Science & Education
https://doi.org/10.1007/s11191-024-00568-2

SI: REPRESENTATIONAL PLURALITY

Conflicting Views of Nature and Their Impact on Evolution Understanding

Andrew Shtulman[1]

Accepted: 22 September 2024

Abstract
In nature, competition within and between species is the norm, yet nature is also reputed to be a "peaceable kingdom" where animals cooperate rather than compete. This study explored how such contrasting views of nature influence students' biological reasoning. College undergraduates ($n = 165$) assessed the prevalence of cooperative behaviors, such as food sharing and symbiotic cleaning, and competitive behaviors, such as cannibalism and parasitism, and these assessments were compared to their understanding of evolution as a process of differential survival and reproduction. Participants underestimated the prevalence of competitive behaviors relative to cooperative ones, particularly for behaviors directed toward other members of the same species, and the accuracy of their judgments predicted how well they understood evolution, even when controlling for other predictors of evolution understanding, including perceptions of within-species variation and perceptions of geologic time. These findings suggest that overly benevolent views of nature compete with more realistic views and may hamper our appreciation of the mechanisms of adaptation.

1 Introduction

In the 1830s, the Quaker minister Edward Hicks created a series of paintings depicting what the Bible calls a "peaceable kingdom," or a place where "the wolf shall dwell with the lamb, and the leopard shall lie down with the young goat, and the calf and the lion and the fattened calf together; and a little child shall lead them" (English Standard Version Bible, 2001, Isaiah 11:6). Hicks' *Peaceable Kingdom* paintings represent an idealized version of nature in which predator and prey live harmoniously, cooperating rather than competing for survival.

Around the same time, the English painter George Stubbs created a series of paintings depicting a very different relation between predator and prey (see Fig. 1). In these paintings, lions attack horses, connoting a view of nature that is more violent than benevolent—a view characterized by the poet Alfred Tennyson as "red in tooth and claw." On this view,

✉ Andrew Shtulman
shtulman@oxy.edu

1 Department of Psychology, Occidental College, 1600 Campus Road, Los Angeles, California 90041, USA

Published online: 07 October 2024

Fig. 1 Contrasting views of nature: Hicks' *Peaceable Kingdom* and Stubbs' *A Lion Attacking A Horse*

organisms are embroiled in a brutal struggle for survival. Competition, not cooperation, is the norm.

This contrast between "peaceable kingdom" and "red in tooth and claw" persists today in popular media. Fictional representations of nature in movies like *Madagascar* or television shows like *Dinosaur Train* depict predators and prey as friends, whereas more realistic representations such as those contained in nature documentaries show predators hunting and consuming their prey. Likewise, nature books that tell fictional stories about animals typically emphasize positive aspects of biology, such as kinship and altruism, whereas those that convey more factual information emphasize negative aspects, such as death and disease (Shtulman et al., 2021; see also Marriott, 2002). Cooperative depictions of nature may or may not be more common than competitive ones, but both depictions are certainly widespread.

Cooperative and competitive views of nature do not stand on equal footing from a scientific perspective, however. While animals engage in many cooperative behaviors, such as grooming and predator signaling, these behaviors require additional explanation; mechanisms like reciprocal altruism, kin selection, and mutualistic symbiosis are needed to explain the origins of cooperation, as any organism prone to cooperate would readily be exploited by those that are not (Axelrod & Hamilton, 1981; see also Dugatkin, 1997; Ridley, 1997).

Competition, on the other hand, requires no additional explanation; it is the logical consequence of living in a world with limited resources. Food, water, and shelter are not abundant enough to support the reproductive potential of all organisms, whose populations would expand exponentially if left unchecked (Mayr, 1982). Limited resources create a struggle for survival—a struggle that occurs both between species and within. Lions compete for resources not only with cheetahs and leopards but also with each other.

Research on naïve ecological reasoning suggests that the struggle for survival is not readily apparent. Many ecology students believe that stable ecosystems are characterized by ample food, water, and shelter; a harmonious balance between births and deaths; a harmonious balance between overpopulation and extinction; a mutually beneficial relationship between organisms and their environment; an absence of ecological disturbances; and the capacity for all species to survive and reproduce (Zimmerman & Cuddington, 2007; see also Ergazaki & Ampatzidis, 2012). Many students also underestimate the likelihood of extinction, particularly human extinction (Poling & Evans, 2004). In fact, most students believe that adaptation is more likely than extinction (Shtulman, 2006) even though biologists estimate that more than 99% of species that once roamed the earth are now extinct (Mayr, 2001).

In this way, many students endorse overly benevolent views of nature. But how do they reconcile such views with the undeniable fact that animals also threaten, attack, and kill one another? One possibility is that students hold two views of nature—a competitive view and a cooperative view—and vacillate between them depending on the context. Precedent for this possibility comes from research on how students reason about other natural phenomena, like heat, buoyancy, illness, and death (Shtulman, 2017). Rather than endorse one, and only one, explanation for these phenomena, students tend to endorse multiple explanations at the same time, even when those explanations are mutually incompatible (Bélanger et al., 2022).

For example, people who endorse evolutionary explanations for the origin of species also tend to endorse creationist ones (Evans & Lane, 2011). People who endorse germ-based explanations for infectious disease also tend to endorse supernatural ones, such as karma (Raman & Gelman, 2004), witchcraft (Legare & Gelman, 2008), or vital forces (Toyama, 2019). When reasoning about buoyancy, people consider an object's size as well as its density, even though density is the only relevant consideration (Foisy et al., 2021; Potvin & Cyr, 2017). When deciding whether something is alive, people consider not only whether it undergoes metabolic activity but also whether it moves on its own (Goldberg & Thompson-Schill, 2009; Shtulman & Young, 2024). Heat is commonly viewed as both a process and a substance (Wiser & Amin, 2001); the earth is commonly viewed as both a sphere and a plane (Carbon, 2010), and death is commonly viewed as both a biological endpoint and a spiritual transformation (Harris, 2011).

When learners are confronted with multiple explanations of the same phenomena, they usually embrace all explanations rather than decide between them. This phenomenon, known as explanatory coexistence, has been observed in a wide range of learners, from novices (Vosniadou et al., 2018; Young & Shtulman, 2020) to experts (Allaire-Duquette et al., 2021; Shtulman & Harrington, 2016), and for a wide range of domains, including chemistry (Potvin et al., 2020), theology (Barlev et al., 2017), geometry (Stricker et al., 2021), and fractions (DeWolf & Vosniadou, 2015). Often learners are unaware of the inconsistencies among coexisting explanations, but even those who are aware tend not to be bothered by them (Legare & Shtulman, 2018); logically incompatible explanations are often still *psychologically* compatible.

