2–6;7) and "older children" ($n = 21$; mean age = 8;3; age range = 6;9–9;11), and we divided adults on the basis of their evolution comprehension score into "transformationist adults" ($n = 19$; mean score = –2.4; score range = –3 to –1) and "variationist adults" ($n = 15$; mean score = 2.3; score range = 1–3). Note that the label "variationist" refers to adults' understanding of evolution (as measured by the 3 evolution questions), not their acceptance of within-species variation (as measured by their variability judgments). The question of interest was whether the latter was related to the former.

The average proportion of properties that each group judged actually variable or potentially variable is displayed in Fig. 2. We compared each proportion to .5 in order to see whether any group of participants accepted variability more often than they denied it. Only variationist adults reliably endorsed both actual variability, $t(14) = 2.93$, $p < .05$; and potential variability $t(14) = 14.41$, $p < .001$. All other groups denied within-species variability (actual, potential, or both) at least as often as they endorsed it. Differences in participants' judgments by participant group, property type, and animal type are discussed later.

3.2. *Judgments of actual variability*

Averaged across animals, participants judged 51% of behavioral properties, 33% of external properties, and 30% of internal properties actually variable. Averaged across properties, participants judged 38% of mammal properties and 38% of insect properties actually variable. These data are displayed in Fig. 3, collapsed across animal type. They were analyzed with

