10 When Competing Explanations Converge

Coronavirus as a Case Study for Why Scientific Explanations Coexist With Folk Explanations

Andrew Shtulman

Introduction

When someone falls ill, with a fever and a cough, what might be the cause? A virus is probably the first thought that comes to mind, but other thoughts might come to mind as well. Perhaps the ill person ingested a toxic substance or ate spoiled food. Perhaps they spent too much time outside in the cold or got caught in a downpour. They may be unduly stressed or fatigued. Their vital energy may not be flowing properly, or their internal chemistry may be out of balance. They may have created bad karma by lying or cheating, or they may have done something unlucky, like break a mirror or walk under a ladder. God might be punishing them for misdeeds, or a jealous neighbor might have cursed them.

Natural phenomena like illness lend themselves to many explanations. Knowing a scientific explanation does not mitigate the influence of other explanations, derived through casual observation or conversation. These "folk" explanations are grounded in intuitive theories, or models of the world constructed prior to learning a scientific theory (Carey, 2009; Gopnik & Wellman, 2012; Vosniadou, 1994). Intuitive theories, like scientific theories, provide an interpretive framework for making sense of natural phenomena. They help us predict future events, explain past events, contemplate alternative events, and change the outcome of present events. Yet unlike scientific theories, they are imprecise and incomplete and thus provide only an approximate understanding of the domain.

Intuitive theories have been shown to impede the learning of scientific theories because they posit a qualitatively different ontology for understanding domain-relevant phenomena (Chi, 2005; Vosniadou, 1994). They carve up the domain into entities and processes that play no role in the scientific theory. Intuitive theories of motion, for instance, posit the

Author Note: This research was supported by James S. McDonnell Foundation grant 220020425. Correspondence should be sent to Andrew Shtulman, Department of Psychology, Occidental College, Los Angeles, CA 90041, shtulman@oxy.edu.

DOI: 10.4324/9781003184324-14

false concept of an internal motive force, or impetus; intuitive theories of growth posit the false concept of an immutable inner nature, or essence; and intuitive theories of life posit the false concept of an internal current of energy, or life force (Shtulman, 2017). Because the concepts of an intuitive theory cannot be aligned with those of a scientific theory, it was long assumed that the former must be restructured to acquire the latter. But recent research suggests that scientific theories, though difficult to acquire, are acquired alongside intuitive ones, leaving both theories intact. Rather than revise and refine a single theory of the domain, we construct multiple theories.

The coexistence of intuitive and scientific theories has been revealed through many methods in many populations (for reviews, see Legare & Shtulman, 2018; Shtulman & Lombrozo, 2016). When providing explanations, people often appeal to intuitive causes and scientific causes in the same breath, and they willingly endorse both types of causes if suggested as possibilities (Evans et al., 2010). When verifying the accuracy of scientific statements, they take longer to verify statements that conflict with intuitive theories (e.g., "the earth revolves around the sun") than to verify closely matched statements that conform to those theories (e.g., "the moon revolves around the earth;" Shtulman & Valcarcel, 2012). Priming people to adopt an intuitive mindset reduces their endorsement of scientific explanations, whereas priming them to adopt a scientific mindset reduces their endorsement of folk explanations (Preston & Epley, 2009). Manipulating time constraints has a similar effect; people in a hurry endorse folk explanations they would normally reject and reject scientific explanations they would normally accept (Barlev et al., 2017). And as people decide between scientific and folk explanations, they recruit areas of the brain associated with inhibition and error-monitoring (Allaire-Duquette et al., 2021).

These findings raise a question of both practical and theoretical importance: why do intuitive theories persist? Why do people continue to rely on explanatory considerations deemed inaccurate or irrelevant by their own scientific knowledge? Here, I address these questions by considering when and how folk explanations are deployed. I argue that folk explanations are retained because, in many situations, they remain as useful as scientific ones. While scientific theories surpass intuitive theories in scope and power, the average person does not require additional scope or power for making sense of everyday phenomena. Such phenomena are the reasons why intuitive theories were constructed in the first place.

I explore this proposal in the context of the coronavirus pandemic, examining how intuitive theories of illness support an understanding of coronavirus risks and precautions that overlaps with a scientific understanding. Intuitive theories of illness appear to converge with scientific theories across many concepts and contexts, but the convergence is not perfect. In fact, the areas of divergence help explain why people hold particular misconceptions about public health information and conform only partially to public health recommendations. Intuitive theories provide a starting point for interpreting scientific information, given their common explanatory goals, but some information will remain uninterpretable, and some interpretations will run counter to science.

Multiple Explanations for Infection

Infectious diseases are an existential threat and thus an ever-present concern. The more tools we have for tracking and avoiding them, the better we may fare. Science has identified germs as the cause of infectious disease, and people now learn about germs and germ transmission early in life, but we maintain other, non-scientific views of infection, as well as many non-scientific strategies for avoiding infection, including dietary restrictions, dietary supplements, herbal remedies, acupuncture, homeopathy, colonics, diuretics, sweating, fasting, purging, bleeding, shamanism, mysticism, and prayer. Here, I focus on two broad considerations that underlie many of these specific folk beliefs: contact contagion and behavioral prescriptions. Both considerations are relevant to the spread of germs, but they operate independent of a genuinely biological understanding of germs and thus provide only partial protection from infectious disease, if any.

Germs

Germ theory explains infectious disease as the transmission and replication of microscopic organisms. Germs were first observed under the microscope in the 17th century, but they were not connected to disease for another 180 years (Thagard, 1999). One of the first scientists to make this connection was Louis Pasteur, and he did so by way of fermentation. While investigating the role of yeast in the fermentation of beer and wine, he discovered that yeast is alive, producing alcohol as a byproduct of digestion. This discovery led him to speculate that disease may be caused by germs similar to how fermentation is caused by yeast. This speculation entailed many counterintuitive propositions: that germs are alive, that germs reside inside other living things, and that germs thrive by consuming the bodies of their hosts.

