Why People Do Not Understand Evolution

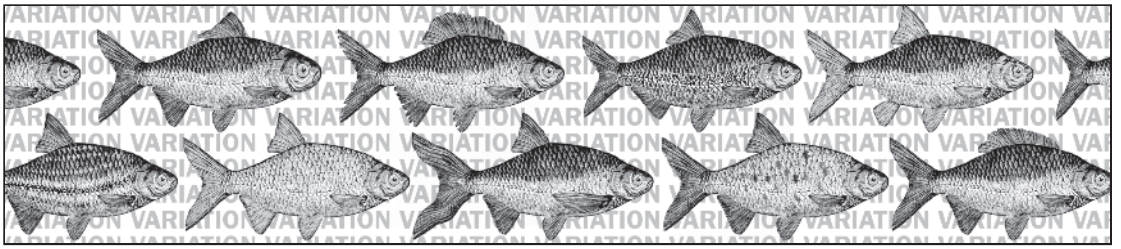
An Analysis of the Cognitive Barriers to Fully Grasping the Unity of Life

BY ANDREW SHTULMAN

In 2005, the parents of nine students attending Dover High School in Dover, Pennsylvania, sued the Dover Area School District over their decision to require high school biology teachers to read a statement alerting their students to the existence of "gaps" in the theory of evolution and encouraging them "to keep an open mind" regarding alternative explanations for the origins of life. The lawsuit, which the parents won, garnered national attention, as it brought to a head the controversial issue of whether Intelligent Design—the claim that complex biological systems could only have arisen through the guidance of a superior intelligence—should be taught in public schools as an alternative to evolution. In 2008, the PBS television series *NOVA* released a documentary on the Dover trial entitled "Judgment Day: Intelligent Design on Trial." One of the individuals interviewed for that documentary was Bill Buckingham, a member of the school board who had advocated for the inclusion of Intelligent Design in the biology curriculum. Buckingham stated that his own views on the matter were simple: "The book of Genesis tells it like it is as to how we came into being. God didn't create monkey and then take man from a monkey. He created man."

What's interesting about this quote, from a scientific perspective, is that Buckingham attributes two positions to his opponents that none actually hold, namely, (1) humans evolved from monkeys, and (2) monkeys appeared on Earth in their current form. Evolutionary biologists actually believe (1) humans and monkeys evolved from a common ancestor, and (2) monkeys evolved from earlier forms of life. In fact, biologists believe that *all* organisms are linked through common ancestry and that *all* organisms evolved from earlier forms of life. Buckingham's conceptions of the scientific ideas he attempted to censor are thus profoundly wrong, but they are not profoundly original. Similar types of misconceptions have resounded within the public sphere since 1859, when Darwin first articulated the theory of evolution by natural selection in *On the Origin of Species*. Today, that theory forms the backbone of the biological sciences, yet misconceptions about evolution have not declined. If anything, they have become more frequent, as the public has become more exposed to the principles and findings of evolutionary biology.

From where do such misconceptions arise? Perhaps the most popular explanation is that evolution is inconsistent with the teachings of most religions, so religious individuals simply reject the theory outright. While this idea certainly holds some truth, it fails to explain why individuals like Buckingham, who deny that evolution occurs, also tend to misunderstand what evolution is and how evolution works. Another popular explanation is that a poor understanding of evolution stems from a poor understanding of the nature of science in general, with skeptics of evolution failing to appreciate the vast extent to which it has been empirically vali-



dated. Again, while this idea holds some truth, it fails to explain why individuals who reject evolution tend not to understand the theory they are rejecting. Below, I outline an alternative explanation that has received increasing attention and support within the fields of cognitive and developmental psychology, an explanation grounded in the fact that humans tend to "essentialize" the biological world and that essentialist thinking is fundamentally incompatible with understanding the basic mechanisms of evolution.

