How Intuitive Beliefs Inoculate Us Against Scientific Ones

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Abstract

Scientific ideas are difficult to teach, difficult to learn, and difficult to accept as true because they contradict our intuitive theories of the world, constructed in childhood but retained across the lifespan, influencing our thinking even as adults. In this chapter, I discuss what intuitive theories are, where they come from, and why they blind us to more accurate theories of the world. I explore two case studies—projectile motion and evolutionary adaptation—to illustrate how intuitive theories are historically entrenched, culturally widespread, resistant to counterevidence, maladaptive for behavior, and seemingly inerasable. I conclude by considering the impact of intuitive theories on human belief and behavior more generally.

Keywords: intuitive theories, belief formation, conceptual development, folk biology, folk physics, science education

Introduction

The coronavirus pandemic has put science denial and science illiteracy at center stage. The pandemic incited widespread misconceptions about how the virus spreads, from consuming Asian foods to touching delivery packages, and widespread misconceptions about how the virus can be treated, including the use of untested drugs and the ingestion of disinfectants. People routinely refused to take the necessary safety precautions, such as wearing masks and social distancing, and refused to get a vaccine when available, sometimes because they refused to believe the virus even exists. Coronavirus deniers have demanded that death certificates be changed in cases where a loved one died of the disease, and they have maintained denial even when dying of the disease themselves (Bordelon, 2021; Rutjens et al., 2021; Villegas, 2021).

This snapshot of the public's rejection of science is part of a larger pattern observed for decades (National Academies, 2016; National Science Board, 2020). Polls reveal that millions of people around the world believe that dinosaurs once coexisted with humans, that the Earth's continents are fixed in place, that antibiotics kill viruses, that atoms are smaller than electrons, and that the sun revolves around the earth. Millions of people also reject the validity of core scientific ideas, such as that the universe began in a Big Bang, that humans are changing the climate, that humans have walked on the moon, that genetically modified foods are safe to eat, and that vaccines are safe to receive.

Science has transformed human society, yielding amazing innovations and technologies, yet scientific ideas are widely misunderstood and misapprehended. Why? The traditional answer is that science must compete with religion, and religion often wins (McCauley, 2011). Religion provides a framework for understanding reality that conflicts with many scientific discoveries, such as the discovery that humans evolved from nonhuman ancestors or the discovery that humans are related to other organisms through common ancestry. Religion posits an alternative explanation for human origins—divine creation—and this explanation pervades many communities, leaving no room for science (Heddy & Nadelson, 2012; Associated Press, 2014).

But religion is not the only impediment to understanding and accepting science. This chapter will focus on a different impediment: intuition. Intuition, like religion, posits alternative explanations for natural phenomena that impede the learning of science, but intuition is more pernicious. It affects everyone, from the religious to the nonreligious, and yields beliefs frequently mistaken for scientific beliefs, as they lack any obvious signs of supernatural causation. But these beliefs can be just as wrong.

Consider the question of human origins. Religion posits that humans are unique, unrelated to other organisms, but intuition concedes that humans are related to at least some other organisms, like monkeys and apes, given obvious resemblances in anatomy and behavior. Still, we don't understand *how* we are related. We intuitively think of the relation as linear and goal-directed: monkeys turned into apes, apes turned into cavemen, and cavemen turned into humans. People may use the word "evolution" to describe this process, but it is a kind of metamorphosis, not evolution. Humans are thought to be related to other primates through direct descent rather than common ancestry, as if chimpanzees are our forebearers rather than our cousins (Novick et al., 2011). Our intuitions about human origins evoke qualitatively different mechanisms than those evoked by modern biology. This chapter will explore such pre-scientific intuitions: their origin, their character, and their impact on how we perceive and interact with the natural world.

Interfering Intuitions

Every day we encounter natural phenomena we must act on or react to, from the heat of our coffee to the speed of an approaching vehicle to the coughing of a sick child. These activities are often mediated by knowledge of how the phenomena operate. Decades of research in cognitive and developmental psychology has revealed that this knowledge is typically organized as coherent networks of cause-effect beliefs, termed “intuitive theories” (Carey, 2009; Gopnik & Wellman, 2012; Shtulman, 2017). They are labeled “theories” because they function similarly to scientific theories, allowing us to predict future events, explain past events, or change the course of present events. Also similar to scientific theories, they are domain-specific; they posit a discrete set of entities and processes intended to explain a discrete range of phenomena.