Germ theory was hotly debated for decades, but today the notion of a germ is commonplace. Children learn of germs within the first few years of life, through admonishments to avoid them and wash them from their bodies. Preschoolers know that rotting food has germs, that sick people have germs, that germs can be passed from contaminated objects to uncontaminated ones, and that contamination is undetectable (Blacker & LoBue, 2016; Kalish, 1996). Yet despite this wealth of knowledge, children do not initially think of germs as living things. They think of them as toxins—inert substances that cause illness if touched or ingested. Children thus deny that germs engage in biological processes, like metabolism and respiration, and they are prone to conflate diseases caused by germs with diseases caused by poison or pollution (Solomon & Cassimatis, 1999). Many adults hold the same misconceptions, viewing germs as contagious but not alive (Au et al., 2008). Much of our reasoning about "germs" is thus non-biological, as discussed later.

Contact Contagion

Avoiding disease has clear advantages from an evolutionary perspective, as pathogens and parasites impose an existential threat. Evolution has thus endowed humans with innate knowledge of contagion, through the emotion of disgust. Humans around the globe are disgusted by the kinds of things that contain pathogens and parasites: bodily products (like vomit and feces), bodily fluids (like spit and sweat), bodily injuries (like wounds and gore), visible signs of infection (like swelling and discoloration), olfactory signs of infection (like flatulence and putrescence), parasites (like ticks and maggots), and decomposing organic matter (like rotten meat and spoiled milk). These stimuli elicit feelings of disgust, as well as expressions of disgust: a scrunched nose and an outthrust tongue. The feelings motivate avoidance, and the expression assists in expelling contaminated air or food, as well as warning others of the threat (Curtis et al., 2004; Rozin et al., 2008).

The evolutionary logic behind the disgust response is seemingly straightforward, but it does have quirks (Rozin et al., 1986). Many substances that pose no threat of disease still disgust us, and many disease-ridden objects fail to elicit disgust. Most adults refuse to eat fudge in the shape of feces, hold a disc of plastic vomit between their teeth, drink juice stirred with a sterilized fly swatter, or eat soup out of a brand-new bedpan. Sights or smells associated with pathogens elicit disgust even when no pathogens are present (and we are aware that no pathogens are present). On the other hand, diseases like cholera and smallpox spread because humans are not inherently disgusted by cholera-infected water or smallpox-infested cloth. Likewise, highly avoidable diseases like syphilis and HIV still plague humanity because the acts that spread them are associated with pleasure rather than repulsion (other sexual taboos withstanding). Our evolved knowledge of disease is thus ill-informed. What disgusts us is not always a threat, and what threatens us is not always disgusting.

Behavioral Prescriptions

A different strategy for avoiding illness is avoiding behaviors associated with illness. If the behavior exposes a person to germs, then this strategy will be effective, but many behaviors become associated with disease for superficial reasons and do not actually increase the risk of infection. People around the world believe that being cold will cause you to catch a cold (Au et al., 2008; Sigelman, 2012), but a person's state of warmth generally has no bearing on viral infection. The fact that viruses spread more efficiently in cold weather, when people are clustered indoors and germs survive longer outside a host, has led many to assume that coldness generates colds. Other behaviors commonly associated with cold and flu transmission include getting wet, dressing inappropriately for the weather, and eating an ill-mixture of foods (Au et al., 2008). In many cultures, the behaviors associated with illness have moral overtones, such as stealing or cheating, as these behaviors are believed to invoke the wrath of supernatural agents (Legare & Gelman, 2008).

Standard forms of health education often emphasize behaviors over causes. They teach people the "do's and don'ts" of disease prevention rather than the biological pathways of germ transmission. They teach a disconnected set of beliefs not readily adaptable to novel contexts or sources of infection (Zamora et al., 2006). "Always wear a condom" may provide a safeguard against STDs in the context of intercourse, but it's not clear how that rule can be adapted to other forms of sexual activity. In contrast, health education programs that focus on germs yield better outcomes than those focused on behavior (Au et al., 2008). Students who are taught to think of viruses as living things outperform students who are taught to curb the spread of viruses, by washing their hands or covering their sneezes, but are not taught what viruses are. The former are better at identifying risk factors for viral transmission, better at explaining why those factors impose a risk, and more likely to take precautions against viral transmission in real life. Beliefs about behavior, like beliefs about contagion, provide only an approximation of what causes disease and thus only partial protection against disease itself, when the relevant behaviors cannot be applied to the current context.

The disconnect between behavior and germ transmission is even more salient for behaviors that relate to a person's moral standing. Disease obeys no moral laws, afflicting wrongdoers and do-gooders alike, yet many people believe otherwise. For instance, when told about a criminal who has contracted a deadly disease, many people think his crimes played a role in his disease, endorsing the view that "what goes around comes around" (Raman & Winer, 2004). Such endorsements are more common among adults than children, implying that the association between morality and illness is learned through informal instruction (Legare & Gelman, 2008).

Beliefs about karma, or "immanent justice," are dissociated not just from germs but also from contagion more generally. Behavioral strategies for avoiding illness are often qualitatively distinct from contagion-based ones. The belief that a person can catch a cold from being cold does not entail contagion; coldness itself is believed to be the cause, and people who endorse this belief fixate on behaviors that will keep them from getting cold. Likewise, the link between moral transgressions and illness is not mediated by contagion. Sometimes prescribed behaviors overlap with contagion concerns, such as prohibitions against consuming raw meat or handling dead carcasses, but the two concerns are easily dissociated. Beliefs about contact contagion and imprudent behavior thus constitute their own form of explanatory coexistence, independent of knowledge of germs. When people reason about infectious disease, they draw upon a varied collection of folk beliefs, some more compatible with germ theory than others.