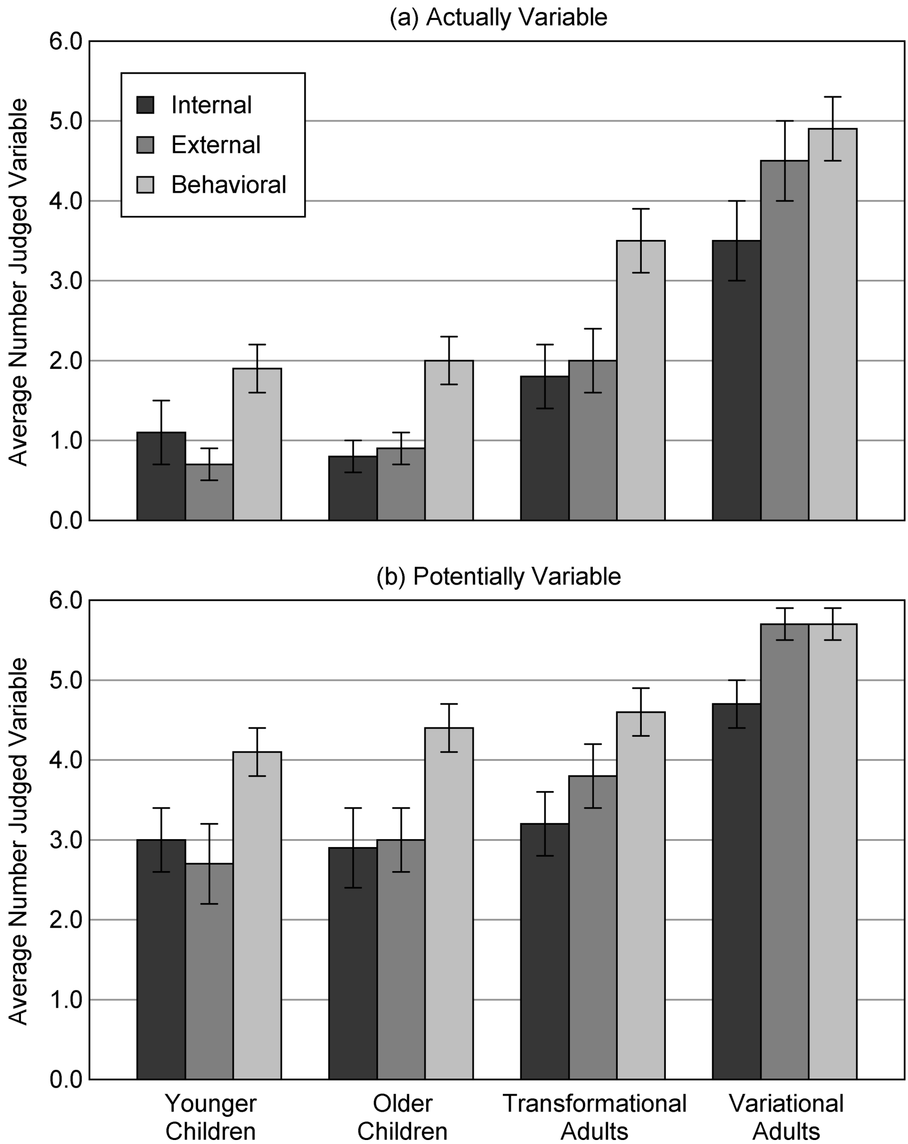

Fig. 3. The average number of behavioral, external, and internal properties (out of 6) judged (a) actually variable and (b) potentially variable by each group of participants (+ standard error). *Note*: Any property judged actually variable was also classified as potentially variable.

a repeated-measures analysis of variance (ANOVA) in which animal type and property type were treated as within-participant factors and participant group was treated as a between-participant factor. This analysis revealed significant main effects of property type, $F(2, 146) = 36.17$, $p < .001$; and participant group, $F(3, 73) = 21.16$, $p < .001$; and a near-significant interaction between those two factors, $F(6, 146) = 2.06$, $p = .06$. No other effects approached significance.

Bonferroni comparisons of the four participant groups revealed that both groups of adults judged significantly more properties actually variable than either group of children, and that variationist adults judged significantly more properties actually variable than transformationist adults. Simple-effects tests of property type for each participant group revealed that three of the four groups—younger children, older children, and transformationist adults—reliably differentiated behavioral properties from non-behavioral properties but did not reliably differentiate external properties from internal properties. Variationist adults, on the other hand, reliably differentiated internal properties from non-internal properties but did not reliably differentiate behavioral properties from external properties. Apparently, variationist adults viewed the distinction between behavior and anatomy as less meaningful than the distinction between external anatomy and internal anatomy, presumably because they believed that changes in internal anatomy might affect the actual viability of the organism.

3.3. Judgments of potential variability

Averaged across animals, participants judged 78% of behavioral properties, 63% of external properties, and 57% of internal properties potentially variable. Averaged across properties, participants judged 66% of mammal properties and 66% of insect properties potentially variable. These data, which are displayed in Fig. 3, were analyzed with the same repeated-measures ANOVA described in the preceding section. This analysis revealed significant main effects of property type, $F(2, 146) = 30.11$, $p < .001$; and participant group, $F(3, 73) = 6.83$, $p < .001$; and a near-significant interaction between those two factors, $F(6, 146) = 2.07$, $p = .06$. No other effects approached significance.

Bonferroni comparisons of the four participant groups revealed that variationist adults judged significantly more properties potentially variable than all other groups. Transformationist adults, on the other hand, did not judge significantly more properties potentially variable than either group of children. Simple-effects tests of property type for each age group revealed that younger children, older children, and transformationist adults reliably differentiated behavioral properties from non-behavioral properties but did not reliably differentiate external properties from internal properties. Variationist adults were once again the only group that did not conform to this pattern, as they reliably differentiated internal properties from non-internal properties but did not reliably differentiate behavioral properties from external properties.

3.4. Justifications for judgments of nonvariability

Whenever participants denied that a property was potentially variable, they were asked to justify that judgment. Participants' justifications were sorted into three categories: (a) species-based justifications, or appeals to the uniformity of species members within or across generations (e.g., "All grasshoppers are the same."; "It will be like its parents."); (b) property-based justifications, or appeals to the undesirability or implausibility of changing a particular property (e.g., "Pandas need thumbs in order to eat."; "An ant couldn't survive with a different kind of heart."); and (c) uninformative justifications (e.g., "I don't know."; "I'm not sure."). Two coders, blind to the identity of the participants, classified all justifications independently.