Yet, unlike scientific theories, intuitive theories posit entities and processes that do not actually exist. Heat is explained as the transfer of an invisible substance, not the vibration of a system’s molecules (Reiner et al., 2000). Motion is explained as the transfer of an internal force, not the interaction of external forces (McCloskey, 1983a). And illness is explained as a consequence of imprudent behavior, not the transmission and replication of microbes (Au et al., 2008). The inferences generated by intuitive theories are thus imprecise or incomplete. They provide us with an adequate understanding of the natural world, for everyday purposes in everyday contexts, but not an accurate one.

Origins of Intuitive Theories

Intuitive theories have three origins: evolution, experience, and culture. Evolution endows us with innate expectations that form the foundations of our theory-building. We have innate expectations about physical objects, for example, including that they are solid, that they are cohesive, and that they move on contact with other objects (Spelke, 1994). When infants are shown events that violate these expectations, through stage magic or sleight hand, they are surprised; they look longer at such events than at closely-matched events that follow expectation. For instance, if infants are shown a fan moving back and forth and then shown an object placed behind the fan, they look longer if the fan continues to move back and forth, as if passing through the object, than if it stops mid-rotation, as if making contact with the object. This pattern of looking times suggests that infants expect that objects cannot pass through one another—that they are solid.

Another source of input into the construction of intuitive theories is experience. Infants may hold innate expectations about solidity, but they have no such expectations about gravity. They show no surprise at watching an object float in mid-air, indicating they must learn through experience that unsupported objects fall (Spelke et al., 1992). Expectations about gravity develop gradually over the first few years of life (Baillargeon et al., 1992; Krist, 2010). Infants must initially learn that contact is required to keep an object from falling. Then they learn where and how contact should be applied, namely, below the object and across its center of mass. Infants refine their beliefs about support as they acquire more experience stacking objects, balancing objects, and observing objects fall.

The final source of input is culture. Humans are one of the only animals that can learn about the world vicariously, through the experiences and discoveries of others. Much of what we learn from other humans is true but not always. We might learn that the earth is round—a fact that is exceedingly difficult to discover on one’s own—but we might also learn, incorrectly, that the earth’s distance from the sun causes the seasons (Dunbar et al., 2007) or the earth’s shadow on the moon causes lunar phases (Trundle et al., 2007). We might learn that disease is caused by germs, but we might also learn that germs can be transmitted by witchcraft or that disease can be cured through magic rituals (Legare & Gelman, 2008). Culture can provide us with scientific ideas, but it can also reinforce non-scientific ideas at the core of our intuitive theories.

Hallmarks of Intuitive Theories

Intuitive theories yield misconceptions about the natural world, but not all misconceptions arise from intuitive theories. The misconception that we use only ten percent of our brain comes from a misinterpretation of early studies of cognitive potential (Boyd, 2008), not a fundamental misunderstanding of brains. What distinguishes intuitive theories from other mistaken beliefs is their consistency—consistency across history, culture, contexts, and experience. This consistency manifests itself as a series of hallmarks, described below. I describe each hallmark on its own and then illustrate them, collectively, with examples from physics (projectile motion) and biology (evolutionary adaptation).

One hallmark is that intuitive theories are historically ancient (Nersessian, 1989). As long as people have been contemplating a particular class of phenomena, they have been constructing intuitive theories of those phenomena. In fact, the first theories formally articulated in the history of science resemble the intuitive theories of non-scientists. Innate expectations about natural kinds, like objects and animals, manifest themselves as attentional and perceptual biases (Carey, 2009), and these biases lead people down the same paths when contemplating the world around them. Intuitive theories are thus reinvented from one generation to the next, with today’s children reinventing the theories of yesterday’s scientists.

Another hallmark of intuitive theories is their prevalence within and across cultures (Legare & Shtulman, 2018). Humans experience natural phenomena in similar ways, regardless of where they live or how they are educated. Phenomena like burning, boiling, floating, and falling are universally observable and thus universally informative. People around the world hit upon the same ideas as they refine and elaborate their innate expectations in light of firsthand experience. While culture adds variation to this process—positing, say, different explanations for illness or different interpretations of the cosmos—this variation is often superficial. Intuitive theories share the same core ideas across cultures.