Are coexisting views of nature psychologically compatible? Here, we explore this possibility in light of two considerations that set the domain of nature apart from other explanatory domains. One such consideration is that the conflict between these views is driven more by inference than observation. Nature is replete with examples of both competition and cooperation, but merely observing these examples does not reveal that the latter depend on evolved mechanisms (like reciprocal altruism, kin selection, and mutualistic symbiosis) distinct from those that drive the former. Consequently, a student who assumes that cooperation is more likely than competition will make less accurate inferences about biological interactions and their outcomes than a student who assumes the opposite.

For example, a student who assumes that predator and prey populations keep each other in check because predators eat only a small number of prey will fail to appreciate the dynamic interaction between these populations, such that predators eat progressively more prey until there are not enough prey to go around, at which point the predators begin to die and the prey begin to rebound (Wilensky & Reisman, 2006). Likewise, a student who assumes that the trees in a forest are evenly spaced because they give each other room to grow will fail to appreciate that any sapling that takes root between established trees will be deprived of enough sunlight to survive (Wohlleben, 2016). Knowing that animals sometimes cooperate and sometimes compete is not sufficient for reasoning through a novel biological interaction. A default expectation must be applied, and that default will determine whether a student is successful at uncovering the true dynamics of the interaction.

Another difference between the domain of nature and previously studied domains is that the most significant consequence for holding contradictory views is downstream of the contradiction itself, in how these views shape students' understanding of evolution. Evolution is driven by competition, particularly competition among members of the same species; members with beneficial traits out-survive and out-reproduce their peers, thereby increasing the prevalence of such traits in future generations. Learners who think that organisms are more likely to cooperate than compete should have difficulty understanding the logic of natural selection.

Historically, the discovery of natural selection was facilitated by an appreciation of competition. Darwin read Malthus's *Essay on the Principle of Population* while deep in his search for mechanisms of adaptation, and this essay opened his eyes to the reality of resource limitation and its role in inciting competition within a population (Millman & Smith, 1997). Darwin combined this insight with two others: that members of a species are highly varied, as he observed in the Galapagos (Lack, 1983), and that incremental changes accrue over time, as he learned from Lyell's *Principles of Geology* (Gruber, 1981). In other words, Darwin inferred that competition among varied organisms could yield species-wide adaptations over several generations.

This inference transformed the study of biology, but it remains elusive to those learning biology in today's classrooms (Gregory, 2009). Most students understand evolution as a kind of cross-generational metamorphosis, where every organism produces offspring better adapted to the environment than it was at birth (Shtulman, 2006). Species are construed as distinct types or "essences," and evolution is construed as the teleological transformation of those essences (see Fig. 2). Teleo-essentialist views of evolution are common among students at all levels of education, from elementary school (Berti et al., 2010; Emmons et al., 2018; Shtulman et al., 2016) to high school (Kampourakis & Zogza, 2008; Settlage Jr, 1994; Shtulman, 2006) to college (Coley & Tanner, 2015; Opfer et al., 2012: Shtulman & Calabi, 2013), and they provide a coherent alternative to a scientific understanding of evolution, namely, the selective propagation of within-species variation.

Though misconceptions about evolution have been well documented, it is not clear that they are associated with misconceptions about competition. In the present study, we explored this possibility by measuring how students perceive competition in nature and comparing those perceptions to their understanding of evolution. To measure perceptions of competition, we asked participants to assess the prevalence of competitive behaviors, like cannibalism and cuckolding, across a variety of animals. We also asked them to assess the prevalence of cooperative behaviors, like food sharing and symbiotic cleaning, with the expectation that participants would underestimate the prevalence of competitive behaviors relative to cooperative ones. We also expected that participants would demonstrate this bias more strongly for behaviors directed within species (like cannibalism) than behaviors directed across species (like cuckolding) given that within-species competition violates the notion of a peaceable kingdom even more saliently than between-species competition.

We expected not only that participants would demonstrate overly benevolent views of nature but also that endorsement of such views would uniquely predict participants'

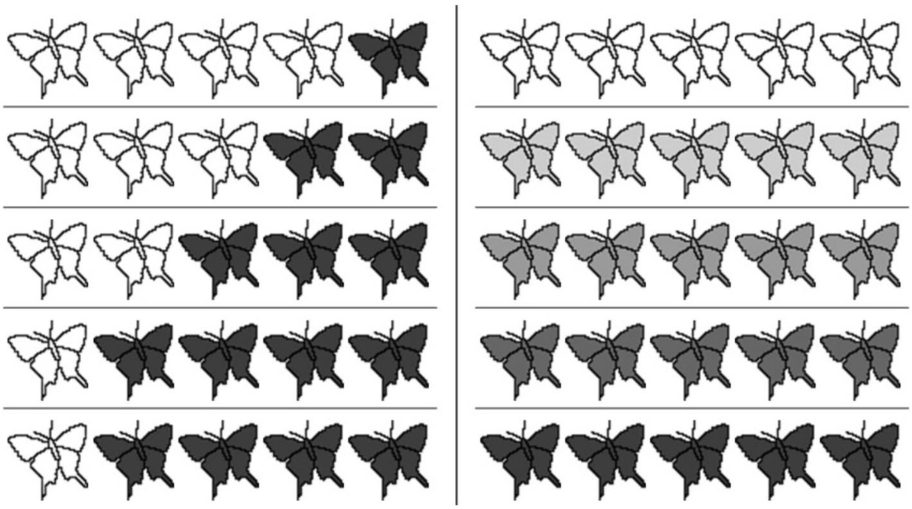

Fig. 2 Illustration of the difference between selection-based views of evolution (left) and teleo-essentialist views of evolution (right), where the former construes evolution as the selective propagation of within-species variation and the latter construes evolution as the uniform, goal-driven transformation of the species' essential form

understanding of evolution (or lack thereof). To that end, we compared perceptions of competition to evolution understanding in combination with other relevant factors, namely, perceptions of variation and perceptions of time. Competition, variation, and time are necessary for adaptation, yet students struggle to understand all three. They are inclined to view stable ecosystems as places of harmony and abundance (Ergazaki & Ampatzidis, 2012; Zimmerman & Cuddington, 2007), inclined to view variation as minimal and non-adaptive (Nettle, 2010; Shtulman & Schulz, 2008), and inclined to view time on a human-centered scale, underestimating the duration of events occurring on a geologic scale (Catley & Novick, 2009; Lee et al., 2011).