Essentialist Thought in Everyday Life

Essentialism is the commonplace assumption that the obvious, observable properties of an object or organism are determined by some non-obvious, non-observable property at its core—its "essence." One of the best illustrations of essentialist thought is Hans Christian Andersen's tale of the ugly duckling. The tale begins with a mother duck sitting on a nest of eggs, waiting for her ducklings to hatch. One duckling hatches later than the others, and he is, to everyone's dismay, larger and uglier than his siblings. A neighboring duck suggests that he may be a turkey, but that suggestion is refuted by the fact that he can swim. That ability, paired with his unusual looks, makes him a target of ridicule from both the ducks and the turkeys. Distressed, the duckling leaves his home in search of animals who will accept him as one of their own. During his journey, he meets geese, who reject him as an unsuitable mate; a tom cat, who rejects him for being unable to purr; and a hen, who rejects him for being unable to lay eggs. Finally, after months of travel, the duckling encounters a group of graceful white swans who, to his surprise, accept him into their family. The reason, he soon discovers, is that he has grown into a graceful white swan himself. "To be born in a duck's nest, in a farmyard," writes Andersen, "is of no consequence to a bird, if it is hatched from a swan's egg."

The plot of this fairytale is predicated on the assumption that an organism's traits are determined by its species kind, and an organism's species kind is, in turn, determined by its parentage. In other words, the reason the ugly duckling turned into a beautiful swan had nothing to do with what it ate, where it lived, or what it desired; it was simply born a swan. And the reason it was born a swan had nothing to do with what its parents ate, where its parents lived, or what its parents desired; its parents had simply been born swans. This assumption—that like begets like begets like—serves us well in our everyday reasoning about the biological world, for an organism's species kind is, indeed, a reliable predictor of its properties. Knowing that an organism is a swan, for instance, allows us to make accurate predictions about how that organism should look (brown as an infant, white as an adult), where that organism should live (by water), what that organism should eat (vegetation), how that organism should reproduce (by laying eggs), and so forth.

Yet, despite its utility for reasoning about the properties of individual organisms, biological essentialism has proven a major impediment for reasoning about population-level phenomena, like evolution and natural selection. The problem is that biological essentialism, while true in spirit, is false in detail. Offspring resemble their parents, but the resemblance is not exact. Every organism is unique, and every population is full of variation, yet our essentialist tendencies lead us to overlook this fact. We impose categories on all the flora and fauna around us, either explicitly (with labels and taxonomies) or implicitly (with analogies and comparisons), yet, as the biologist Joan Roughgarden aptly notes in *Evolution's Rainbow*, nature not only abhors a vacuum; it also abhors a category.

Essentialist Thought in the History of Science

Essentialist thinking is not the product of a lazy mind; it is the way we all perceive and conceptualize the natural world, biologists included. In fact, historians of science have long pointed to essentialism as a key impediment—if not *the* key impediment—to the discovery of natural selection. According to the great Harvard evolutionary theorist and historian of science, Ernst Mayr, Greek scholars had formulated the concept of descent with modification as early as 600 BC, but for all pre-Darwinian thinkers this process merely produced variations on a theme, to which they also deduced something like a process of natural selection that eliminated those members of the population who varied too far from the species' core essence. Even with a mechanism for selecting out these deviations from the essential type, those who attempted to solve the mystery of the origin of new species invariably fell prey to essentialist thinking, conceptualizing species as discrete, homogenous units, whose aggregate properties are true of all members of the species and are faithfully transmitted from one generation to the next. This view correctly implies that every baby swan has the potential to grow into an adult swan, but it incor-

rectly implies that differences between swans are unimportant and inconsequential. Indeed, it positively obscures the fact that most baby swans will *not* survive to adulthood, let alone produce babies of their own.