Intuitive theories are also resistant to counterevidence (Chi, 2005; Vosniadou, 1994). While they explain many commonplace observations, they render us blind to the observations they cannot explain. Objects do not always move in accordance with our intuitive theories of motion, and temperature does not always change in accordance with our intuitive theories of heat, but we remain ignorant of the discrepancies, either because we do not notice them or because we misperceive them. The same is true for classroom instruction. Much of what students are taught in science class contradicts the assumptions of their intuitive theories, but students manage to learn the new information without registering the contradiction, often distorting that information by shoehorning it into a non-scientific framework.

When intuitive theories are applied to novel situations, they can have maladaptive consequences (Au et al., 2008; McCloskey, 1983a). Intuitive theories are constructed to explain the situations we encounter on a regular basis, and they can lead to systematic errors when applied beyond those situations, similar to cognitive heuristics (Kahneman, 2011). Behaviors motivated by intuitive theories often fail to accomplish the goals they are intended to meet, and attitudes engendered by those theories often run counter to science.

Finally, intuitive theories are surprisingly resilient (Shtulman & Valcarcel, 2012). Learning a scientific theory does not erase the intuitive theory we constructed in its absence. Instead, the two theories coexist, causing conflict in situations where they make different predictions or provide different explanations. This conflict has been observed using several methods, from reaction-time studies to priming studies to neuroimaging (Shtulman & Lombrozo, 2016). It has also been observed in several domains, from astronomy to physiology to thermodynamics (Barlev et al., 2017; Shtulman & Valcarcel, 2012), and for people with varying amounts of scientific expertise, including professional scientists (Allaire-Duquette et al., 2021; Kelemen et al., 2013; Shtulman & Harrington, 2016). Theories developed in early childhood thus appear to persist across the lifespan. We can suppress them in favor of scientific knowledge but not supplant them entirely.

The Case of Projectile Motion

Lay beliefs about motion aptly illustrate the five hallmarks of intuitive theories described above. Here, I focus on projectile motion, such as a cannonball fired from a cannon or a ball that has rolled off a table. Such objects fall along parabolic paths, produced by the objects' horizontal velocity in combination with the downward pull of gravity. In fact, gravity is the only force acting on a projectile. A bullet shot horizontally from a gun will hit the ground at the same time as a bullet dropped from an equal height. The shot bullet will cover more ground, but both bullets will fall at the same rate.

Most people don't think of projectile motion in these terms. Instead, they assume that projectiles inherit an internal force when set in motion. This force, traditionally labeled "impetus," keeps the object moving until it dissipates or is overcome by an external force, like friction or gravity. Impetus helps explain motion at a distance, but such motion, from a Newtonian point of view, does not require explanation; only changes in motion (acceleration) require explanation. Still, most people assume the push or pull that launches a projectile is transferred from the launcher into the launched. We call this force "momentum" (which it is not), and we draw it as an upward arrow counteracting the downward arrow of gravity in a force diagram (Clement, 1982). We depict it as larger than gravity at the projectile's ascent, equal to gravity at its apex, and smaller than gravity at its descent. Impetus is a fiction, but it constitutes the core of how we intuitively understand motion.

Historical Precedence

The term "impetus" comes from medieval theories of motion that explicitly appealed to this construct. Medieval physicists were in agreement that impetus exists, but they debated its nature—whether impetus dissipates on its own or only when counteracted by an external force, whether impetus can be curved or is always linear, whether carried objects inherit the impetus of their carriers (McCloskey, 1983b). When medieval physicists drew the paths of projectiles, they depicted them as parabolic at the beginning but flat at the end. They assumed gravity would eventually overtake the projectile's impetus, causing it to fall straight down (McCloskey, 1983a). Despite having observed countless projectiles, they misremembered their trajectories as conforming to their erroneous theories.

The concept of an internal force survived the Middle Ages and permeated the thinking of Renaissance physicists as well, including Galileo. In his treatise *On Motion*, Galileo explains that an object launched into the air "moves upward, provided the impressed motive force is greater than the resisting weight. But since that force is continually weakened, it will finally become so diminished that it will no longer overcome the weight of the body" (McCloskey, 1983b). Even Newton began his career as an impetus theorist, writing in an early notebook that "force must be communicated from the mover into the moved" (Steinberg et al., 1990). Newton would eventually swap impetus for inertia in his laws of motion, but Newton's laws remain largely unappreciated by lay people, who cling steady to impetus.