Why Maintain Multiple Explanations?

Before focusing on how explanatory coexistence shapes our understanding of coronavirus, let us consider the broader question of why explanatory systems coexist. In the analysis of coronavirus beliefs and behaviors, I endorse the explanation that intuitive theories remain useful in everyday contexts, but this explanation is one of several possibilities. Intuitive theories may persist because they have a privileged connection to innate knowledge, because they are deeply entrenched in our current knowledge, because they operate autonomously from scientific theories, or because we simply cannot forget them. These explanations are not mutually exclusive and may apply to different degrees, depending on the theory. But the persistent utility of intuitive theories is a common theme that cuts across domains and learning contexts. Intuitive theories are sometimes viewed pejoratively, as misguided substitutes for theories with greater scope and power (see DiSessa, 2008), but this view underestimates intuitive theories' success at providing a rich and comprehensive understanding of the world around us, including an understanding of newly emergent phenomena like a global pandemic.

Innateness?

Humans enter the world prepared to encounter certain kinds of entities, like physical objects and intentional agents, and experience certain kinds of events, like heating and cooling. Evolution has endowed humans with perceptual biases that shape our earliest expectations about these entities and events (Carey, 2009). For instance, human infants do not need to learn that physical objects are solid, cohesive, and move on contact with other objects. These principles appear to be innate, as revealed by studies in which infants look longer at events that violate these principles than at closely matched events that entail no such violations (Spelke, 2000). If innateness accounts for the origin of certain beliefs, it might also account for their longevity. Beliefs grounded in basic perceptual biases may not be open to revision and will persist even when we acquire contradictory beliefs, as in the case of learning a scientific theory that contradicts an intuitive theory.

While many perceptual biases remain unchanged across the lifespan (Carey, 2009), they are unlikely to provide a general explanation for the persistence of intuitive theories because these theories are as much a cultural construction as their scientific counterparts. The belief that being cold will cause you to catch a cold comes from the observation that colds are more common during the winter and from cultural input about the link between colds and coldness (Au et al., 2008). Folk beliefs with moral overtones (karma) or supernatural overtones (bewitchment) are also unlikely to be grounded in innate knowledge, as these beliefs emerge in late childhood or early adolescence (Legare & Gelman, 2008; Raman & Gelman, 2004; Raman & Winer, 2004). Contagion-based explanations for illness are shaped by culture as well (Rozin et al., 2008). Certain activities can become associated with contagion through cultural teachings even if they pose no inherent threat of disease, such as taboos against eating (cooked) pork or taboos against homosexuality, indicating that beliefs about contagion are not inherently tied to innate knowledge.

Entrenchment?

Perhaps an intuitive theory need not be innate to survive the acquisition of a scientific theory but merely early-developing. The longer we use an intuitive theory, the more difficult it might be to erase, as it becomes increasingly entrenched in how we view the world. Intuitive theories constitute our first understanding of a domain, and as such, they provide a framework for interpreting and organizing a wealth of experience. When we acquire a new theory of a domain, we may need to retain the earlier theory to understand information encoded in its terms, similar to how we may need to retain early versions of a software program to open files that newer versions of the program cannot. Intuitive theories may thus be maintained as a means of accessing or interpreting information encoded prior to the acquisition of a scientific theory. The belief that witches cause AIDs, for instance, is not interpretable on a germ theory of illness and may require earlier theories of illness, incorporating moral or supernatural considerations, to be fully understood.

Intuitive theories may indeed serve this function, of retroactive interpretation, but they are not limited to this function. Sentence-verification studies reveal that intuitive theories are accessed even when evaluating information learned subsequent to conceptual change (Shtulman & Valcarcel, 2012; Shtulman & Legare, 2020). For instance, people verify the statement “germs have DNA” more slowly and less accurately than “germs have a shape” because germs are understood intuitively as tiny particles but not as living things. If we maintained intuitive theories only to make sense of ideas encoded early in life, then those theories should not interfere with the interpretation of genuinely scientific information—in this case, biological information about germs. Other statements about germ biology, such as "heat kills germs" and "germs enter the body through the eyes," are also verified more slowly and less accurately than statements that probe a more generic, behavior-based understanding of germs, such as "hand sanitizer kills germs" and "germs enter the body through cuts." Intuitive theories appear to be elicited whenever we reason about the phenomena they cover, even novel phenomena.

Autonomy?

Another reason intuitive theories might coexist with scientific ones is that they recruit distinct systems of reasoning, commonly known as "System 1" and "System 2" (Evans, 2008; Kahneman, 2011). System 1 operations are fast and frugal, grounded in associative or heuristic-based computations, whereas System 2 operations are slow and deliberate, grounded in analytic or principle-based computations. Perhaps the reason that intuitive theories survive the acquisition of scientific theories is that intuitive theories are grounded in System 1 and scientific theories are grounded in System 2, rendering them computationally autonomous.

Some intuitive theories do have an associative flavor. Contagion-based theories of illness, for instance, draw heavily on association. Fudge shaped like feces elicits disgust (and avoidance) by way of visual associations, clean bedpans elicit disgust by way of functional associations, and the ashes of a cremated body elicit disgust by way of historical associations. But not all intuitive theories are this shallow. Many have a logic and coherence as sophisticated as scientific theories (Shtulman, 2017). Folk beliefs about bewitchment entail specific ideas about who has the power to bewitch others, who can become bewitched, how bewitchment intersects with biology, and how it can be prevented or counteracted (Legare & Gelman, 2008). Likewise, the belief that being cold causes a person to catch a cold is embedded in a larger network of beliefs about activities that induce a health-threatening state of coldness, how this state affects the body, and how it can be counteracted (Au et al., 2008). What sets an intuitive theory apart from a collection of random misconceptions is its consistency, both internally (across concepts) and externally (across contexts). Such consistency is more characteristic of System 2 than System 1.