Accordingly, we expected that participants' understanding of evolution would be predicted by their perception of all three concepts—competition, variation, and time—but that perceptions of competition would predict understanding even when controlling for the other two. Such findings promise to inform our understanding of the obstacles to learning evolution, as well as our understanding of the conflict inherent in biological reasoning more generally. If students hold conflicting views of nature, then those views could either impel or impede evolutionary reasoning depending on which view is more dominant or more easily activated. This study sought to document the influence of such views as a first step toward understanding the conceptual ecology that allows misconceptions about evolution to develop and thrive, even after multiple years of college-level biology education (Shtulman & Calabi, 2013).

2 Method

2.1 Participants

The participants were 165 undergraduates at Occidental College. They were recruited from psychology courses as well as the broader campus community and were compensated with extra credit or a gift card. Seventy-six percent were female and 24% were male. Participants were not asked to report their race or ethnicity; however, this population as a whole is 49% White, 17% Hispanic, 13% Asian, 11% multiracial, 5% international, and 4% Black, and 14% are first-generation college students (U.S. News & World Report, 2024).

Participants reported having taken an average of 1.2 college-level biology courses (*SD* = 1.5) and an average of 4.1 math and science courses overall (*SD* = 3.8). The range of prior coursework was wide; some participants reported having taken no college-level biology or STEM courses, and others reported having taken as many as 8 and

Table 1 Overall accuracy on the four tasks, as well as correlations between accuracy and the number of college-level courses taken in biology or any STEM discipline. * $p < .05$

Task	Scoring	Range	Mean	*SD*	*r*: Bio	*r*: STEM
Perceptions of competition	Proportion correct	0.42 to 0.75	0.56	0.05	.17*	.12
Perceptions of variation	Proportion correct	0.17 to 1	0.61	0.20	.03	.03
Perceptions of time	Proportion correct	0 to 0.61	0.31	0.13	−.05	.02
Evolution understanding	−30 to 30	−25 to 24	−2.3	11.5	.17*	.13

16, respectively. Nevertheless, correlations with prior coursework (displayed in Table 1) remain largely the same when excluding participants with course totals more than two standard deviations beyond the mean.

2.2 Procedure

Participants completed tasks that measured their perceptions of competition, variation, and time, followed by an assessment of their understanding of evolution (from Shtulman, 2006). The first three tasks were presented in a random order, as were the items on those tasks. The tasks are described below and reproduced in full in the Appendices. They were administered as online surveys, which participants completed in the author's laboratory under the supervision of a research assistant. All participants completed all tasks.

2.2.1 Perceptions of Competition

Participants were shown several behaviors and asked to indicate which of several animals exhibit that behavior. The behaviors were either competitive or cooperative and were either directed toward members of the same species (intraspecies) or directed toward members of a different species (interspecies). Participants saw four behaviors of each type—intraspecies competitive, interspecies competitive, intraspecies cooperative, and interspecies cooperative—for a total of 16. Of interest was whether participants would overestimate the number of animals who exhibit cooperative behaviors relative to those who exhibit competitive behaviors, particularly for intraspecies behaviors.

Competitive behaviors within a species included siblicide, cannibalism, rape, and gang warfare, and competitive behaviors across species included vampirism, parasitism, cuckolding, and extra-predatorial hunting. Cooperative behaviors within a species included food sharing, food signaling, allonursing, and alloprotection, and cooperative behaviors across species included symbiotic nesting, symbiotic cleaning, symbiotic feeding, and symbiotic protection.

Each behavior was presented with six animals, half of which routinely exhibit the behavior and half of which do not. Each animal, in turn, was presented twice, once with a behavior they exhibit and once with a behavior they do not. For instance, meerkats were an option for the behavior "engages in gang warfare with other members of the same species" (which they do) as well as the behavior "procures food for organisms of a different species" (which they do not). The animal-behavior pairings were intended to be unfamiliar to most participants so that they would have to make an informed inference rather than recollect a known fact. In this way, the task tapped participants' underlying expectations about the likelihood of cooperation and competition and not just information learned by rote.

2.2.2 Perceptions of Variation

Participants' perception of the prevalence of within-species variation was assessed with a task developed by Shtulman and Schulz (2008). Participants were presented with three traits for each of six animals and asked whether those traits vary across individuals, both in the current population and in future populations. For instance, participants were told that kangaroos are commonly observed to have two stomachs and asked whether they thought that all kangaroos have two stomachs or just most kangaroos and whether a kangaroo could be born with a different number of stomachs.

Participants were asked about two types of animals (mammals and insects) and three types of traits (behavioral, external anatomical, and internal anatomical). They were asked, for instance, about giraffes' sleeping behavior, spotted coats, and extra neck joint and about grasshoppers' chirping behavior, large hind legs, and green blood. This combination of animals and traits provided a wide range of exemplars and thus a wide range of judgments.

Previous research has found that behavioral traits tend to be judged most variable and internal anatomical traits least variable, though variability judgments are also influenced by a trait's familiarity (Nettle, 2010) and functionality (Emmons & Kelemen, 2015). Regardless of the specific traits judged variable, adults' overall willingness to attribute variability has been shown to track their understanding of evolution, with greater attributions predicting more accurate understanding (Shtulman & Schulz, 2008). We sought to replicate this correlation in the present study, as a point of comparison for participants' perceptions of competition.

2.2.3 Perceptions of Time

A task developed by Lee et al. (2011) was used to measure participants' perception of geologic timespans such as those inherent in evolutionary events. Evolution can occur on any timescale, but many major evolutionary transitions, such as the emergence of vertebrates or the extinction of the dinosaurs, occurred millions of years ago, on a timescale better calibrated to geological events than human events. Participants were presented with 18 events from the distant past and asked to estimate how long ago they occurred. They made their estimates by selecting one of ten increasingly longer timespans, beginning with a hundred years ago and ending with a trillion years ago.

Sample events include "time since Rome was founded" (2750 years), "time since the extinction of dinosaurs" (65 million years), "time since the appearance of the first vertebrates" (485 million years), and "time since the Earth was formed" (4.5 billion years). Lee et al. (2011) found that college undergraduates systematically underestimate how long ago such events occurred, with the magnitude of their errors increasing for more distant events.

2.2.4 Evolution Understanding

Participants' understanding of evolution was assessed with a test developed by Shtulman (2006) for diagnosing teleo-essentialist interpretations of evolutionary phenomena. Participants completed five items assessing their understanding of each of six phenomena: variation, inheritance, selection, domestication, speciation, and extinction. The items elicited a mixture of open- and closed-ended responses. Correct, selection-based responses were assigned a score of +1; incorrect, teleo-essentialist responses were assigned a score of −1, and ambiguous or uninformative responses were assigned a score of 0.

As an illustration, consider this question from the section on inheritance: "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 is more likely." The correct answer is (c) because offspring vary randomly from their parents, but respondents typically select (a) on the assumption that offspring will be born with the traits they need in order to survive.

