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WHY DO LOGICALLY INCOMPATIBLE BELIEFS SEEM PSYCHOLOGICALLY COMPATIBLE?

Science, Pseudoscience, Religion, and Superstition

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Introduction

Humans' understanding of science is at once impressive and appalling. Humans, as a species, have uncovered the hidden causes of most natural phenomena, from rainbows to influenza to earthquakes. Unobservable causal agents, like germs and genes, have been discovered and studied and are now familiar to everyone, scientists and nonscientists alike. Even children are familiar with germs and genes, despite our ignorance of these entities for the majority of human history. On the other hand, individual humans often lack an understanding of core scientific ideas – ideas that most educated adults have encountered in books, museums, and classes but still fail to understand. National polls in the United States and other countries have revealed that millions of people believe that dinosaurs coexisted with humans, that atoms are smaller than electrons, and that the earth's continents are fixed in place. Likewise, millions are skeptical that genetically modified foods are safe to eat, that climate change is caused by humans, and that humans evolved from non-human ancestors (National Science Board, 2018; Pew Research Center, 2015).

Exposure to scientific ideas does not guarantee their comprehension or acceptance. While there are several reasons why scientific ideas remain elusive, one primary reason is that they conflict with the explanations we devise on our own about how the world works (Carey, 2009; Shtulman, 2017; Vosniadou, 1994). These explanations, termed "folk theories" or "intuitive theories," are typically constructed in childhood prior to any formal instruction in the relevant domain. They are derived from a combination of inputs – innate concepts, empirical observations, culturally transmitted beliefs – and they serve the same function as scientific theories, namely, furnishing us with systematic and coherent inferences about natural phenomena (though see DiSessa, 2008, for an alternative view of how conceptual knowledge is structured).

Intuitive theories allow us to interpret and intervene on the phenomena they cover, but they also act as an impediment to learning more accurate theories of those phenomena. In the domain of evolution, for instance, children form creationist theories of the origin of species that impede learning about common descent (Blancke, De Smedt, De Cruz, Boudry, & Braeckman, 2012), and they construct essentialist theories of biological adaptation that impede learning about natural selection (Shtulman & Calabi, 2012). Intuitive theories impede the learning of scientific theories because they carve the world into entities and processes that do not actually exist – entities and processes that better align with how we perceive reality than with reality itself (Thagard, 2014). Learning a scientific theory thus requires learning a new ontology, or abstract causal framework.

Learning a new ontology is quite difficult (Slotta & Chi, 2006), but it is not the only difficulty posed by intuitive theories. Another difficulty is avoiding the influence of intuitive theories even after one has learned the new ontology. Several lines of research indicate that intuitive theories are never fully replaced by scientific theories. Rather, the two theories coexist in the mind of the learner, providing competing interpretations of the same phenomena (Barlev, Mermelstein, & German, 2017; Foisy, Potvin, Riopel, & Masson, 2015; Goldberg & Thompson-Schill, 2009; Kelemen, Rottman, & Seston, 2013; Merz, Dietsch, & Schneider, 2016; Shtulman & Valcarcel, 2012).

Consider illness. The scientific explanation for illness is germs – microscopic organisms that invade a body and hijack its resources to further their own replication and survival – but learning about germs does not displace other, more intuitive ways of thinking about illness. We also explain illness as the result of behaviors that are not actually associated with germ transmission or germ reproduction, such as going out into the cold without a jacket or going to sleep with wet hair (Au et al., 2008). We may evoke supernatural causes as well, pointing to karma if we are Indian (Raman & Gelman, 2004), witchcraft if we are African (Legare & Gelman, 2008), or God if we are Judeo-Christian (Laurin & Kay, 2017).

This chapter discusses several phenomena for which scientific explanations coexist with non-scientific ones. We explore a range of nonscientific explanations, including religious explanations (e.g., attributing illness to God), superstitious explanations (e.g., attributing illness to witchcraft), and pseudoscientific explanations (e.g., attributing illness to behaviors unrelated to germs). We argue that the ubiquity of coexisting explanations across cultures and domains implies that coexistence is an inherent feature of conceptual representations and a regular impediment to understanding science. We conclude by considering several questions about the origin and dynamics of coexistence that may shed further light on our understanding and acceptance of scientific explanations.