Lack of Forgetting?

A more basic explanation for why intuitive theories persist is that we simply do not, or cannot, forget them. Our long-term memory has no obvious capacity limit, and we may retain any cognitive tool that once served a purpose, even when we acquire better tools. Old tools might be recruited when we re-encounter the situations where we last deployed them. This explanation has been offered to account for the influence of misleading testimony on eyewitness memory; when we hear information about an event that conflicts with our perception of the event, we appear to encode both versions of the event and later switch between them, depending on the retrieval context (McCloskey & Zaragoza, 1985; Zaragoza & Lane, 1994). We tend to privilege the testimony-based version under direct questioning but privilege the perception-based version given retrieval cues that align with what we actually perceived.

A purely memory-based account of explanatory coexistence treats intuitive theories as vestigial structures, akin to the human tailbone or the human appendix. They are present because they served a function in the past, and they are retained because our cognitive systems do not have the means to delete a representation that has become obsolete after acquiring a more adaptive one. But intuitive theories are not vestigial; they actively compete with scientific theories, as discussed previously. More significantly, intuitive theories remain active in the minds of professional scientists. Despite decades of training and experience, scientists, like non-scientists, verify counterintuitive scientific ideas more slowly and less accurately than intuitive ones (Allaire-Duquette et al., 2021; Kelemen et al., 2013; Shtulman & Harrington, 2016). If intuitive theories are simply triggered by old retrieval cues, then scientists should acquire enough new cues to override the old ones. Yet studies show that scientists experience nearly as much conflict as non-scientists when evaluating counterintuitive ideas, suggesting that intuitive theories continue to play an active role in their reasoning.

Utility?

The robustness of the conflict between scientific and intuitive theories is difficult to explain if intuitive theories are preserved for historical or structural reasons but not functional ones. If they persist mainly because of their origin—as innate or early developing forms of knowledge—then their influence should wane with domain-relevant experience and education. If they persist mainly because of format—as an associative or quasi-associative network—then their influence should wane as we acquire new associations between the relevant phenomena and the scientific principles that explain them. But their influence does not wane, at least not substantially. Counterintuitive scientific ideas evoke cognitive conflict for experts as well as novices (Allaire-Duquette et al., 2021; Goldberg & Thompson-Schill, 2009; Kelemen et al., 2013) and for ideas that vary in content and complexity (Barlev et al., 2017; Shtulman & Legare, 2020; Stricker et al., 2021), which implies that intuitive theories remain a useful alternative framework for understanding the world.

The utility of intuitive theories is often cited as a reason why scientific theories are difficult to learn in the first place (Chi, 2005; Ohlsson, 2009; Shtulman, 2017). If an intuitive theory succeeds at explaining the phenomena it was intended to explain, then why learn a new theory? Even when intuitive theories are explicitly contrasted with scientific theories in the science classroom, students can be slow to recognize the latter's superior accuracy, parsimony, and generativity (Samarapungavan, 1992). The utility of intuitive theories may explain not only why people struggle to learn scientific theories but also why they struggle to deploy them once acquired. In the case of illness, for instance, many diseases can be adequately explained in terms of contact contagion and adequately avoided in terms of behavioral prescriptions. In the next section, I outline ways that the disease of recent global concern—coronavirus—can be explained and avoided through the lens of intuitive theories, thus bolstering their utility. The lens is not a perfect fit; many intuitive interpretations of coronavirus-related information yield substantive misconceptions. But the illusion of understanding produced by intuitive theories may bolster their utility nonetheless (Keil, 2003).

Multiple Interpretations of Coronavirus

The coronavirus pandemic forced laypeople to consider (or reconsider) several science-based practices for combatting disease, from wearing masks to social distancing to receiving vaccines. In the following sections, I discuss how each practice can be understood in terms of contact contagion or behavioral prescriptions without considering the biology of viruses and viral transmission. I also highlight maladaptive attitudes and behaviors that may arise from the mismatch between intuitive and scientific theories of disease.

Some maladaptive attitudes and behaviors are grounded in sociopolitical factors, like conspiracy theories and conservative propaganda, but I do not discuss these factors. Instead, I focus on misconceptions that are more clearly grounded in intuitive theories. The wholesale rejection of scientific practices, like masking and vaccination, is unlikely to happen without social impetus, though negative social reactions do often track intuitive misconceptions (Blancke et al., 2012; Blancke et al., 2015). Masks and vaccines are more easily rejected if you misunderstand their purpose. Note that well-understood practices like washing hands and disinfecting surfaces have not been the target of conspiracy theories or conservative politics, presumably because it would take more effort to convince us that we should desist.

Wearing Masks

Coronavirus is a respiratory disease, spread through the air. The disease travels on the respiratory particles we emit when breathing and talking and can linger in the surrounding environment. Masks block the reception of these particles, as well as their emission. Because coronavirus is transmitted by air rather than touch, it defies our intuitions about contact contagion. Such intuitions are further defied by the fact that coronavirus is transmitted without any visual or olfactory cues. While people readily associate bad odors with contagion, coronavirus-laden air is not detectable by smell. Ironically, diseases spread through water, like cholera and malaria, *are* associated with air because their transmission vectors smell; cholera spreads through feces-infected water and malaria spreads through mosquito-infested swamps (Johnson, 2007). A truly airborne disease like coronavirus, on the other hand, is imperceptible.