Or consider this question from the section on selection: “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 the adaptation of species? (a) Each returning team member grew taller over the summer; (b) more people tried out for the same number of spots this year; (c) any athlete who participates in a sport for more than one season will improve at that sport; (d) on average, each team member practiced harder this season.” The correct answer is (b) because only this explanation evokes selection over a population, but respondents typically select one of the other explanations, which evoke factors that operate over individuals.

3 Results

The focus of this investigation was on perceptions of competition and how those perceptions impact one’s understanding of evolution. Accordingly, we analyze responses to the competition task first, followed by their relation to scores on the evolution assessment. We then assess whether this relation holds even when controlling for other factors that may be relevant to evolution understanding.

3.1 Perceptions of Competition

The proportion of animals attributed competitive and cooperative behaviors are displayed in Fig. 3. Overall, participants estimated cooperative behaviors to be more prevalent than competitive ones, though this difference was substantially larger for intraspecific behaviors. We assessed the reliability of these effects with a repeated-measures analysis of variation

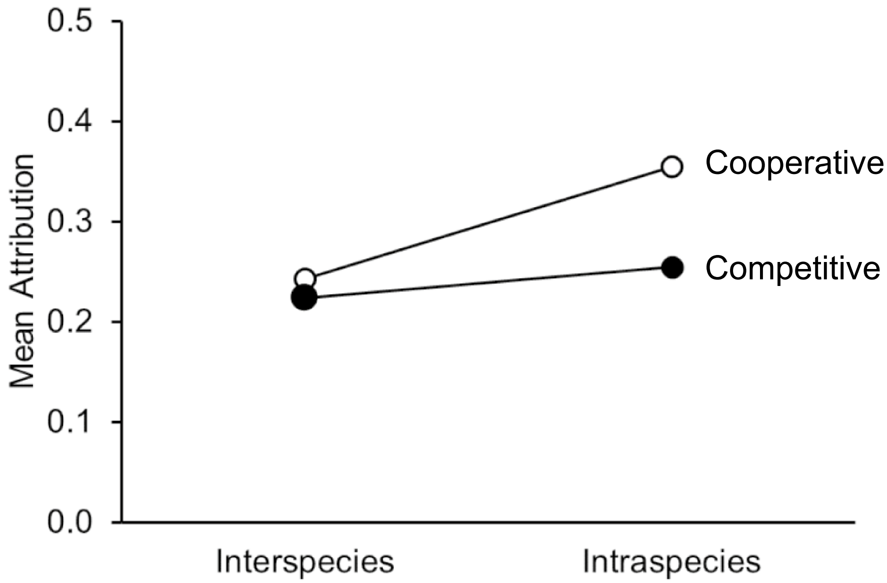

Fig. 3 The average proportion of animals attributed each behavior; all $SE < .02$

(ANOVA) with behavior type (competitive vs. cooperative) and behavior target (intraspecies vs. interspecies) as repeated measures. This analysis revealed significant effects of both behavior type ($F(1, 164) = 65.2$, $p < .001$, $\eta_p^2 = .29$) and behavior target ($F(1, 164) = 89.4$, $p < .001$, $\eta_p^2 = .35$), as well as a significant interaction between them ($F(1, 164) = 38.0$, $p < .001$, $\eta_p^2 = .19$).

Cooperative behaviors were judged more prevalent than competitive ones ($M = .30$ vs. $M = .24$), and intraspecies behaviors were judged more prevalent than interspecies ones ($M = .31$ vs. $M = .23$). But these effects were qualified by an interaction, as the difference between cooperative and competitive behaviors was significant for intraspecies behaviors (M difference = .10, $t(164) = 9.75$, $p < .001$) but only marginal for interspecies behaviors (M difference = .02, $t(164) = 1.94$, $p = .054$).

No participants attributed exclusively competitive behaviors or exclusively cooperative behaviors, implying that no participants held strictly competitive views of nature or strictly cooperative views. Still, 66% attributed more cooperative behaviors than competitive ones, and 72% did so for intraspecific behaviors in particular.

3.2 Relation to Evolution Understanding

Participants' scores on the evolution assessment were consistent with previous studies (Shtulman, 2006; Shtulman & Calabi, 2013). Scores could range from −30 to +30 in principle; in actuality, they ranged from −25 to +24. The mean score was −2.3, and 55% of participants received scores below zero, indicating pervasive teleo-essentialist reasoning (see Fig. 4).

Participants' accuracy on the competition task was significantly correlated with their accuracy on the evolution assessment: $r = .38$, $p < .001$. That is, the more accurately participants attributed competitive and cooperative behaviors to the target animals, the more often they provided correct, selection-based responses to the evolution assessment. Conversely, the less accurately participants attributed competitive and cooperative behaviors, the more often they provided incorrect, teleo-essentialist responses.

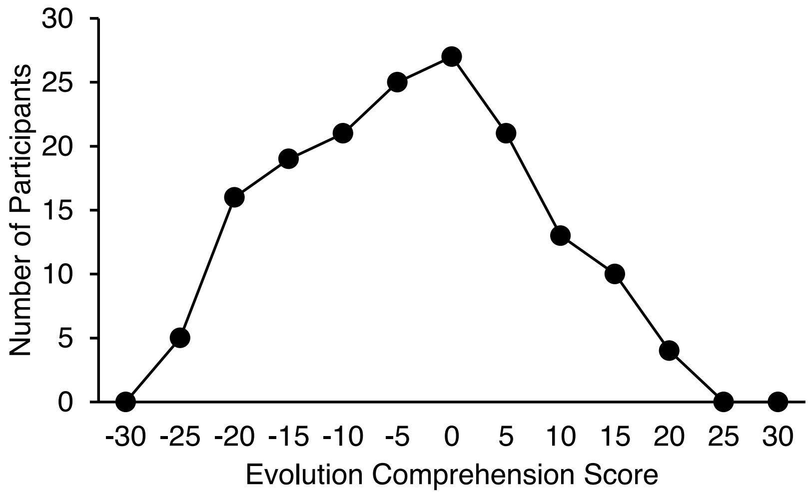

Fig. 4 Distribution of scores on the evolution assessment, where negative scores indicate teleo-essentialist misconceptions and positive scores indicate correct, selection-based reasoning

3.3 Comparison to Other Predictors

Perceptions of competition predicted evolution understanding, but were they uniquely predictive? We addressed this question by regressing evolution assessment scores against performance on the competition task controlling for performance on the variation and time tasks. Descriptive statistics for all four tasks are shown in Table 1. Performance on these tasks was generally uncorrelated with participants' prior coursework, with the exception that participants who took more college-level biology courses demonstrated more accurate perceptions of competition ($r = .17$, $p = .029$) and a more accurate understanding of evolution ($r = .17$, $p = .027$).