By focusing on the similarities among members of the same species rather than their differences, early evolutionary theorists posited mechanisms of evolution that operated over all individuals within a population indiscriminately—mechanisms like the inheritance of acquired traits (Jean-Baptiste Lamarck's mechanism) or the law of accelerated growth (Edward Cope's mechanism). Mayr terms these pre-Darwinian theories of evolution "transformational" theories because they construe evolution as the cross-generational *transformation* of an entire species, with every organism producing offspring more adapted to the current environment than it was itself at birth. In other words, each member of the species was thought to "evolve" in lock-step with every other member, propelled by a mysterious mechanism that somehow coordinated this species-wide event. Not until Darwin did evolutionary biologists begin eschewing species-wide similarities for within-species differences. The result was a qualitatively different view of evolution—what Mayr terms a "variational" theory—in which evolution is (correctly) construed as the selective propagation of within-species variation, with some members of the species possessing variations that allow them to survive and reproduce more successfully than others.

Today, all biologists subscribe to variational theories of evolution of one form or another, but the paradigm shift from "transformationism" to "variationism" took millennia to achieve. Biologists continued to debate the merits of each framework well into the 20th century, and aspects of essentialist thinking still pervade modern discourse about biological phenomena. In *Full House*, the late Harvard paleontologist Stephen Jay Gould eloquently analyzes this predicament as essentialism gone awry: "Our Platonic heritage prompts us to view means and medians as the hard 'realities,' and the variation that permits their calculation as a set of transient and imperfect measurements of this hidden essence. But all evolutionary biologists know that variation itself is nature's only irreducible essence. Variation is the hard reality, not a set of imperfect measures for a central tendency. Means and medians are the abstractions."

Essentialist Thought in Early Childhood

Gould points to Plato as the original progenitor of essentialism, but Plato is not to blame. Young children are natural born essentialists. Recent work by cognitive anthropologists and developmental psychologists suggests that essentialist thinking is ubiquitous not only across cultures but also across age. (See, for example, Bruce Hood's *SuperSense* and Paul Bloom's *How Pleasure Works* for recent works documenting the phenomenon.) Young children from England to Mexico, Japan to Brazil, have revealed essentialist intuitions about the nature and origin of biological properties, particularly in the context of two main paradigms: an unknown-property paradigm and a switched-at-birth paradigm.

In the unknown-property paradigm, preschool-aged children are taught something novel about a familiar organism—say, that cats (a familiar organism) can see in the dark (a novel property). They are then shown a handful of novel organisms and asked which might also possess that property. Some of the novel organisms are of the same species as the familiar organism but differ in appearance (e.g., a cat that looks like a skunk), and others share the same appearance but are of a different species (e.g., a skunk that looks like a cat). Children of all ages reliably extend the novel property to the former (the skunk-like cat) but not the latter (the cat-like skunk), implying that they view species kind as a better predictor of shared properties than mere appearance. This is why children can appreciate the tale of the ugly duckling from an early age, long before they've had any formal schooling in biology. They understand, at least tacitly, that what you are inside (say, a swan) matters more than what you look like (say, a duck). They also understand that organisms retain their species kind throughout their lifespan, even as they undergo dramatic changes in size, shape, or complexity. A frog is a frog is a frog, even if it starts out life looking more like a fish than an amphibian.

In the switched-at-birth paradigm, children are presented with scenarios that resemble the tale of the ugly duckling even more closely. They are told of a baby animal that was removed from its birth parents (e.g., cows) and raised by members of a different species (e.g., pigs) and are asked to predict the biological properties that animal will possess as an adult: those of its birth parents (a straight tail and a diet of grass) or those of its adopted parents (a curly tail and a diet of slop). Children of all ages tend to predict the baby will come to possess the properties of its birth parents. They also tend to justify their judgments with explicit appeals to the