Accordingly, intuitions about contagion do not support the practice of masking; however, behavioral prescriptions do. The decree to "wear a mask" is easy to share and easy to follow. A person need not understand why a mask is effective to wear one; the behavior itself can be viewed as a form of protection, similar to staying warm or taking vitamin C to avoid the common cold. Social norms and regulations further enforce this behavior, leading to regular use of masks even without understanding their biological rationale.

The absence of such understanding does have consequences, though. People sometimes wear masks in situations that pose no threat of viral transmission (errors of commission) and sometimes fail to wear masks in situations that do pose a threat (errors of omission), at least among the unvaccinated, as all people were at the beginning of the pandemic. Experts say that masks are unnecessary in outdoor areas where people can easily distance themselves from others, such as walking one's dog or jogging along a trail, yet many people continued to wear masks in these situations and sometimes yell at others who do not (Paulus, 2020). The mandate to wear a mask in public is often overextended to include any situation outside one's home, even driving alone in the car.

On the flipside, people are apt to remove their mask in public situations when the mask interferes with their current goals, such as talking to a friend at the grocery store or responding to a cashier. If wearing a mask is viewed as a good habit, then temporarily removing one's mask can be viewed as a reasonable allowance, similar to taking a break from one's diet. But this view neglects the mask's dual role in minimizing both viral reception and viral emission, particularly in cases of asymptomatic transmission. A purely behavioral understanding of masks obscures their function as a safeguard of public health, not just personal health. The scientific value of masking resides at the aggregate level, yet a behavioral understanding shifts its value to the individual level, creating conflict between personal and social goals (for additional examples of the mismatch between individual- and aggregate-level explanations, see the chapter in this volume by Johnson and Nagatsu).

Social Distancing

Since respiratory diseases spread through breathing, one means of minimizing their spread is to stand far enough away from others so the virus-carrying particles in one's breath disperse before they can be inhaled. This practice is more effective with greater distances and better ventilated spaces.

Distancing oneself from a source of contagion is intuitive even without knowledge of viral transmission, so long as the contagion is obvious. We instinctively avoid people who are sneezing, coughing, and vomiting because we understand contagion to be transmissible on contact with sick people and their effluvia. But people who are infected with coronavirus do not initially show symptoms, rending intuitions about contact contagion moot. Moreover, contagion is thought to be spread on contact, but social distancing requires more than just lack of contact; it requires six feet of separation. Conversing without masks can facilitate viral transmission even when no one is touching, as is likely what happened in the fall of 2020 when several prominent members of the US government contracted coronavirus after attending a social event at the White House (Buchanan et al., 2020).

That said, the mandate to stay six feet apart can be embraced as a behavioral prescription and followed regardless of the surrounding context. But following the rule to the letter leads to situations where people distance themselves unnecessarily, as well as situations where people distance themselves but still create a risk of viral transmission. A case of unnecessary distancing can be seen in the reluctance of schools to reopen after they closed at the start of the pandemic. Many schools justified their prolonged closure by citing the impossibility of spacing students six feet apart in standard classrooms, yet six feet is an unnecessary benchmark if students are wearing masks, which block the virus at its source. In response to this concern, the US Center for Disease Control issued a statement acknowledging that students need remain only three feet apart if they are wearing masks.

The reverse situation can be seen in cases where people maintain six feet of distance in poorly ventilated spaces, like restaurants or offices, and then converse without wearing masks. In these spaces, people's respiratory particles do not dissipate and can lead to infection at distances far greater than six feet. Social distancing is effective only when considering the surrounding context, because the context determines whether distance alone will suffice. Blind obedience to the rule can easily lead to situations where well-intentioned people create potent transmission vectors. Consider the case of Mark Meadows, who served as White House Chief of Staff during the height of the pandemic. Meadows dutifully wore a mask while in the White House but would remove it to talk to reporters, albeit from a distance of six feet. When a reporter insisted he re-cover his face, Meadows responded, "I'm more than ten feet away . . . I can take this off. I'm not going to talk through a mask" (Shabad, 2020). Practices like these may have contributed to the high number of White House staff who contracted coronavirus at that time, including Meadows.

Sanitizing Hands and Surfaces

At the beginning of the pandemic, hand sanitizer and cleaning disinfectants became a scarce commodity. People were urged to sanitize their hands regularly, as well as the surfaces of their home. Grocery stores, which typically remained open during lockdowns, implemented elaborate cleaning rituals, wiping down carts, checkout lanes, and even the products they were selling. Many stores banned the use of reusable bags, on the assumption that they could act as transmission vectors. When it came to light that coronavirus is spread primarily by air and not surfaces, the mandate to sanitize oneself and one's belongings persisted. Many companies instituted deep-cleaning regimens that they were reluctant to abandon, even though experts say the practice is unnecessary and wasteful (Lewis, 2021). The resources spent on deep cleaning could have been better spent on improving ventilation systems (though it's an open question whether customers would have preferred better ventilation to deep cleaning).

Washing hands and disinfecting surfaces does, of course, kill germs, but the public's fixation on sanitization over other forms of disease prevention is counterproductive. Many lists of coronavirus prevention strategies include handwashing alongside masking and social distancing, even though those strategies do not stand on equal footing. Masking is clearly the most effective strategy of the three, followed by contextually-appropriate social distancing. Handwashing is generally a good idea, but it's not a strategy that will minimize the spread of coronavirus in particular.