Coordinating Multiple Representations of the Natural World

Natural phenomena can be mentally represented in several ways. Sometimes these representations are compatible with one another, and sometimes they are not. Representations at different levels of abstraction are frequently compatible, as when we represent the diffusion of a gas at both the macroscopic level (in terms of pressure and volume) and the microscopic level (in terms of molecular interactions; Chi, Roscoe, Slotta, Roy, & Chase, 2012). Likewise, representations that evoke different scales of causation are frequently compatible, as when we represent sexual behavior as both an evolved adaptation (for perpetuating one's genes) and an environmentally-triggered response (in the presence of potential mates; Tinbergen, 1963).

Representations that conflict are those that evoke mutually incompatible ontologies – ontologies that operate at the same level of abstraction and on the same scale of causation. Those who hold incompatible ontologies are sometimes aware of the conflict, but in many cases that conflict is implicit, revealed only when we are asked to reason about the ontologically relevant phenomena under time pressure or cognitive load. The fact that we are often unaware of holding mutually incompatible ontologies underscores the pervasiveness of this phenomenon and raises questions about the psychological status of scientific explanations, which are almost always learned after we have first learned a religious, superstitious, or pseudoscientific explanation. Such explanations may vary in their surface-level features, but they share the deeper commonality of arising from an intuitive theory that is ontologically distinct from scientists' current theory of the domain.

Coexistence of Science and Pseudoscience

Explanations for natural phenomena that do not conform to science but also do not evoke supernatural causes are termed here "pseudoscientific." These explanations are often endorsed by children, who construct them prior to formal schooling, and they were once endorsed even by scientists, prior to the discoveries that displaced them (Shtulman, 2017). Consider intuitive models of the solar system. Everyday observation of the sun, moon, and earth suggests that the sun and moon are in motion but the earth is not. These observations motivate a geocentric model of the solar system, in which day and night are caused by the sun and moon orbiting the earth in alternation. Most children hold this model, as did most adults centuries ago (Vosniadou & Brewer, 1994).

Today, most adults know that the sun is at the center of the solar system, not the earth, and that day and night are caused by the earth's motion, not the sun's or the moon's. Under time pressure, however, adults reveal evidence of harboring geocentric models. In recent studies by Shtulman and colleagues (Shtulman & Harrington, 2016; Shtulman & Valcarcel, 2012), college-educated adults were asked to verify two types of scientific statements: those that accord with intuition and those that conflict with it. The statements covered ten domains of knowledge, including astronomy. In the domain of astronomy, participants verified statements about planets, stars, lunar phases, the seasons, and the solar system. Participants' verifications for intuitive statements, like "the moon revolves around the earth," were compared to their verifications for closely-matched counterintuitive statements, like "the earth revolves around the sun." Overall, participants were less accurate at verifying counterintuitive statements relative to intuitive ones, and when they verified counterintuitive statements correctly, they took longer to do than to verify intuitive statements of the same form.

Similar results have been documented in the domain of biology, with respect to adults' conceptions of life. Biologists identify life with the capacity to engage in metabolic processing, but young children identify life with self-directed motion (Piaget, 1929). That is, young children construct intuitive theories of life that correctly classify animals as alive (because animals move on their own) but incorrectly classify plants as not alive (because plants do not move on their own, at least not to the naked eye). By age ten, most children have learned to associate life with metabolic activities rather than motion (Stavy & Wax, 1989), but this knowledge does not erase the previous misconception that only moving things are alive. Under time pressure, adolescents and adults often misclassify plants as not alive. They also misclassify nonliving objects that move on their own, like the sun and the clouds, as alive (Babai, Sekal, & Stavy, 2010; Goldberg & Thompson-Schill, 2009; Young et al., 2018).