Widespread Prevalence

When lay people are asked to predict the paths of projectiles, their responses conform to impetus theory more than Newtonian mechanics. If asked to draw the path a ball would take as it rolls off a table, most people draw non-parabolic paths (McCloskey, 1983b). The most common error is to assume the ball will eventually fall straight down, after its impetus has been depleted, but some assume that if the ball is moving fast enough, it will remain horizontal to the ground just after leaving the table, propelled solely by impetus. They thus draw paths similar to the one Wylie Coyote takes when he runs off a cliff without falling (until he looks down).

In contrast to launched projectiles, carried projectiles are not attributed any impetus. People typically assume an object dropped from a plane would fall straight down, neglecting to realize it would have the same horizontal velocity as the plane itself. These kinds of errors have been documented in people of varying ages, cultures, and educational backgrounds (Clark et al., 2011; Fischbein et al., 1989; Halloun & Hestenes, 1985; Howe et al., 2012). Even students who have taken college-level physics courses tend to revert back to impetus theory when drawing motion trajectories (Caramazza et al., 1981).

Resistance to Counterevidence

Projectiles do not trace the paths they are predicted to trace, yet this discrepancy does not lead people to question their theories. Even systematic observation of moving objects in the context of a physics experiment often proves inadequate. Most students think heavy objects fall faster than light ones, given the extra impetus of their weight, and this misconception is impervious to the experience of timing objects as they fall and observing firsthand that objects of different weight fall at the same speed (Renken & Nunez, 2010). Likewise, manipulating the paths of projectiles in a computer microworld has no effect on students' understanding of motion. Students who spend six hours interacting with virtual projectiles reveal as many impetus-based misconceptions on follow-up tests as those who do not (Masson et al., 2011).

Instruction centered on problem sets is equally ineffective. Students who have solved thousands of physics problems reveal as many impetus-based misconceptions as those who have solved only a few hundred (Kim & Pak, 2002). Problem sets help students apply equations to physical situations and use those equations to solve for particular variables, but they do not improve students' qualitative reasoning about motion. There are, of course, methods for improving qualitative reasoning, such as model-based instruction (Vosniadou et al., 2001) and analogy-based instruction (Clement, 1993), but these methods explicitly challenge impetus theories, while also scaffolding the construction of a Newtonian framework. Simply observing motion, or manipulating symbolic representations of motion, does not provide the right kind of impetus for revising impetus theory.

Maladaptive Consequences

Theories of motion are useful not just for predicting motion and explaining motion but also for interacting with moving objects. Our interactions with familiar objects in familiar situations are fine-tuned by experience (diSessa, 1993), but novel interactions can lead to problems. Consider the task of dropping a ball into a trashcan while running past it. The ball cannot be thrown but merely dropped. At what point do you release it? Many people release the ball directly over the trashcan, thinking it wall fall straight down, but the ball has the same horizontal velocity as its carrier and will fly past the trashcan, falling in a parabolic arc (McCloskey, 1983a; see also Kim & Spelke, 1999).

Or consider the task of pushing a hockey puck across a table so it passes through a macaroni-shaped tube on the other side. This feat can be accomplished by sending the puck on a straight path through the tube—the path tangent to the tube's inner curve—but many people push the puck in a curve before releasing it, hoping to impart a curved impetus. Pushed this way, the puck will enter the tube at the wrong angle and get trapped inside (McCloskey, 1983a). We do not expect water to take a curved path if pumped through a curved garden hose because our experience with water and hoses overrides our beliefs about impetus, but in the absence of such experience, impetus prevails (Kaiser et al., 1986).

Enduring Resilience

Even people with extensive instruction in physics have trouble shedding impetus-based misconceptions. In one study (Foisy et al., 2015), physics experts watched pairs of balls fall to the ground—one heavy and one light—and judged whether they fell correctly. The balls fell at the same rate on some trials and at different rates on other trials. Experts were highly accurate at classifying the former as correct and the latter as incorrect, but it took them reliably longer to make the second classification, implying they had to inhibit a latent misconception that heavy objects fall faster than light ones. Indeed, fMRI scans revealed that experts recruited areas of the brain associated with inhibition (in the prefrontal cortex) to a greater extent than novices, who classified the trials incorrectly.

Similar results have been found when scientists are asked to verify counterintuitive statements about object motion (Shtulman & Harrington, 2016). Statements that contradict impetus theory, like "constant force can yield constant rest," are verified more slowly than closely-matched statements that conform to this theory, like "constant acceleration requires constant force." And when scientists verify counterintuitive physics statements, they recruit areas of the brain associated with inhibition (Allaire-Duquette et al., 2021), just as they do when evaluating counterintuitive motion events. These results imply that impetus theory is never truly erased from our brains, though experts learn how to inhibit impetus-based misconceptions.