Participants' judgments for within-species variation and geologic time were consistent with those documented in previous research. On the variation task, participants judged 47% of traits actually variable and 61% potentially variable. Behavioral traits were judged potentially variable most often (66%), followed by external anatomical traits (63%), followed by internal anatomical traits (53%). Judgments of potential variability ranged from 17 to 100% this percentage constituted our measure of variation perception.

On the time task, participants tended to overestimate the amount of time that had passed for events occurring within the last ten thousand years, such as the extinction of the Dodo, and underestimated the amount of time that had passed for events occurring over 100,000 years ago, such as the appearance of hominids. The events for which participants were least accurate were the appearance of mammals (215 million years ago) and the appearance of vertebrates (485 million years ago). The number of events that participants correctly time-stamped ranged from 0 to 11 and averaged 5.6. This average was low, given that participants made judgments for 18 events, and could have been higher if participants were shown fewer events or fewer response options. Still, the median number of events correctly time-stamped was 6, as was the mode, so participants were not at floor. We used the proportion of events correctly time-stamped as our measure of time perception.

Both measures were entered into a four-step hierarchical regression, summarized in Table 2. In the first step, we entered information on participants' background, including their gender (dummy coded 1 for female and 2 for male), number of college-level biology courses taken, and number of STEM courses taken overall. This model did not explain a significant amount of variance in participants' evolution understanding ($R^2 = .04$, $F(3, 161) = 2.41$, $p = .064$), nor did any of the individual factors emerge as significant predictors.

In the second step, we entered scores on the variation task. This model did explain a significant amount of variance in evolution understanding ($R^2 = .11$, $F(4, 160) = 4.81$, $p <$

Table 2 Predictors of evolution understanding analyzed via hierarchical regression; standardized estimates for each predictor are presented at the top, and the variance explained by each model is presented at the bottom. *$p < .05$, **$p < .01$, ** $p < .001$

Predictors	Model 1	Model 2	Model 3	Model 4
Biology classes	.17	.16	.19	.14
STEM classes	.00	.00	−.02	−.01
Gender	.12	.08	.02	.04
Perceptions of variation		.26***	.23**	.19*
Perceptions of time			.26***	.18*
Perceptions of competition				.27***
R^2	.04	.11**	.17***	.23***
R^2 change		.06***	.06***	.06***

.001), with perceptions of variation emerging as a significant predictor ($\beta = .26$, $t = 3.39$, $p < .001$). Scores on the time task were entered in the third step. This model explained significantly more variance than the previous model (R^2 change = .06, $F(1, 159) = 12.4$, $p < .001$), and perceptions of time emerged as a significant predictor alongside perceptions of variation ($\beta = .23$, $t = 3.52$, $p < .001$, and $\beta = .26$, $t = 3.18$, $p = .002$, respectively).

In the final step, we added scores on the competition task. The added variance explained by perceptions of competition was significant (R^2 change = .06, $F(1, 158) = 12.0$, $p < .001$), and this factor emerged as the strongest predictor of evolution understanding ($\beta = .27$, $t = 3.46$, $p < .001$) relative to perceptions of variation ($\beta = .19$, $t = 2.57$, $p = .011$) and perceptions of time ($\beta = .18$, $t = 2.28$, $p = .024$). Perceptions of competition were thus uniquely predictive of evolution understanding, explaining variance in whether participants viewed evolution as a selective process or a teleo-essentialist process beyond that explained by their appreciation of within-species variation and geologic time.

4 Discussion

In the biological world, life is a struggle for survival. Prey struggle against predators. Producers struggle against consumers. Generalists struggle against specialists. Scavengers struggle against hunters. Mimics struggle against models. Hosts struggle against parasites. Immune systems struggle against pathogens. And members of a species struggle against one another other.

The struggle for survival is critical to evolution, as competition drives adaptation, but this view of nature must itself struggle against a popular alternative: nature as a peaceable kingdom, where organisms cooperate within and across species to ensure their mutual well-being. Here, we investigated the degree to which students endorse one view of nature relative to the other, and how those endorsements impact their understanding of evolution.

Consistent with the peaceable-kingdom view, participants judged cooperative behaviors to be more prevalent than competitive ones, particularly when those behaviors were directed toward other members of the species. A behavior like nursing unrelated members of the same species was attributed to 10% more animals than a behavior like eating other members of the same species, even though both behaviors were true of the same number of target animals (three of six). This asymmetry implies that learners are predisposed to think of the interactions between organisms as more cooperative than competitive, even though the opposite must be true in any environment with limited resources.

Furthermore, participants with more accurate perceptions of competition demonstrated more accurate views of evolution, and this relation held even when controlling for how accurately participants perceived within-species variation and geologic time. All three factors were significant predictors of evolution understanding, but they were also independent predictors—independent of each other as well as the number of college-level biology courses participants had taken previously. Thus, perceptions of competition did not function as a proxy for general knowledge of biology. Participants who had taken more biology courses had more accurate perceptions of competition, but these perceptions still explained unique variance in evolution understanding. Admittedly, our sample was unique in that most had taken at least one college-level biology of course, and it remains to be seen whether perceptions of competition predict evolution understanding in populations with less evolution education, such as children or non-college-educated adults.

Still, these results confirm the historical analysis of Darwin's discovery of natural selection: just as Darwin's discovery required an appreciation of competition, variation, and time, students' understanding that discovery appears to require the same conceptual foundations. Interestingly, historians of biology have focused on Darwin's appreciation of variation as the key insight separating him from his predecessors, who proposed theories of evolution that treated species as essentialized types rather than collections of variation (Gould, 1996; Hull, 1965; Mayr, 1982), yet Darwin's appreciation of competition may have been just as influential. In the current study, an appreciation of competition was not just predictive of evolution understanding but *more* predictive than any other conceptual measure.

Still, it is possible that evolution understanding fosters an appreciation of competition rather than the other way around, especially for students. Students may come to appreciate the struggle for survival by way of understanding how that struggle creates selection pressures within and across populations. Biologically accurate conceptions of evolution and competition are mutually supportive; thinking of evolution as a selection-driven process begs the question of who is selected, and appreciating that organisms must compete for limited resources begs the question of what happens to those who lose the competition. The same mutual dependence holds for *inaccurate* conceptions of evolution and competition; thinking of evolution as a process of directed mutation obviates the need for competition, and a lack of competition is expected if all organisms are born with traits that will ensure their survival.