An even more striking demonstration of the resilience of motion-based, or "animistic," theories of life comes from studies of how Alzheimer's Disease affects biological reasoning (Zaitchik & Solomon, 2008). When individuals with Alzheimer's Disease are asked to name some things that are alive, they frequently mention animals but rarely mention plants. When asked about the life status of natural phenomena, like fire and wind, they typically judge them to be alive, even when they are given no time limit for responding. And when asked for a definition of life, they cite the capacity for motion more often than metabolic activities, like breathing or growing. These impairments are not just the result of age; elderly adults who are not afflicted by Alzheimer's Disease cite plants as examples of living things, judge natural phenomena as not alive, and define life in metabolic term. The cognitive impairments wrought by Alzheimer's Disease thus appear to strip away scientific knowledge of life, revealing an intuitive theory of life constructed decades earlier, when these elderly adults were children.

Coexistence of Science and Religion

A dominant source of non-scientific explanations is religion. Religious explanations for natural phenomena typically evoke supernatural agents (like gods, spirits, and ancestors), which, in turn, evoke our intuitions about agents in general – that is, our theory of mind (Heiphetz, Lane, Waytz, & Young, 2016). Consider the difference between scientific and religious explanations for why organisms are adapted to their environment. The scientific explanation – evolution by natural selection – views adaptation as the selective propagation of randomly-occurring mutations across many generations of an interbreeding population, whereas the most popular religious explanation – creationism – views adaptation as the product of a divine creator. Evolutionary explanations for adaptation require coordinating several unfamiliar processes: mutation, heredity, differential survival, differential reproduction, population change. Creationist explanations, on the other hand, typically tap into a single, well-understood process: intentional design.

Because creationist explanations are intuitively compelling, they are difficult to dispel. Interventions that have proven successful at teaching evolutionary principles rarely uproot inclinations toward creationism. For instance, museum exhibits that succeed at increasing visitors' scientific understanding of micro-evolutionary change have no effect on their endorsement of creationist explanations for those changes (Spiegel et al., 2012). Likewise, storybooks that succeed at teaching elementary schoolers selection-based explanations for the origin of biological traits have no effect on their endorsement of creationist explanations for those traits (Shtulman, Neal, & Lindquist, 2016). If people are allowed to endorse both evolutionary and creationist accounts of biological change, they do.

In this same vein, people who endorse evolutionary explanations for life can be induced to doubt those explanations in anxiety-provoking situations, such as when contemplating their own mortality. In a study by Tracy, Hart, and Martens (2011), participants read and evaluated two passages: an argument in favor of an evolutionary explanation for life, written by biologist Richard Dawkins, and an argument in favor of a creationist explanation, written by the intelligent design proponent Michael Behe. Half of the participants were primed to think about their mortality prior to reading the passages, and half were primed to think about an unpleasant experience other than death. The mortality prime decreased participants' ratings of the quality and truthfulness of the evolutionary passage and increased their ratings of the quality and truthfulness of the creationist passage, relative to the non-mortality prime. These changes held regardless of how educated the participants were, how religious they were, and how strongly they accepted evolution prior to the study.

Similar results have been obtained in comparing people's endorsement of religious and scientific explanations for the origin of the universe: God vs. the Big Bang. In a study by Preston and Epley (2009), participants read a passage about the Big Bang that either affirmed or challenged the theory's validity. They then completed a speeded categorization task in which the concepts *God* and *science* were implicitly primed. In this task, participants categorized adjectives like "excellent" and "awful" as positive or negative as quickly as possible. On some trials, the adjectives were preceded by the word "science" for 15 milliseconds or the word "God" for 15 milliseconds – too quickly for participants to consciously register their appearance.

Participants who read the passage that affirmed the validity of the Big Bang were faster to respond to positive adjectives than negative adjectives when those adjectives were preceded by the word "science," whereas participants who read the passage that challenged the validity of the Big Bang were faster to respond to positive adjectives than negative adjectives when preceded by the word "God." In other words, priming participants to think of the Big Bang as valid rendered their implicit associations with science more positive and their implicit associations with God less positive, whereas priming participants to think of the Big Bang as invalid had the opposite effect. These findings imply that people have access to both religious and scientific explanations and can be induced to shift their evaluations of those explanations by subtle contextual cues. These findings also imply that people view religious and scientific explanations as conflicting, because priming participants to value one explanation led them to devalue the other.