Table 2
The proportion of participants in each group who provided (a) mostly species-based justifications or (b) mostly property-based justifications

	Modal Justification Type	
Participant Group	Species Based	Property Based
Younger children	0.55	0.41
Older children	0.57	0.33
Transformationist adults	0.47	0.53
Variationist adults	0.07	0.67

Intercoder agreement was high (Cohen's $k = 0.85$), and all disagreements were resolved via discussion.

Because participants varied extensively in the overall number of justifications provided (range = 0–18), we analyzed between-group differences in the tendency to provide species-based and property-based justifications in terms of the proportion of participants who provided those justifications as their modal response. Those proportions are displayed in Table 2. Proportions for both groups of children do not total 1.0 because some children provided only uninformative justifications, and proportions for the variationist adults do not total 1.0 because some variationist adults claimed that all properties could vary and thus provided no justifications for why they could not.

Chi-square analyses of the relationship between participant group and justification type revealed that variationist adults were significantly less likely to provide species-based justifications than the participants in any other group (younger children: $\chi^2[1, N = 32] = 6.91$, $p < .01$; older children: $\chi^2[1, N = 30] = 8.29$, $p < .01$; transformationist adults: $\chi^2[1, N = 30] = 4.59$, $p < .05$). There were no other significant differences between groups. Apparently, variationist adults were the only group of participants who believed that appeals to within-species uniformity were either explanatorily inadequate or factually inaccurate.

4. Discussion

Drawing on the extensive literature demonstrating an essentialist bias in the conceptualization of individual animals, we investigated the possibility of a parallel bias in the conceptualization of species kinds. By asking participants to judge the variability of different species-specific properties, we were able to assess the degree to which participants conceptualized species as collections of unique individuals (consistent with post-Darwinian biology) or as the homogenous instantiation of an underlying "essence" (consistent with pre-Darwinian biology).

Overall, we found that most participants, from 4-year-old children to 40-year-old adults, held the latter conceptualization rather than the former—that is, most children and most adults denied that within-species variation is both prevalent and probable. Only adults who had achieved a selection-based understanding of evolution affirmed both aspects of variation significantly more often than not. Although adults who espoused a transformational, need-based understanding of evolution were significantly more likely than children to judge species-specific properties actually variable, they were *not* significantly more likely than children to judge such properties potentially variable. Moreover, their pattern of responses was qualitatively similar to children's pattern of responses, both in the type of properties they judged variable and the type of considerations they used to justify their claims of nonvariability. These findings suggest that psychological essentialism, although useful for reasoning about changes to an individual animal, is harmful for reasoning about changes to an entire species; this bias appears to prevent individuals from appreciating within-species variation and, consequently, the processes that operate over it.

Note that the negative relationship between essentialist reasoning and evolutionary reasoning documented in the present study, although similar to that discussed by historians who have studied the paradigm shift from transformational theories of evolution to variational ones, is quite different from that discussed by psychologists who have studied the developmental shift from creationist theories of speciation to evolutionist ones (e.g., Evans, 2001; Samarapungavan & Wiers, 1997). The latter have claimed that essentialist reasoning is incompatible with evolutionary reasoning because learners assume that a species' essence is immutable. Although this account might explain adherence to creationism, it does not explain adherence to transformationism—that is, it does not explain why even adults who accept evolution so often misunderstand it (Shtulman, 2006). Our account, in contrast, suggests that even when students come to accept evolution, they are likely to believe that the mechanisms of evolution operate on the species' essence rather than on the species' members.

Our finding that an understanding of natural selection is correlated with acceptance of within-species variation raises the question of whether the former leads to the latter or the latter to the former. Both empirical and theoretical work suggests that learners may be sensitive to certain variables only once they appreciate the variables' causal role (e.g., Block, 1998; Waldmann, Holyoak, & Fratianne, 1995). Thus, it is possible that students may only come to appreciate within-species variation as they come to understand the process by which evolution takes place. However, given that recognition of the prevalence of within-species variation was, for Darwin, a crucial precursor to the discovery of natural selection (see Gruber, 1974), it seems likely that students must recognize the prevalence of within-species variation before they can learn a concept predicated on this recognition.