The Case of Evolutionary Adaptation

Just as Newtonian mechanics defies our physical intuitions, evolution by natural selection defies our biological intuitions. Natural selection explains the long-pondered question of why organisms are so well adapted to their environment. Adaptation is now understood to be a byproduct of differential survival and differential reproduction. Organisms that are randomly born with useful traits out-survive and out-reproduce other members of their species, passing on their traits at higher rates. Over the course of many generations, those traits spread through the population, changing the makeup of the species as a whole.

Intuitively, we think of adaptation in terms of individuals, not populations (Bishop & Anderson, 1990; Shtulman, 2006). We assume that individual organisms will be born more adapted to the environment than their parents were at birth, leading to uniform adaptation across the species. Species are not viewed as populations of unique individuals but as manifestations of an underlying essence (Shtulman & Schulz, 2008). This essence, or inner nature, determines the species' appearance and behavior, while also ensuring that it develops the traits it needs to survive. This essentialist, need-based view of adaptation is more akin to metamorphosis than evolution, as mutation and selection plays no role in the process.

Historical Precedence

Darwin was the first biologist to propose a selection-based theory of evolution. Biologists before Darwin proposed theories that resemble the essentialist theories of non-biologists, as these theories construed species as homogenous types rather than heterogeneous populations (Mayr, 1982). The mechanisms of adaptation posited by such theories operate on species as a whole, changing their essence rather than their composition (Bowler, 1983).

The American paleontologist Edward Cope (1896) proposed that growth and development accelerate from one generation to the next, so that early stages of adaptation are compressed as new stages emerge. The German zoologist Theodor Eimer (1898) proposed that adaptation unfolds along discrete pathways determined by the lawful organization of organic matter. And the French naturalist Jean-Baptiste Lamarck (1809) proposed that organisms acquire characteristics over their lifetime, through habits of use and disuse, and then pass the acquired characteristics to their offspring. These theories are more explicit and more complex than the essentialist theories of lay people, but they share the same assumption that adaptation is about changing individuals rather than culling a population.

Widespread Prevalence

My colleagues and I have developed several tasks for diagnosing intuitive theories of evolution (Shtulman, 2006; Shtulman & Calabi, 2013; Shtulman & Schulz, 2008). One task is asking people to predict the traits of an organism in an environment where it would be useful to possess new traits—traits its parents do not have. For example, imagine biologists discover a new species of woodpecker 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 which of the following: (a) a longer beak, (b) a shorter beak, or (c) either a longer beak or a shorter beak, neither being more likely? The correct answer is (c), because offspring vary randomly from their parents, but most people select (a), reasoning that offspring will inherit the traits they need to survive (see also Ware & Gelman, 2014).

Another task that elicits essentialist misconceptions asks people to predict within-species variation. Participants are told that England's native moth species, *Biston betularia*, evolved darker coloration over the nineteenth century in response to the pollution produced by the Industrial Revolution. They are then asked to predict what the moths would look like if sampled at 25-year intervals by shading five samples of moths, arrayed in rows labeled 1800, 1825, 1850, 1875, and 1900. The correct response is to depict a mutation for darker coloration spreading through the population over time, but the most common response is to shade the moths in each row slightly darker than those in the previous row, varying darkness across generations but not within generations. The latter pattern indicates that participants believe the moths will evolve uniformly, such that every moth is guaranteed to be darker than its parents.

Tasks like these have revealed essentialist misconceptions about evolution in students of all ages and educational backgrounds, including elementary schoolers, middle schoolers, high schoolers, college biology majors, medical school students, preservice biology teachers, and even graduate students in the biological sciences (for reviews, see Gregory, 2009; Pobiner, 2016).

Resistance to Counterevidence

While adaptation is readily observable, the processes that bring it about are not. Natural selection typically occurs over long spans of time and geography. Still, the prerequisites for selection—intraspecies variation and intraspecies competition—often go unnoticed or unappreciated when we observe nature. Many people underestimate trait variability, claiming, for instance, that all giraffes have spots on their coat, not just most giraffes, and that a baby giraffe couldn't be born with a different kind of coat (Shtulman & Schulz, 2008). People also underestimate the frequency of competition within a species relative to cooperation. They judge that members of the same species are more likely to engage in cooperative behaviors, like food sharing, alarm signaling, and allonursing, than to engage in competitive behaviors like cannibalism, siblicide, and coalitional violence (Shtulman, 2019). Competitive behaviors are also underrepresented in the input children receive about the biological world, from children's nature books to conversations with their parents (Shtulman et al., 2021).