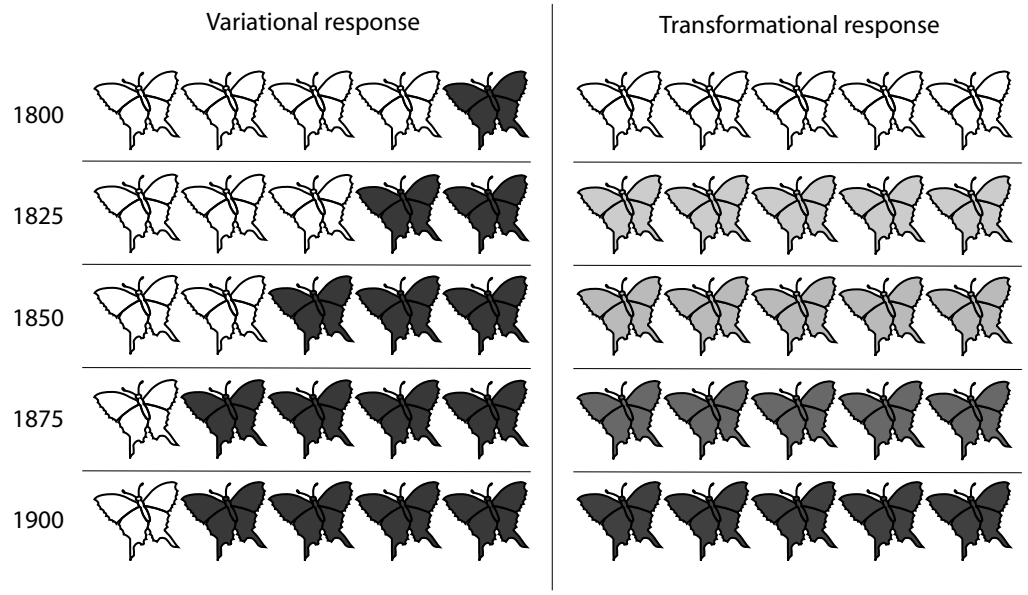
continuity of species kind, arguing, for example, that the animal will eat grass "because it's a cow, not a pig!" In short, young children assume that an organism's species kind is conferred at birth and remains intact across changes in appearance, environment, and upbringing.

Essentialist Thought in the Classroom

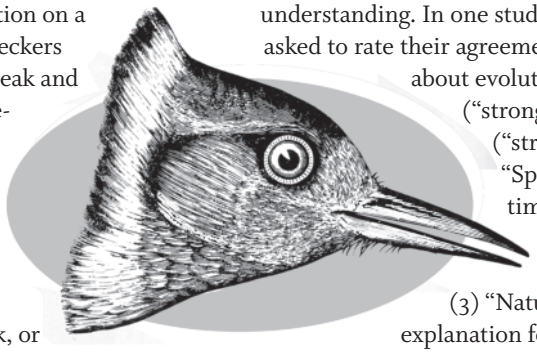
Young children are not the only ones who construe the biological world in terms of hidden essences and unobservable causal powers; students receiving formal instruction in biology reveal similar intuitions. While these intuitions are generally harmless for learning most biological concepts—"essence of swan" easily translates to "swan DNA" in the context of modern physiology or modern genetics—they pose a formidable obstacle to learning evolution, for just as essentialism led early evolutionary biologists to undervalue within-species variation and overvalue shared traits, modern-day students do the same. As a result, they fail to understand the variational principles of modern evolutionary biology and come, instead, to hold views of evolution that more closely resemble pre-Darwinian theories of evolution (transformationism) than post-Darwinian ones (variationism).

The transformational nature of students' misconceptions is well illustrated by the following task. Students are presented with a 5 x 5 matrix of moth-shaped figures and told the following: "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, England's native moth species *Biston betularia* became, on average, darker in color. If you had gathered a random sample of *Biston betularia* every 25 years over the course of the nineteenth century, what range of colorations would you have expected to find at each point in time?" The rows of the matrix are labeled "1800," "1825," "1850," "1875," and "1900," and the students are instructed to shade the moths within those rows to depict random samples gathered during that time. The two most common response patterns are shown in *Figure 1*. The pattern on the left, typically provided by only a handful of students, depicts an adaptive variation spreading through a population over time and is an instance of (correct) variational reasoning. The pattern on the right, provided most frequently, depicts a population uniformly acquiring the same adaptation and is an instance of (incorrect) transformational reasoning. Note that the main difference between these two patterns is the inclusion or exclusion of within-species variation. Whereas the pattern on the left depicts variation occurring both within and across generations, the pattern on the right depicts variation occurring only across generations.