A likely reason people fixate on handwashing and sanitization more generally is its intuitive connection to contagion. While contagion cannot be seen, they are associated with filth and can be eliminated through cleaning and cleansing. If we suspect we have come into contact with contagion, we will wash our hands even without seeing evidence of contamination. Handwashing is also widely touted as a disease-prevention strategy, to be followed habitually like brushing one's teeth. This habit, combined with the intuition that disease spreads through physical contact, may lead people to focus on sanitization even when coronavirus is more effectively combatted with proper ventilation. Once again, the overlap between behavioral prescriptions and biological realities is imprecise. Sanitization is not only ineffective against an airborne virus but can actually exacerbate other health problems, such as allergies and immune deficiencies, by depriving the immune system opportunities to respond to microbes in small doses (Thompson, 2012).

Diagnostic Testing

Testing for the presence of coronavirus was critical for mitigating its spread, given the virus's prolonged incubation period. A person could contract the virus but not show symptoms for ten days, all the while spreading it to others. This aspect of the disease—that one could have it but show no symptoms—seems counterintuitive, but research suggests that the delay between contracting a disease and showing symptoms is fairly easy to understand. People of varying ages and educational backgrounds grasp this idea (Legare & Gelman, 2008), possibly because they view diseases from an essentialist perspective (Ahn et al., 2000). Illness is understood not just as a cluster of symptoms but as a causal chain, in which having the disease is necessary but not sufficient for developing symptoms. People are also willing to endorse causes with delayed effects if they know a mechanism that can account for the delay (Buehner & May, 2002).

Essentialist views of disease fit well with intuitive beliefs about contagion. Contagion, like essences, are invisible yet have perceptible consequences. Contagion can be diagnosed from the presence of symptoms, but the absence of symptoms does not guarantee the absence of contagion. In fact, the mere suggestion of contagion can elicit a disgust response, as when people refuse to eat soup from a brand-new bedpan or refuse to drink a beverage stirred with a brand-new flyswatter (Rozin et al., 1986). Simply witnessing a disgust reaction in someone else can elicit the same reaction in ourselves, both viscerally and neurologically (Wicker et al., 2003). The logic of contagion beliefs accords well with the delayed symptomology of coronavirus and the need to test for coronavirus in asymptomatic people.

On the other hand, a contagion-based understanding of infection leads to the expectation that people either have coronavirus or they do not. It affords no understanding of viral load, or the amount of virus in one's body at a particular time, because contamination is typically viewed as an all-or-nothing phenomenon (Rottman & Young, 2019; see also Fisher & Keil, 2018). While contamination (or exposure) matters, viral load is a substantially better predictor of disease outcomes; it predicts when a person will become contagious, when their symptoms will commence, and how effective different treatment options will be (Mukherjee, 2020). Viral load also explains variability in disease severity. The more virus a person is exposed to, the sicker they will become, which explains why healthcare workers could develop severe cases of coronavirus even when they were young and healthy. Viral load also explains the historical success of variolation, or inoculating people against diseases by exposing them to small doses of live virus before they might encounter higher doses in the surrounding environment.

Variolation has been practiced throughout the world but always remained controversial, presumably because it contradicts our understanding of contagion as all-or-nothing. This understanding continues to foster inappropriate attitudes about infectious disease today (Mukherjee, 2020). Rather than view the risk of exposure on a continuum, we are inclined to categorize some situations as safe and others as unsafe. Being at home is a prototypically safe situation, but the surge in coronavirus cases during the holidays suggests that many people transmitted the virus at home, through gatherings of unmasked family members. Applied to diagnostic testing, black-or-white beliefs about infection cause confusion when interpreting test results. Tests can fail to detect a low load of coronavirus at the beginning of infection, and two tests can reveal different results if one's viral load falls below some critical threshold. Tests vary in accuracy and sensitivity, just as viruses vary in load and virulence, and neither reality accords with the dichotomous logic of contagion.

Treatment

Former US President Donald Trump caused a huge stir when he suggested that coronavirus could be cured by applying ultraviolet light internally or by ingesting bleach. Trump was ridiculed for these suggestions, but they are not completely irrational. Radiation and disinfectants are effective at killing germs on surfaces, and some disinfectants can be used on the surface of the body as well. Trump was overapplying his knowledge of sanitization to the treatment of infection. This overapplication was part of a larger pattern in which Trump and his allies touted the discovery of quick-and-easy "cures." The most notorious of such cures was Hydroxychloroquine, a malaria drug that showed no evidence of treating or preventing coronavirus in clinical trials. When Trump was hospitalized for coronavirus himself, he received a variety of treatments—steroids, monoclonal antibodies, and antiviral drugs—which he also touted as cures. "To me, it wasn't a therapeutic," Trump said in a public address. "It just made me better. I call that a cure" (Gregorian et al., 2020).

The idea that coronavirus can be cured makes sense on a contagion-based view of the disease, where a contagion is viewed all-or-nothing. In reality, treatments for coronavirus either regulate the immune system, suppressing an overreaction, or modulate viral load, by preventing the virus from replicating. Treatments help the body manage and neutralize the virus rather than destroy it. Further contributing to the lay conflation of treatments and cures is that bacterial infections *can* be cured—by antibiotics—but viral infections cannot. Antibiotics kill bacteria but are useless against viruses because viruses lack the cellular structures targeted by these drugs. Biological distinctions between bacteria and viruses are moot on a contagion-based understanding of disease because a contagion is viewed as essentially non-biological.

If beliefs about coronavirus "cures" are unconstrained by biology, then potentially any practice can be a cure. And the internet is full of false cures, including drinking water every 15 minutes, drinking ginger tea, drinking alcohol, eating garlic, eating sit should be honey, should be applying essential oils, applying colloidal silver, inhaling saline solution, and taking vitamin C. These pseudoscientific practices are particularly likely to be endorsed by people who rely on intuition over logic (Teovanovic et al., 2021). But people who endorse such practices are also likely to engage in practices that are more biologically sound, like handwashing and social distancing. The finding that scientific practices are observed alongside pseudoscientific ones suggests that, for many people, both practices are grounded in non-scientific considerations—namely, contact contagion and behavioral prescriptions (see Shtulman, 2013, for further examples of the overlap between scientific and non-scientific reasoning).