Coexistence of Science and Superstition

The two types of non-scientific explanations discussed thus far – pseudoscientific explanations and religious explanations – differ in their form of causation (natural vs. supernatural), as well as their relation to cultural institutions. Religious explanations are embedded in a coherent, institutionally-endorsed narrative about the origins of the world and humans' place within it, whereas pseudoscientific explanations are typically constructed on one's own and are not part of the doctrines or teachings of any institution. Superstitious explanations fall between these two extremes. They evoke supernatural causes, like religious explanations, but they are constructed and transmitted through informal channels, like pseudoscientific explanations.

Illness is a domain in which superstitious explanations proliferate, possibly because of the anxiety aroused by existential threats to oneself and one's loved ones. The particular superstitions vary by culture. South Africans often appeal to curses cast by jealous neighbors and displeased ancestors, at least for serious illnesses like AIDS (Legare & Gelman, 2008). South Asians appeal to imminent justice, or the conviction that bad things happen to bad people (Raman & Gelman, 2004). Vietnamese individuals appeal to evil spirits and magic spells, fixating on omens of misfortune such as broken mirrors, haunted houses, or graveyards (Nguyen & Rosengren, 2004). Critically, appeals to superstition do not occur in isolation; they typically accompany appeals to biological factors, such as contact with a disease-infected person or disease-infected object. Individuals who appeal to superstition also typically know a fair amount about the transmission, symptoms, and treatment of the target disease (Legare & Gelman, 2008). Superstition is embraced in spite of, not in place of, biological knowledge.

Teleology is another form of cognition that can take on supernatural overtones. Teleology is explaining something in terms of its end, purpose, or goal (Lennox & Kampourakis, 2013), as when we appeal to sight as the explanation for eyes or flight as the explanation for wings. Kelemen (1999) has shown that children are more "promiscuous" with their teleological explanations than adults are. Whereas both children and adults provide teleological explanations for human artifacts (e.g., pencils are "for writing") and biological parts (e.g., ears are "for hearing"), only children provide teleological explanations for whole organisms (e.g., birds are "for flying") and naturally occurring objects (e.g., clouds are "for raining"). Children become more selective in their use of teleology by early adolescence, but that selectivity is tenuous.

When college-educated adults are asked to judge the acceptability of teleological explanations under speeded conditions, they tend to accept explanations they would normally reject, such as "birds are for flying" and "clouds are for raining" (Kelemen et al., 2013). Moreover, just as Alzheimer's patients willingly endorse animistic conceptions of life, they also willingly endorse teleological conceptions of nature. Alzheimer's patients claim that teleological explanations for natural phenomena, like "rain exists so that plants and animals have water for drinking," are not only acceptable but are actually preferable to mechanistic explanations, like "rain exists because water condenses in clouds and forms droplets" (Lombrozo, Kelemen, & Zaitchik, 2007).

Teleology is also regularly evoked to explain events, particularly the events in one's own life. Most college-educated adults eschew the possibility that life events transpire at random and believe instead that "everything happens for a reason" (Banerjee & Bloom, 2014; Norenzayan & Lee, 2010; Svedholm, Lindeman, & Lipsanen, 2010). Emotionally significant events (e.g., meeting a future spouse) and statistically unlikely events (e.g., holding a royal flush in poker) are attributed to fate and assigned meaning, even by adults who are not religious and do not believe in God. These adults deny that supernatural agents are responsible for life events, yet they cannot shake the idea that such events portend larger patterns of meaning.

Coexistence Is a Cognitive Default

The studies reviewed earlier indicate that scientific explanations coexist with non-scientific ones in a variety of domains, from astronomy to evolution to illness. Coexistence has been observed in other domains as well, including motion (Foisy, et al., 2015), matter (Potvin, Masson, Lafortune, & Cyr, 2015), electricity (Masson, Potvin, Riopel, & Foisy, 2014), cosmography (Carbon, 2010), and neuroscience (Preston, Ritter, & Hepler, 2013). In any domain where intuitive theories precede scientific theories, the former appears to survive the latter. This finding has been observed using behavioral methods, such as those described above, as well as neurocognitive methods. Using function magnetic resonance imaging (fMRI), researchers have observed that physics experts' ability to judge intuitively plausible events, like a heavy object falling to the ground faster than a lighter object, as physically impossible requires heightened activity in the anterior cingulate cortex and prefrontal cortex (Foisy et al., 2015; Masson et al., 2014). These areas of the brain are involved in inhibition, and their activation suggests that physics experts must inhibit latent misconceptions in order to respond in accordance with known physical principles.