Evolutionary misconceptions are also resistant to instruction. Most teaching interventions achieve only minimal success at increasing selection-based reasoning and decreasing essentialist reasoning (Legare et al., 2018). In one study, my colleagues and I assessed evolutionary misconceptions before and after a semester of college-level biology across six different courses. We found that 80% of students exhibited no change in understanding, regardless of whether they were enrolled in an introductory course or an advanced one (Shtulman & Calabi, 2013). While nearly all students passed their courses, they did so without revising their essentialist theories.

Maladaptive Consequences

Evolution is not only widely misunderstood but also widely rejected. Only 15% of Americans accept that humans evolved without any intervention from God. While many accept a theistic view of evolution, where God guided the process, nearly 40% claim that God created humans outright, denying that evolution played any role. These numbers have remained roughly the same over the past four decades (Swift, 2017). While Americans are particularly hostile to evolution, they are not alone. Anti-evolutionary views are common globally and experiencing a resurgence in many secular countries (Blancke et al., 2014).

The appeal of creationism over evolution is due, at least in part, to intuition. Creationism involves the well-understood process of intentional design, whereas evolution involves the not-so-well understood processes of mutation and selection. Creationism also assumes that species are discrete, stable types (a tenet of essentialism), whereas evolution implies they are fluid and ever-changing. Consistent with this analysis, people's understanding of evolution is correlated with their acceptance of evolution as true. People who hold a correct, selection-based understanding are more likely to accept evolution than those who hold an essentialist understanding (Shtulman & Calabi, 2012; Weisberg et al., 2018). The latter is not particularly satisfying, as it provides no explanation for how organisms adapt to their environment other than that they need to adapt, so people who understand evolution in these terms often find creationism more appealing.

Enduring Resilience

Pop quiz: which of the following statements are true? (1) Humans are descended from tree dwelling creatures; (2) Humans are descended from plants; (3) Humans are descended from chimpanzees; (4) Humans are descended from sea dwelling creatures.

The first statement is true and so is the fourth, but you likely experienced a tug to judge the third statement true and the fourth statement false. The third statement coheres with the intuition that chimpanzees evolved into humans, as opposed to both evolving from a common ancestor, and the fourth statement conflicts with the intuition that humans are fundamentally distinct from aquatic creatures, even though all life originated in the sea.

When people are asked to verify these statements under time pressure, statements like (3) and (4) are verified more slowly and less accurately than statements like (1) and (2), indicating that our reasoning about evolution is plagued by essentialist theories, even after many years of science instruction (Shtulman & Valcarcel, 2012; Shtulman & Harrington, 2016). Indeed, teaching-intervention studies find that when people are taught evolutionary principles, they do not relinquish their essentialist misconceptions (Evans et al., 2010; Shtulman et al., 2016). They explain adaptation by appealing to the needs of individual organisms ("they grew longer beaks because they needed longer beaks") alongside selection pressures ("and the longer beaks helped them survive and reproduce"), seeing no contradiction between need-based and selection-based accounts.

Why Intuitive Theories Matter

Projectile motion and evolutionary adaptation are just two of many phenomena understood through the lens of intuitive theories. Our first understanding of matter, energy, gravity, geology, and astronomy are constructed prior to formal schooling, as is our first understanding of life, growth, inheritance, illness, and ancestry (Shtulman, 2017). In all cases, the theories we construct early in life, from casual observation and informal instruction, stay with us throughout development, shaping how we perceive and interact with the world around us. While generally helpful, these theories can lead to systematic misconceptions, maladaptive attitudes, and suboptimal behaviors. Below I discuss ways in which research on intuitive theories can, and should, inform our understanding of belief and behavior more generally.

Theoretical Implications

Intuitive theories have changed our understanding of how we acquire scientific knowledge. This knowledge cannot be represented within an intuitive framework because these frameworks posit a qualitatively different ontology of the domain, which make use of nonexistent constructs like "impetus" and "essence." Learning science requires constructing a new conceptual framework (Carey, 2009; Nersessian, 1989). Concepts that articulate our intuitive theories must be reorganized and reanalyzed to achieve a scientific understanding of the domain. This process, known as conceptual change, takes time and effort (Chi, 2005; Vosniadou, 1994).