Vaccination

Vaccines are a widespread and widely accepted means of preventing viral infection. Cellular material from the virus is injected into the body, allowing the body's immune system to develop antibodies tailored to the virus, which then prevents a full-blown infection upon subsequent exposure. While anti-vaccination movements have been gaining traction in recent years, particularly in the US, the vast majority of people vaccinate themselves and their children (National Center for Health Statistics, 2019). The habit of receiving vaccines—against influenza, measles, mumps, rubella, polio, hepatitis, rotavirus, diphtheria, tetanus, meningitis, and other viruses—reinforces the behavioral prescription to inoculate oneself from diseases that once plagued humanity. This prescription allows us to benefit from vaccines without understanding what they are or how they work. Perhaps the sparsest understanding of vaccines is that they function as a shield against contagion. A contagion poses an imminent threat, and vaccines counteract that threat by conferring an enduring immunity.

A contagion-based view of viruses can, however, support an alternative model of vaccines that cannot be reconciled with how they actually work. On this model, vaccines function as the antidote to an infection, directly attacking the virus, similar to how antibiotics attack bacteria. Jee and colleagues (2015) found that this model is widespread among science students, as illustrated by descriptions like this: "A vaccine is like an anti-version of the virus. A vaccine works the same way viruses attack our cells. I think the chemicals or whatever they inject has cells to it, and those are more powerful than the virus itself and it attacks the virus in the body." Another student described vaccines as "liquid antibodies."

This direct-attack model is common among individuals who lack an understanding of the interaction between a virus and its host. Viruses require resources to replicate, and they commandeer those resources by breaking into a host's cells. Hosts respond by attempting to block the virus's entry, thus preventing it from replicating. The naïve model neglects the role of the host in this interaction and assumes instead that viruses replicate on their own, with no additional resources required. Such a view can lead to confusion about when a vaccine is effective. Injecting someone who is already infected by a virus will not aid their ability to fight it; the vaccine must be administered preemptively. Thus, the conflation of treatments and cures is compounded by a further conflation of treatments and prophylactics.

Trade-offs of Maintaining Multiple Theories

The coronavirus pandemic has plunged the average person into a sea of scientific messages and recommendations. In considering six aspects of this pandemic—wearing masks, social distancing, sanitization, diagnostic testing, treatment, and vaccination—I have attempted to show how intuitive theories can supplement scientific theories in supporting our understanding of infectious disease. Many scientific messages can be understood through the lens of contact contagion, without considering the biology of viruses, and many scientific recommendations can be embraced as behavioral prescriptions, without delving into the epidemiological rationale behind them. A person who thinks of coronavirus as transmittable on contact will be as motivated to distance themselves from others as a person who understands transmission to occur through shared respiratory particles. And a person who views vaccines as shields against contagion will be as motivated to vaccinate themselves as a person who understands vaccines as stimulating antibody production.

Even people who possess adequate knowledge to understand the science behind public health information may still default to an intuitive interpretation because the latter typically require less effort and entail fewer explanatory considerations. For instance, the risk of viral transmission in a public space depends on several factors: the density of the crowd, the history of the crowd, how well the space is ventilated, whether the space is partitioned, how humid the air is, how hot the air is, whether people are talking, and so forth. Following the prescription "wear a mask" bypasses these considerations while typically leading to the same outcome.

Additionally, our scientific knowledge is limited in detail and scope (Rozenblit & Keil, 2002), and we may prefer to deploy a theory that has fewer noticeable gaps and that has also proved successful in the past. Consider your own knowledge of infectious disease. Do you know what a virus is, biochemically, and how it differs from bacteria? What is an antibody, and how does it stop a virus from replicating? What are the active ingredients in a vaccine, and how do they stimulate the production of antibodies? What materials do diagnostic tests detect, and why do these tests sometimes fail? Details like these may hinder our ability to apply a scientific theory to a novel situation but would not constrain the application of an intuitive theory, which lacks this level of complexity. The intuitive notion of contagion, for instance, lacks specification of internal parts, means of transmission, and effects on the body; a contagion is simply an invisible substance that passes on contact and makes a person sick. This notion may lack sophistication, but it fosters many of the same behaviors and attitudes as a biochemically-detailed understanding of microbial infection.

On the other hand, there are tangible costs to interpreting scientific information through the lens of an intuitive theory. Such theories can foster misconceptions when they only partly cover the scientific phenomena they are intended to explain. In the case of coronavirus, mismatches between science and intuition include wearing masks when alone outside but failing to wear masks when inside with others (especially prior to vaccination), social distancing as a substitute for wearing masks in indoor spaces, fixating on handwashing and deep cleaning rather than the more effective practices of masking and social distancing, interpreting infection as all-or-nothing rather than a continuum of viral load, conflating treatments with cures, and construing vaccines as treatments rather than prophylactics. These mismatches reveal the pernicious influence of intuitive theories, even for scientifically literate adults, and they may be inevitable if intuitive theories are never fully eclipsed by scientific ones. Still, egregious mismatches could be publicly identified and addressed, with the understanding that they arise not from a rejection of science but from a misinterpretation of science.