The coexistence of scientific and non-scientific explanations appears to be pervasive across cultures as well. This phenomenon has been observed most extensively in American and European samples but has also been observed in samples from China (Rottman, Zhu, Wang, Seston Schillaci, Clark, & Kelemen, 2017), India (Raman & Gelman, 2004), Vietnam (Nguyen & Rosengren, 2004), Mexico (Rosengren, Miller, Gutiérrez, Chow, Schein, & Anderson, 2014), South Africa (Legare & Gelman, 2008), Madagascar (Astuti & Harris, 2008), and Vanuatu (Watson-Jones, Busch, Harris, & Legare, 2017). People in different cultures construct different intuitive theories, but the resilience of intuitive theories in the face of scientific theories appears to be universal.

Conflict between intuitive and scientific theories has been observed across the lifespan as well, in children (Legare, Evans, Rosengren, & Harris, 2012), adolescents (Babai et al., 2010), young adults (Shtulman & Valcarcel, 2012), and elderly adults (Barlev, Mermelstein, & German, 2018). It has even been observed in populations with extensive scientific knowledge, including high school science teachers (Potvin & Cyr, 2017) and college science professors (Shtulman & Harrington, 2016). Under time pressure, biology professors are prone to judge plants as not alive (Goldberg & Thompson-Schill, 2009), and physics professors are prone to endorse teleological explanations for natural phenomena (Kelemen et al., 2013). This finding – that even professional scientists harbor non-scientific explanations – suggests that coexistence is an inevitable byproduct of acquiring more than one representation of the same domain. Professional scientists may deploy scientific theories on a daily basis, but that practice does not appear to erase, or even weaken, intuitive theories of the same domain.

Questions About the Origin and Nature of Explanatory Coexistence

The phenomenon of coexisting explanations has been well documented, but its causes and consequences are not well understood. Here we consider questions about the origin of coexistence and its effects on everyday reasoning, with the goal of identifying directions for future research.

Does Coexistence Require Belief?

In some cases of coexistence, individuals explicitly endorse incompatible explanations, whereas in others, individuals show evidence of mentally representing incompatible explanations but endorse only one. When South Africans point to both witchcraft and unprotected sex as reasons for contracting AIDS or when museum visitors endorse both creationism and evolution as explanations for the origin of species, they are exhibiting an explicit form of coexistence reasoning. On the other hand, when biologists take longer to classify plants as alive than to classify animals as alive or when physicists endorse teleological explanations for natural phenomena under time pressure, they presumably do not endorse the non-scientific ideas their behavior has betrayed. Biologists and physicists may represent nonscientific ideas at an implicit level, but they have the knowledge and knowhow to reject those ideas at an explicit level.

That said, biologists and physicists were once children who lacked scientific knowledge and believed nonscientific ideas, accepting those ideas as true descriptions of reality. Does a nonscientific idea have to be believed, at some point in development, to survive the acquisition of a scientific alternative? Or can an idea that was entertained but never accepted as true still cause cognitive conflict in the relevant domain?

Research on the coexistence of scientific and supernatural explanations suggests that coexistence can, in fact, occur in the absence of belief. Atheists, after all, show signs of representing the supernatural ideas that all life events are meaningful (Banerjee & Bloom, 2014), that people continue to think and feel after they have died (Bering, 2002), and that animals, plants, and other natural kinds were purposely created by some kind of being (Järnefelt, Canfield, & Kelemen, 2015). These findings suggest that the nonscientific ideas prevalent in one's culture may be mentally represented as viable alternatives to science, even if those ideas are not personally endorsed.