This interdependence between evolution and competition implies that evolution educators might benefit from teaching these ideas in tandem. It also implies that, if students hold both cooperative and competitive views of nature consistent with how nature is depicted in popular media (Marriott, 2002; Shtulman et al., 2021), then evolution educators could help students appreciate how cooperation arises from competition, through mechanisms evolved specifically to quell competition in contexts where cooperation yields greater payoffs. Biologists struggled to explain the origins of cooperation for decades (Ridley, 1997), and students of biology could benefit from learning how biologists embraced alternative frameworks for evolutionary adaptation in order to resolve this dilemma.

One noteworthy aspect of participants' perceptions of competition, aside from their relation to evolution understanding, was their overall magnitude. Participants attributed competitive behaviors to 24% of the target animals when those behaviors actually applied to 50%. Estimates of variation and time also fell short of their true mark. Participants claimed that 61% of target traits were potentially variable, even though all biological traits are potentially variable, and their estimates of the time that had passed since the appearance of new lifeforms (e.g., vertebrates, mammals, hominids) were off by several orders of magnitude. These findings imply that students systematically underestimate the prevalence and duration of key biological processes. They also imply that students' understanding of evolution could be improved by improving their understanding of the background conditions necessary for evolution to occur.

We have argued that the reason participants underestimated the prevalence of competition relative to cooperation is that they hold conflicting views of nature, but our measure (described in Appendix 1) provides only indirect evidence for this possibility. Another possibility is that participants held a single view of nature—competitive or cooperative—but made allowances for the opposite type of behavior, as exceptions to the rule. Our measure cannot distinguish between these possibilities, but it could be revised to do so by also collecting response times. If, for instance, participants took longer to attribute competitive behaviors than cooperative ones, this lag would imply that participants must suppress the intuition that animals cooperate in order to affirm that they sometimes compete.

Alternatively, participants could be administered our measure under time pressure, with the prediction that the asymmetry between attributions of cooperation and competition should increase when participants have less time to suppress the intuition that animals cooperate. Such a manipulation was used by Kelemen et al. (2013) to show that physicists will accept teleological explanations for natural phenomena, such as "trees produce oxygen so that animals can breathe," if they do not have sufficient time to suppress the intuition that all things exist for a purpose.

Time-sensitive measures could be supplemented with interviews to establish whether, and how, students make sense of the fact that animals sometimes cooperate and sometimes compete. While some students might appeal to cooperation and competition without attempting to explain or coordinate their varied occurrence, others might construct more integrated models, as seen in research on how students make sense of illness (Legare & Gelman, 2008), death (Harris, 2011), and adaptation (Evans & Lane, 2011). If students' integrated models are explanatorily productive, they could serve as stepping stones for introducing scientific models of how cooperation arose from competition.

In conclusion, many students appear to view nature as more "peaceable kingdom" than "red in tooth and claw." Animals are assumed to cooperate more often than compete, which may curtail their understanding of the mechanisms of evolution. Nature is not always red in tooth and claw, but this view aligns more closely with the biological reality that competition drives adaptation and, accordingly, our ability to understand that reality. Future research is thus needed to determine how we develop overly benevolent views of nature and how we can learn to manage those views when learning the logic of natural selection.

Appendix 1. Perceptions of Competition

Intraspecies Competition

Which of the following routinely kill their siblings?
    True: cattle egrets, sand tiger sharks, spotted hyenas
    False: wolves, leaf-cutter ants, pistol shrimp
Which of the following routinely eat other members of the same species?
    True :crocodiles, cane toads, meadow voles
    False: vervet monkeys, ichneumon wasps, plover birds
Which of the following routinely rape other members of the same species?
    True: orangutans, mallard ducks, water beetles
    False: vampire bats, baboons, zebras
Which of the following engage in gang warfare with other members of the same species?
    True: chimpanzees, meerkats, badgers
    False: raccoons, black-ray gobies, sharp-beaked ground finches

Interspecies Competition

Which of the following feed on the blood of other living organisms?
    True: sea lampreys, sharp-beaked ground finches, nutmeg snails
    False: boxer crabs, squeaker catfish, cane toads
Which of the following trick organisms of a different species into raising their young?
    True: cowbirds, squeaker catfish, large blue butterflies

False: gopher tortoise, gibbons, spotted hyenas
Which of the following inject larvae into the bodies of other living organisms?
True: ichneumon wasps, botflies, gravid mussels
False: honey bees, yellow meadow ants, water beetles
Which of the following hunt and kill animals they do not intend to eat?
True: orcas, dolphins, weasels
False: crocodiles, sea lampreys, barracudas

Intraspecies Cooperation

Which of the following share food with unrelated members of the same species?
True: gibbons, vampire bats, wolves
False: bluestreak wrasse fish, clown fish, cowbirds
Which of the following signal the location of food to unrelated members of the same species?
True: ravens, honey bees, raccoons
False: sand tiger sharks, large blue butterflies, nutmeg snails
Which of the following protect unrelated members of the same species from predators?
True: vervet monkeys, water buffalo, baboons
False: gravid mussels, botflies, badgers
Which of the following will nurse the offspring of unrelated members of the same species?
True: capuchin monkeys, zebras, lions
False: dolphins, weasels, orangutans

Interspecies Cooperation

Which of the following protect organisms of a different species from predators?
True: yellow meadow ants, black-ray gobies, clown fish
False: orcas, lions, water buffalo
Which of the following share their nests or burrows with organisms of a different species?
True: prairie dogs, gopher tortoises, pistol shrimp
False: ravens, mockingbirds, mallard ducks
Which of the following clean parasites off organisms of a different species?
True: bluestreak wrasse fish, mockingbirds, plover birds
False: chimpanzees, capuchin monkeys, prairie dogs
Which of the following procure food for organisms of a different species?
True: barracudas, leaf-cutter ants, boxer crabs
False: cattle egrets, meadow voles, meerkats

Appendix 2. Perceptions of Variation

Giraffes

It is commonly observed that giraffes sleep on their feet.
Do you think all giraffes sleep on their feet or just most giraffes?
Could a giraffe sleep in a different way?

It is commonly observed that giraffes have spots on their coat.
Do you think all giraffes have spots on their coat or just most giraffes?
Could a giraffe be born with a different kind of coat?
It is commonly observed that giraffes have an extra neck joint relative to other mammals.
Do you think all giraffes have an extra neck joint or just most giraffes?
Could a giraffe be born with a different kind of neck?

Kangaroos

It is commonly observed that kangaroos have two stomachs.
Do you think all kangaroos have two stomachs or just most kangaroos?
Could a kangaroo be born with a different number of stomachs?
It is commonly observed that kangaroos have pouches on their bellies.
Do you think all kangaroos have pouches or just most kangaroos?
Could a kangaroo be born with a different kind of belly?
It is commonly observed that kangaroos hop on their back legs.
Do you think all kangaroos hop on their back legs or just most kangaroos?
Could a kangaroo get around in a different way?