Figure 1—The two most common responses to the question "What range of colorations would you have expected to find if you had gathered a random sample of *Biston betularia* every 25 years at each point in time?"



Another question that reliably elicits transformational misconceptions is as follows: "Imagine that biologists discover a new species of woodpecker that lives in isolation on a 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: (a) a longer beak, (b) a shorter beak, or (c) either a longer beak or a shorter beak; neither is more likely." The correct, variational response is (c), because offspring vary randomly from their parents and are not guaranteed to possess adaptive traits (though those who do are more likely to survive and reproduce). Only a handful of students select this response. Instead, most students select (a), an incorrect response predicated on the transformational assumption that organisms tend to produce offspring that are more adapted to their environment than they were at birth.



These two tasks are but a small sample of the many tasks that reliably elicit untutored, transformational misconceptions in modern-day students. One of the most interesting findings to emerge from this research is that these misconceptions pervade all aspects of students' evolutionary cognition, from their reasoning about microevolutionary topics such as inheritance and adaptation to their reasoning about macroevolutionary topics such as speciation and extinction. These misconceptions are also highly intercorrelated. Students who hold transformational misconceptions of some topics (say, inheritance) tend to hold transformational misconceptions of other topics (say, speciation), and they tend to retain these misconceptions across multiple years of biology instruction, even college-level instruction. These findings suggest that students' transformational views are not isolated errors, implanted by bad teachers or misleading texts, but are instead deep-seated confusions that arise from a pragmatically useful, but fundamentally flawed, view of the biological world—an essentialist view, in place since early childhood if not earlier.

From Misconceptions to Misapprehensions

Misconceptions about evolution abound, but is there any connection between holding such misconceptions and denying the basic fact of evolution? It turns out there is; those who misunderstand *what evolution is* are less likely to accept *that evolution occurs* than those who hold an accurate understanding. In one study, participants were asked to rate their agreement with five statements about evolution on a scale from 1 ("strongly disagree") to 5 ("strongly agree"): (1) "Species have changed over time;" (2) "The species in existence today have not always existed;" (3) "Natural selection is the best explanation for how species adapt to their environment;" (4) "Natural selection is the best explanation for the origin of new species;" and (5) "The origin of human beings does not require a different explanation than the origin of other species." They were also assessed on their understanding of evolution using tasks designed to elicit either correct, variational conceptions or incorrect, transformational conceptions. Comparison of the two measures revealed that participants who held a variational view of evolution were more likely to agree with all five statements—particularly the last statement about *human* evolution—than those who held a transformational view.

This finding has positive implications for the evolution-creation debate: the better the public understands evolution, the less likely it will fight the teaching of evolution in the public schools. To be sure, the correlation between understanding and acceptance is not perfect—some of the variation in who does and does not accept evolution cannot be explained in terms of understanding alone—but it is not trivial either. In fact, in some studies, it has been shown to be as large as the *negative* correlation between a person's religiosity and his or her acceptance of evolution, which implies that increasing the public's understanding of evolution may be a more productive approach to changing current attitudes towards evolution than attacking creationist beliefs directly. It also implies that, if and when the state of evolution education in the U.S. has markedly improved, the American public will come to view the question of whether Intelligent Design should be taught as an alternative to evolution no more favorably than the question of whether astrology should be taught as an alternative to astronomy or alchemy should be taught as an alternative to chemistry. Biology's most valuable theory might finally become too well appreciated to be denied. ■