However, it's not clear that the atheists in these studies have always been atheists. Additional research is needed to verify that explanations one has never endorsed can indeed compete with the explanations one currently endorses. Such research could introduce participants to novel nonscientific explanations (e.g., magnet therapy for treating chronic pain) and then manipulate the believability of those explanations, though such a manipulation would likely require sustained reinforcement of the target explanation to prove effective. Another possibility would be to explore the onset of coexistence in cultures that differ in their baseline levels of acceptance for some nonscientific explanation (e.g., creationism, as endorsed in Scandinavia vs. the Middle East), with the goal of disentangling the roles of personal acceptance and cultural acceptance on the cognitive conflict induced by coexisting explanations.

Does Coexistence Require Comprehension?

In research by Shtulman and colleagues (Shtulman & Harrington, 2016; Shtulman & Valcarcel, 2012), the presence of coexistence was explored in ten domains: astronomy, evolution, fractions, genetics, germs, matter, mechanics, physiology, thermodynamics, and waves. Using a speeded sentence-verification task (described above), Shtulman and colleagues documented cognitive conflict between intuitive and scientific theories in all ten domains. In some domains, the relevant scientific concepts are acquired early in life, such as physiology (Hatano & Inagaki, 1994) and matter (Smith, 2007), whereas in others the relevant concepts are acquired late in life, such as evolution (Shtulman & Calabi, 2013) and mechanics (Halloun & Hestenes, 1985). The discovery of coexistence in the latter domains was unexpected, given that most college-educated adults exhibit only partial understanding of these domains on unspeeded, comprehensive assessments. Nevertheless, partial understanding appears to be sufficient for creating cognitive conflict between scientific and intuitive theories.

Consistent with this finding, research in science education has found that coexistence emerges early in instruction. Studies that have explored the efficacy of various teaching interventions have found that increased use of scientific concepts is not necessarily accompanied by decreased use of intuitive concepts (Coley, Arenson, Xu, & Tanner, 2017; Nehm & Reilly, 2007; Schneider & Hardy, 2013; Shtulman et al., 2016; Spiegel et al., 2012). Successful instruction appears to increase the number of reasoning strategies rather than the accuracy of a single strategy, and this result can occur after a single lesson (see Siegler, 1998, for parallel findings in the development of procedural knowledge). A single lesson may not be enough time for students to fully comprehend a new scientific explanation, but it may be enough for students to appreciate the utility of that explanation.

Utility has been cited as the prime reason intuitive theories persist in the face of scientific ones (Ohlsson, 2009; Shtulman & Lombrozo, 2016), and utility may also be the reason that scientific theories begin to conflict with intuitive theories before they are fully understood. Further research is needed to explore the conditions under which a scientific explanation is transformed from a hypothetical idea to a viable alternative account. The utility of a scientific explanation may have to cross some threshold before it begins to conflict with a more intuitive explanation. Alternatively, the utility of an intuitive explanation may have to drop below some threshold before a scientific explanation can begin to compete with it.

Are Coexisting Explanations Activated Serially or In Parallel?

To date, the most common measure of coexistence is a decrease in the speed or accuracy of scientific reasoning when that reasoning conflicts with intuitive reasoning (Babai et al., 2010; Barlev et al., 2017, 2018; Foisy et al., 2015; Goldberg & Thompson-Schill, 2009; Kelemen et al., 2013; Merz et al., 2016; Potvin et al., 2015; Potvin & Cyr, 2017; Rottman et al., 2017; Shtulman & Harrington, 2016; Shtulman & Valcarcel, 2012). Findings of this nature imply that intuitive responses have to be inhibited in order for scientific ones to be articulated, but the dynamics of this process are not yet understood. Scientific responses may be activated in parallel with intuitive ones, or they may be activated only after the intuitive ones have been inhibited.

One reason to favor a parallel-activation account is that the conflict between science and intuition is seemingly impervious to expertise (Goldberg & Thompson-Schill, 2009; Kelemen et al., 2013; Shtulman & Harrington, 2016). If experts routinely deploy scientific concepts, then those concepts should become more closely associated with science-relevant contexts than their intuitive counterparts and should not have to await activation following the inhibition of an erroneous ideas. Indeed, interventions that increase people's accuracy at verifying counterintuitive scientific ideas have no effect on the speed of those verifications (Young et al., 2018), implying that the activation of erroneous ideas is inevitable.