Pandas

It is commonly observed that pandas have thick, bumpy throats.
Do you think all pandas have thick, bumpy throats or just most pandas?
Could a panda be born with a different kind of throat?
It is commonly observed that pandas live by themselves.
Do you think all pandas live by themselves or just most pandas?
Could a panda live in a different social arrangement?
It is commonly observed that pandas have thumbs on their forepaws.
Do you think all pandas have thumbs on their forepaws or just most?
Could a panda be born with a different kind of paw?

Ants

It is commonly observed that ants live inside mounds of dirt.
Do you think all ants live in anthills or just most ants?
Could an ant live in a different kind of home?
It is commonly observed that ants have a tube-shaped heart.
Do you think all ants have a tube-shaped heart or just most ants?
Could an ant be born with a different kind of heart?
It is commonly observed that ants have two antennae on their heads.
Do you think all ants have antennae on their heads or just most ants?
Could an ant be born with a different kind of head?

Bees

It is commonly observed that bees have five eyes.
Do you think all bees have five eyes or just most bees?
Could a bee could be born with a different number of eyes?
It is commonly observed that bees make honey.
Do you think all bees make honey or just most bees?
Could a bee make a different kind of food?
It is commonly observed that bees have poison in their stingers.
Do you think all bees have poison in their stingers or just most bees?
Could a bee be born with a different kind of stinger?

Grasshoppers

It is commonly observed that grasshoppers have large hind legs.
Do you think all grasshoppers have large hind legs or just most grasshoppers?
Could a grasshopper be born with a different kind of leg?
It is commonly observed that grasshoppers have green blood inside their bodies.
Do you think all grasshoppers have green blood or just most grasshoppers?
Could a grasshopper be born with a different kind of blood?
It is commonly observed that grasshoppers make chirping sounds.
Do you think all grasshoppers make chirping sounds or just most grasshoppers?
Could a grasshopper make a different kind of sound?

Appendix 3. Perceptions of Time

Answer Choices

Between 100 and 1000 years
Between 1000 and 10,000 years
Between 10,000 and 100,000 years
Between 100,000 and 1,000,000 years
Between 1,000,000 and 10,000,000 years
Between 10,000,000 and 100,000,000 years
Between 100,000,000 and 1,000,000,000 years
Between 1,000,000,000 and 10,000,000,000 years
Between 10,000,000,000 and 100,000,000,000 years
Between 100,000,000,000 and 1,000,000,000,000 years

Events

Extinction of the Dodo [320 years]
Invention of the printing press [570 years]
Founding of Rome [2750 years]
Origin of the oldest known tree [9550 years]

Domestication of dogs [15,000 years]
Extinction of Neanderthals [30,000 years]
Appearance of modern humans [200,000 years]
Formation of the youngest Hawaiian island [400,000 years]
Creation of the first stone tools [2,000,000 years]
Appearance of the first hominids [4,000,000 years]
Appearance of the first primates [60,000,000 years]
Extinction of dinosaurs [65,000,000 years]
Appearance of the first mammals [215,000,000 years]
Appearance of the first vertebrates [485,000,000 years]
Appearance of the first lifeforms [3,500,000,000 years]
Origin of the Earth [4,500,000,000 years]
Origin of the Milky Way Galaxy [12,200,000,000 years]
Origin of the Universe [13,800,000,000 years]

Acknowledgements The author would like to thank Alison Ban and Daniel Watson for their assistance with data collection.

Funding Open access funding provided by SCELC, Statewide California Electronic Library Consortium. This research was supported by grant DRL-0953384 from the U.S. National Science Foundation awarded to Andrew Shtulman.

Data Availability All data are available upon request.

Declarations

Conflict of interest The author declares no competing interests.

References

Allaire-Duquette, G., Brault Foisy, L. M., Potvin, P., Riopel, M., Larose, M., & Masson, S. (2021). An fMRI study of scientists with a Ph. D. in physics confronted with naive ideas in science. *NPJ Science of Learning, 6*, 11.

Axelrod, R., & Hamilton, W. D. (1981). The evolution of cooperation. *Science, 211*, 1390–1396.

Barlev, M., Mermelstein, S., & German, T. C. (2017). Core intuitions about persons coexist and interfere with acquired Christian beliefs about God. *Cognitive Science, 41*, 425–454.

Bélanger, M., Potvin, P., Horst, S., Shtulman, A., & Mortimer, E. (2022). *Multidisciplinary perspectives on representational pluralism in human cognition*. Routledge.

Berti, A. E., Toneatti, L., & Rosati, V. (2010). Children's conceptions about the origin of species: A study of Italian children's conceptions with and without instruction. *The Journal of the Learning Sciences, 19*, 506–538.

Carbon, C. C. (2010). The earth is flat when personally significant experiences with the sphericity of the earth are absent. *Cognition, 116*, 130–135.

Catley, K. M., & Novick, L. R. (2009). Digging deep: Exploring college students' knowledge of macroevolutionary time. *Journal of Research in Science Teaching, 46*, 311–332.