The fact that all adults in the present study—transformationists and variationists alike—affirmed the actual variability of species-specific properties significantly more often than children did suggests that this recognition develops partly from increased experience with the biological world, direct or indirect. Compared to children, adults likely have a greater appreciation of sex differences (or caste differences) within the same species. They also likely have a greater appreciation of the complexity of biological classification—a point relevant to the present study in that common animal names, like "panda" and "ant," actually encompass multiple species as defined by modern taxonomy. Exactly how experience shapes one's understanding of species identity and within-species variability is a question in need of further research. Certainly, there is a precedent in the literature on intuitive biology for supposing that experience is relevant not only to differences in reasoning between children and adults but also to differences in reasoning between transformationist adults and variationist ones (Ross, Medin, Coley, & Atran, 2003; Tarlowski, 2006; Wolff, Medin, & Pankratz, 1999).

To conclude, we consider three implications of our findings for evolution education. First, evolution instructors should not assume that their students recognize and appreciate within-species variation; most individuals appear to doubt that species members can, and do, vary on virtually all dimensions. Relevant to this point, recent research on evolution education has shown that drawing students' attention to within-species variation is highly effective at replacing transformational conceptions with variational ones (Shtulman & Calabi, 2008). Second, attempts to teach students about within-species variation in anatomy may benefit from an analogy to within-species variation in behavior, for individuals of all ages appear more willing to accept the latter than the former. Although this difference in acceptance may be due to the mistaken belief that behavioral traits are not under genetic control, the juxtaposition of behavioral variation and anatomical variation may help draw students' attention to within-species variation in general.

Finally, although students' failure to understand evolution by natural selection is a source of frustration to educators, it is worth noting that inductive biases can constrain students' inferences both for better and for worse: A belief in essentialism may lead to difficulty in understanding natural selection, but it also appears to support the accurate projection of species-specific properties. Indeed, this predictive power may make such biases particularly difficult to overturn (e.g., see Schulz, Tenenbaum, & Jenkins, 2007). We may have more patience with students' learning difficulties if we consider that such difficulties may be the byproduct of inferential processes that, in other contexts, support rapid and accurate learning.

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Appendix

Question 1

"During the 19th century, England underwent an Industrial Revolution that resulted in the unfortunate side effect of covering the English countryside in soot and ash. During this same period of time, the members of England's native moth species *Biston betularia* became, on average, darker in color. Assuming that darker coloration was adaptive, how might a change in the moths' environment brought about a change in the moths' color?" Variational responses (scored +1): scenarios that referenced individual differences (e.g., "darker moths were better able to hide from predators than lighter moths"). Transformational responses (scored –1): scenarios that referenced the needs of the population as a whole (e.g., "the moths had to become darker to blend in with the trees").

Question 2

"Imagine that biologists discover a new species of woodpecker that lives in isolation on some secluded island. These woodpeckers have, on average, a one inch beak, and their only food source is a tree-dwelling insect that lives, on average, one-and-a-half inches under the tree bark. Compared to its parents, the offspring of any two woodpeckers should develop which of the following features? (a) A longer beak; (b) A shorter beak; (c) Either a longer beak or a shorter beak; neither feature is more likely. Please explain your answer." Variational responses (scored +1): choice (c) because offspring vary randomly from their parents; choice (c) because the environment does not influence the direction of mutations. Transformational responses (scored –1): choice (a) because a longer beak is necessary for survival; choice (c) because one generation is not enough time for longer beaks to evolve.

Question 3

"A youth basketball team scores more points per game this season than they did the previous season. Which explanation for this change is most analogous to Darwin's explanation for the adaptation of species? (a) Each returning team member grew taller over the summer; (b) Any athlete who participates in a sport for more than one season will improve at that sport; (c) More people tried out for the same number of spots this year; (d) On average, each team member practiced harder this season." Variational response (scored +1): choice (c), a selection-based explanation. Transformational responses (scored –1): choices (a), (b), and (c), ontogenetic explanations.