On the other hand, research on the processing dynamics of a similar task – the Cognitive Reflection Test (CRT; Frederick, 2005) – reveals that intuitive reasoning has to be inhibited before analytic reasoning can be engaged. The CRT measures a person's tendency to reflect on the validity of intuitive, yet inaccurate, responses and override those responses in favor of more accurate ones. Consider this item: "A bat and a ball cost $1.10 in total. The bat costs $1 more than ball. How much does the ball cost?" Many adults provide the intuitive response of 10 cents, defaulting to simple subtraction, yet the correct answer is 5 cents (because the bat must cost $1.05 if the sum of their costs is $1.10 and the difference $1.00). When the response options "5 cents" and "10 cents" are displayed on opposite sides of a computer screen and must be selected using a mouse, respondents' mouse trajectories reveal an initial pull toward the intuitive option even when the correct option is ultimately selected (Travers, Rolison, & Feeney, 2016). This result implies that the intuitive response is activated first, and the correct response is activated second, following inhibition of the intuitive response. Measures of online processing, such as mouse tracking or eye tracking, could clarify whether the conflict between intuitive theories and scientific theories follows the same pattern as the conflict between intuitive reasoning and analytic reasoning, as elicited by the CRT.

What Is the Role of Executive Function in Prioritizing Science?

When cognitive conflict arises, we typically resolve that conflict though executive function (Koechlin & Summerfield, 2007). Executive function refers to a suite of domain-general abilities – working memory, inhibitory control, comprehension monitoring, set shifting – and its operation has been linked to science learning. Children with higher executive function construct biological theories of life, death, and the body earlier than those with lower executive function (Zaitchik, Iqbal, & Carey, 2014), and they profit more from instruction on these topics as well (Bascandziev, Tardiff, Zaitchik, & Carey, 2018). Conversely, the loss of executive function has been linked to the loss of scientific knowledge and the reemergence of childlike misconceptions, such as the misconception that the sun and the wind are alive but plants are not (Tardiff, Bascandziev, Sandor, Carey, & Zaitchik, 2017).

Executive function may also be linked to the prioritization of scientific theories over intuitive theories when those theories compete to provide inferences about the same phenomena. Inhibitory control is an aspect of executive function, and brain networks implicated in inhibitory control are activated when science experts access counterintuitive scientific ideas, as noted earlier (Foisy et al., 2015; Masson et al., 2014). Behavioral measures of inhibitory control have not, however, revealed consistent associations between inhibition and the ability to prioritize scientific responses over intuitive responses. At least three studies (Barlev et al., 2017; Barlev et al., 2018; Kelemen et al., 2013) have failed to observe correlations between speeded scientific-reasoning tasks and the Stroop task – a measure of cognitive control in which participants must name the color of ink used to print words denoting a different color (e.g., "red" printed in blue ink) – though another study (Vosniadou et al., 2018) did document such correlations.

This pattern of results suggests that inhibitory control may be less important than other aspects of executive function for prioritizing scientific responses over nonscientific ones. Alternatively, inhibition may be important, but the Stroop task measures the wrong type of inhibition. The Stroop task measures inhibition of perceptual information, whereas a task that measures the inhibition of conceptual information, such as the CRT, may be more appropriate for assessing the inhibition needed to coordinate competing conceptual representations. Individuals with high CRT scores do perform better on tests of science understanding than those with low CRT scores (Shtulman & McCallum, 2014; Young & Shtulman, 2018), but it's unclear whether cognitive reflection is needed to prioritize scientific ideas over intuitive ideas or merely to learn scientific ideas in the first place.

Conclusions

Psychologists have long observed the prevalence and popularity of pseudoscientific, religious, and superstitious explanations, but those explanations were presumed to occupy the minds of people ignorant of science or actively opposed to science. That presumption has now been overturned. Findings from cognitive psychology, developmental psychology, cognitive neuroscience, and science education indicate that scientific explanations coexist with nonscientific ones in the same minds – even the minds of the most scientifically literate adults. The coexistence of scientific and nonscientific explanations appears to be an inherent feature of how humans represent and reason about the natural world. Studying this phenomenon promises to refine our theories of conceptual representation, as well as improve the teaching and learning of counterintuitive scientific ideas.

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