Coley, J. D., & Tanner, K. (2015). Relations between intuitive biological thinking and biological misconceptions in biology majors and nonmajors. *CBE-Life Sciences Education, 14*, 8.
DeWolf, M., & Vosniadou, S. (2015). The representation of fraction magnitudes and the whole number bias reconsidered. *Learning and Instruction, 37*, 39–49.
Dugatkin, L. A. (1997). *Cooperation among animals: An evolutionary perspective*. Oxford University Press.
Emmons, N. A., & Kelemen, D. A. (2015). Young children's acceptance of within-species variation: Implications for essentialism and teaching evolution. *Journal of Experimental Child Psychology, 139*, 148–160.
Emmons, N. A., Lees, K., & Kelemen, D. (2018). Young children's near and far transfer of the basic theory of natural selection: An analogical storybook intervention. *Journal of Research in Science Teaching, 55*, 321–347.
English Standard Version Bible. (2001). Retrieved May 15, 2024. ESV Online. https://esv.literalword.com/
Ergazaki, M., & Ampatzidis, G. (2012). Students' reasoning about the future of disturbed or protected ecosystems & the idea of the 'balance of nature'. *Research in Science Education, 42*, 511–530.
Evans, E. M., & Lane, J. D. (2011). Contradictory or complementary? Creationist and evolutionist explanations of the origin(s) of species. *Human Development, 54*, 144–159.
Foisy, L. M. B., Ahr, E., Sarrasin, J. B., Potvin, P., Houdé, O., Masson, S., & Borst, G. (2021). Inhibitory control and the understanding of buoyancy from childhood to adulthood. *Journal of Experimental Child Psychology, 208*, 105155.
Goldberg, R. F., & Thompson-Schill, S. L. (2009). Developmental "roots" in mature biological knowledge. *Psychological Science, 20*, 480–487.
Gould, S. J. (1996). *Full house: The spread of excellence from Plato to Darwin*. Three Rivers Press.
Gregory, T. R. (2009). Understanding natural selection: Essential concepts and common misconceptions. *Evolution: Education and Outreach, 2*, 156–175.
Gruber, H. E. (1981). *Darwin on man: A psychological study of scientific creativity*. University of Chicago Press.
Harris, P. L. (2011). Conflicting thoughts about death. *Human Development, 54*, 160–168.
Hull, D. (1965). The effect of essentialism on taxonomy: 2000 years of stasis. *British Journal for the Philosophy of Science, 15-16*, 314–326.
Kampourakis, K., & Zogza, V. (2008). Students' intuitive explanations of the causes of homologies and adaptations. *Science & Education, 17*, 27–47.
Kelemen, D., Rottman, J., & Seston, R. (2013). Professional physical scientists display tenacious teleological tendencies: Purpose-based reasoning as a cognitive default. *Journal of Experimental Psychology: General, 142*, 1074.
Lack, D. (1983). *Darwin's finches*. Cambridge University Press.
Lee, H. S., Liu, O. L., Price, C. A., & Kendall, A. L. (2011). College students' temporal-magnitude recognition ability associated with durations of scientific changes. *Journal of Research in Science Teaching, 48*, 317–335.
Legare, C. H., & Gelman, S. A. (2008). Bewitchment, biology, or both: The co-existence of natural and supernatural explanatory frameworks across development. *Cognitive Science, 32*, 607–642.
Legare, C. H., & Shtulman, A. (2018). Explanatory pluralism across cultures and development. In J. Proust & M. Fortier (Eds.), *Interdisciplinary approaches to metacognitive diversity* (pp. 415–432). Oxford University Press.
Marriott, S. (2002). Red in tooth and claw? Images of nature in modern picture books. *Children's Literature in Education, 33*, 175–183.
Mayr, E. (1982). *The growth of biological thought: Diversity, evolution, and inheritance*. Harvard University Press.
Mayr, E. (2001). *What evolution is*. Basic Books.
Millman, A. B., & Smith, C. L. (1997). Darwin's use of analogical reasoning in theory construction. *Metaphor and Symbol, 12*, 159–187.
Nettle, D. (2010). Understanding of evolution may be improved by thinking about people. *Evolutionary psychology, 8*, 205–228.
Opfer, J. E., Nehm, R. H., & Ha, M. (2012). Cognitive foundations for science assessment design: Knowing what students know about evolution. *Journal of Research in Science Teaching, 49*, 744–777.
Poling, D. A., & Evans, E. M. (2004). Are dinosaurs the rule or the exception? Developing concepts of death and extinction. *Cognitive Development, 19*, 363–383.
Potvin, P., & Cyr, G. (2017). Toward a durable prevalence of scientific conceptions: Tracking the effects of two interfering misconceptions about buoyancy from preschoolers to science teachers. *Journal of Research in Science Teaching, 54*, 1121–1142.

Potvin, P., Malenfant-Robichaud, G., Cormier, C., & Masson, S. (2020). Coexistence of misconceptions and scientific conceptions in chemistry professors: A mental chronometry and fMRI study. *Frontiers in Education, 5*, 542458.
Raman, L., & Gelman, S. A. (2004). A cross-cultural developmental analysis of children's and adults' understanding of illness in South Asia (India) and the United States. *Journal of Cognition and Culture, 4*, 293–317.
Ridley, M. (1997). *The origins of virtue*. Penguin.
Settlage, J., Jr. (1994). Conceptions of natural selection: A snapshot of the sense-making process. *Journal of Research in Science Teaching, 31*, 449–457.
Shtulman, A. (2006). Qualitative differences between naïve and scientific theories of evolution. *Cognitive Psychology, 52*, 170–194.
Shtulman, A. (2017). *Scienceblind: Why our intuitive theories about the world are so often wrong*. Basic Books.
Shtulman, A., & Calabi, P. (2013). Tuition vs. intuition: Effects of instruction on naïve theories of evolution. *Merrill-Palmer Quarterly, 59*, 141–167.
Shtulman, A., & Harrington, K. (2016). Tensions between science and intuition across the lifespan. *Topics in Cognitive Science, 8,* 118-137.
Shtulman, A., Neal, C., & Lindquist, G. (2016). Children's ability to learn evolutionary explanations for biological adaptation. *Early Education and Development, 27*, 1222–1236.
Shtulman, A., & Schulz, L. (2008). The relationship between essentialist beliefs and evolutionary reasoning. *Cognitive Science, 32*, 1049–1062.
Shtulman, A., Villalobos, A., & Ziel, D. (2021). Whitewashing nature: Sanitized depictions of biology in children's books and parent–child conversation. *Child Development, 92*, 2356–2374.
Shtulman, A., & Young, A. G. (2024). Tempering the tension between science and intuition. *Cognition, 243*, 105680.
Stricker, J., Vogel, S. E., Schöneburg-Lehnert, S., Krohn, T., Dögnitz, S., Jud, N., et al. (2021). Interference between naïve and scientific theories occurs in mathematics and is related to mathematical achievement. *Cognition, 214*, 104789.
Toyama, N. (2019). Development of integrated explanations for illness. *Cognitive Development, 51*, 1–13.
U.S. News & World Report. (2024). Occidental College overview. Retrieved May 15, 2024. https://www.usnews.com/best-colleges/occidental-college-1249
Vosniadou, S., Pnevmatikos, D., Makris, N., Lepenioti, D., Eikospentaki, K., Chountala, A., & Kyrianakis, G. (2018). The recruitment of shifting and inhibition in on-line science and mathematics tasks. *Cognitive Science, 42*, 1860–1886.
Wilensky, U., & Reisman, K. (2006). Thinking like a wolf, a sheep, or a firefly: Learning biology through constructing and testing computational theories—an embodied modeling approach. *Cognition and Instruction, 24*, 171–209.
Wiser, M., & Amin, T. (2001). "Is heat hot?" Inducing conceptual change by integrating everyday and scientific perspectives on thermal phenomena. *Learning and Instruction, 11*, 331–355.
Wohlleben, P. (2016). *The hidden life of trees*. Greystone.
Young, A. G., & Shtulman, A. (2020). How children's cognitive reflection shapes their science understanding. *Frontiers in Psychology, 11*, 1247.
Zimmerman, C., & Cuddington, K. (2007). Ambiguous, circular and polysemous: Students' definitions of the "balance of nature" metaphor. *Public Understanding of Science, 16*, 393–406.