The discovery that intuitive theories survive conceptual change has further informed our understanding of science learning (Shtulman & Lombrozo, 2016). Traditional models of conceptual change assume that intuitive theories are erased in the process of restructuring them, similar to how the floorplan of a house is erased as the house is renovated. Knocking down old walls and erecting new walls leaves no trace of the house's original structure. But given that intuitive theories are not erased by scientific ones, a better metaphor for conceptual change is making a palimpsest. Palimpsests are documents in which one text is transcribed on top of another. They were common during the Middle Ages, when parchment was scarce and scribes would reuse old scrolls, scratching off one text to record another. Despite the scribes' best efforts, old transcriptions were usually still readable beneath the newer ones.

In this same way, scientific theories appear to be transcribed over intuitive theories. One theory may be more salient than the other, but both are accessible. Indeed, intuitive theories are preferentially accessed when we are burdened or rushed, implying that they are our default understanding of the natural world (Kelemen et al., 2013). They may be less accurate, but they remain inferentially useful in everyday contexts (Shtulman & Lombrozo, 2016), and they are reinforced by everyday language and perception (Shtulman & Legare, 2020). An object's weight may not affect how quickly it falls, but we frequently see heavy objects fall faster than light ones given air resistance. Likewise, you may fully accept that projectiles have no impetus, but other people think they do, and they talk about impetus when describing motion, using terms like "momentum" and "force of motion." Intuitive theories will always be with us because of their close connection with how we perceive the world and how we talk about it with others.

Pedagogical Implications

Science educators generally recognize that students hold pre-instructional misconceptions, but they might not appreciate the scope and coherence of those misconceptions. A student who holds an alternative theory of the domain presents a different challenge than one who holds a miscellaneous collection of false beliefs. The alternative theory must be acknowledged and refuted. Instruction that fails to make contact with intuitive theories leads to impasses in communication and systematic misinterpretations of the course material (Carey, 2000; Chi, 2005; Vosniadou, 1994).

Successful instruction will allow students to reason about the domain from a scientific point of view but will not erase their prior theories, as discussed above. This outcome suggests that science educators should not focus on eliminating intuitive ideas but on helping students identify such ideas and think critically about them, along with the attitudes and behaviors they inform. Intuitive theories will conflict with scientific theories long after instruction, but students can learn to prioritize the latter by reflecting on their own conceptual understanding (Vosniadou et al., 2001). Cognitive reflection, or thinking about one's thinking, has been shown to facilitate science learning and science understanding (Young & Shtulman, 2020), and students could benefit from instruction that promotes this skill.

Social Implications

Intuitive theories also impact our health, wealth, and wellbeing. We routinely make decisions about what to buy or how to spend our time that would be better informed by science than intuition. These decisions include whether to eat genetically modified foods or drink unpasteurized milk, whether to get vaccinated or donate organs, how to increase fertility or decrease body fat, how to interpret a diagnostic test or treat an infection. Intuition can lead people to consider the wrong information or value the wrong outcomes.

Intuition is also a poor guide for making decisions about public policy, such as what organizations to support and what legislation to endorse. As a society, we face many global challenges related to science, including how to curb climate change, how to fight disease, how to power our cities, and how to feed the poor. These challenges require more than just understanding the costs and benefits of a policy proposal; they also require understanding the science behind the proposal. Many people oppose genetically-modified foods not because they are concerned about the politics of agrotechnology but because they view genetic engineering as violating the purity of an organism's essence (Blancke et al., 2015). Likewise, many oppose vaccines not because they are ignorant of the dangers of infectious disease but because they view vaccines as lethal chemicals rather than stimulants to the immune system (Jee et al., 2015). Public policies that rest on counter-scientific intuitions are likely to do more harm than good.

Conclusion

In Galileo's writings on astronomy, he decreed that "all truths are easy to understand once they are discovered; the point is to discover them" (Galilei, 1632). But Galileo was wrong. Research on scientific cognition reveals that many truths are not easy to understand because they defy our gut intuitions about how the world works. These intuitions emerge early in development and resist remediation by counterevidence and counterinstruction, shaping our reasoning across the lifespan. If we want to embrace the benefits of science, for ourselves and for our society, we must acknowledge the prevalence of intuitive theories and think critically about their impact on our attitudes and behaviors.

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