An additional reason people may default to intuitive theories, despite knowing the relevant science, is that intuitive theories are often better aligned with how we talk about natural phenomena in everyday contexts. This language invites, if not demands, an intuitive interpretation. For instance, we describe coats as "warm" even though the warmth we experience when wearing a coat comes from our own bodies; a better label would be "insulating." We describe wind as "cold" even though the cold we feel in windy weather is just the disruption of our own thermal equilibrium; a better label for wind would be "disequilibrating." When we see meteors burn up in the earth's atmosphere, we describe them as "shooting stars," and when we watch the sun recede from view due to the earth's rotation, we describe the event as a "sunset" rather than a "sun occlusion." The language used to describe infectious disease may also be biased toward intuitive interpretations. Words like "ill" and "sick" can be applied to any malady—infectious or non-infectious, viral or bacterial—and words like "cure" and "remedy" are colloquially applied to any disease-mitigating intervention, including therapeutics and prophylactics.

A related reason we may default to intuitive theories over scientific ones is that they are better aligned with how we perceive natural phenomena.

We call coats warm because they feel warm, and we call wind cold because it feels cold. Stars appear to shoot across the sky, and the sun appears to set behind the horizon. We may know full well that the Earth is moving, not the sun, but we do not feel the Earth's motion, nor can we easily adopt the perspective of being situated upon a revolving sphere (Jee & Anggoro, 2019). With respect to infectious disease, we may know full well that viruses can spread without detection and that a person can have a virus without showing symptoms, but we are predisposed to fixate on perceptible signs of infection—coughing, sneezing, clamminess, diarrhea, vomit—and ignore the threat posed by asymptomatic cases and airborne particles. Coronavirus became a pandemic precisely because it required vigilance against threats we intuitively perceive as nonthreatening.

In short, our vocabulary for discussing disease and our perceptual strategies for identifying disease align well with intuitive notions of contagion, and this alignment contributes to the utility of such notions beyond our ability to apply them (or misapply them) to scientific information about disease.

Conclusions

A wealth of evidence indicates that intuitive theories survive the acquisition of scientific theories and compete with those theories to interpret domain-relevant phenomena. Sometimes, however, intuitive and scientific theories converge rather than compete, providing the same inferences for different reasons. That is, they conflict in their content but converge in their implications or applications. This convergence may help to explain why intuitive theories persist, as they remain useful even when we have access to a more accurate alternative. The coronavirus pandemic provides a window onto the myriad of ways that folk explanations of disease can supplement scientific ones in supporting everyday reasoning. While the speculations provided here need testing, they paint a different picture of the coexistence of intuitive and scientific theories. These theories may clash in the science lab and science classroom, but they can coexist peacefully in the minds of scientifically literate adults as we navigate many everyday situations.

References

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

Ahn, W., Kim, N. S., Lassaline, M. E., & Dennis, M. J. (2000). Causal status as a determinant of feature centrality. *Cognitive Psychology*, *41*, 361–416.

Au, T. K. F., Chan, C. K., Chan, T. K., Cheung, M. W., Ho, J. Y., & Ip, G. W. (2008). Folkbiology meets microbiology: A study of conceptual and behavioral change. *Cognitive Psychology*, *57*, 1–19.

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

Blacker, K. A., & LoBue, V. (2016). Behavioral avoidance of contagion in children. *Journal of Experimental Child Psychology*, *143*, 162–170.

Blancke, S., De Smedt, J., De Cruz, H., Boudry, M., & Braeckman, J. (2012). The implications of the cognitive sciences for the relation between religion and science education: The case of evolutionary theory. *Science & Education*, *21*, 1167–1184.

Blancke, S., Van Breusegem, F., De Jaeger, G., Braeckman, J., & Van Montagu, M. (2015). Fatal attraction: the intuitive appeal of GMO opposition. *Trends in Plant Science*, *20*, 414–418.

Buchanan, L., Gamio, L., Leatherby, L., Stein, R., & Triebert, C. (2020, Oct. 5). Inside the White House event now under Covid-19 scrutiny. *The New York Times*. Retrieved from: www.nytimes.com/interactive/2020/10/03/us/rose-garden-event-covid.html

Buehner, M. J., & May, J. (2002). Knowledge mediates the timeframe of covariation assessment in human causal induction. *Thinking & Reasoning*, *8*, 269–295.

Carey, S. (2009). *The origin of concepts*. Oxford University Press.

Chi, M. T. H. (2005). Commonsense conceptions of emergent processes: Why some misconceptions are robust. *The Journal of the Learning Sciences*, *14*, 161–199.

Curtis, V., Aunger, R., & Rabie, T. (2004). Evidence that disgust evolved to protect from risk of disease. *Proceedings of the Royal Society of London B: Biological Sciences*, *271*, S131-S133.

DiSessa, A. A. (2008). A bird's-eye view of the "pieces" vs. "coherence" controversy (from the "pieces" side of the fence). In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 35–60). Routledge.

Evans, E. M., Spiegel, A. N., Gram, W., Frazier, B. N., Tare, M., Thompson, S., & Diamond, J. (2010). A conceptual guide to natural history museum visitors' understanding of evolution. *Journal of Research in Science Teaching*, *47*, 326–353.

Evans, J. S. B. (2008). Dual-processing accounts of reasoning, judgment, and social cognition. *Annual Review of Psychology*, *59*, 255–278.

Fisher, M., & Keil, F. C. (2018). The binary bias: A systematic distortion in the integration of information. *Psychological Science*, *29*, 1846–1858.

Goldberg, R. F., & Thompson-Schill, S. L. (2009). Developmental "roots" in mature biological knowledge. *Psychological Science*, *20*, 480–487.

Gopnik, A., & Wellman, H. M. (2012). Reconstructing constructivism: Causal models, Bayesian learning mechanisms, and the theory theory. *Psychological Bulletin*, *138*, 1085–1108.

Gregorian, D., & Alexander, P. (2020, Oct. 7). Trump returns to Oval Office, declares himself cured of coronavirus. *NBC News*. Retrieved from: www.nbcnews.com/politics/donald-trump/trump-returns-oval-office-despite-being-treated-coronavirus-n1242460

Jee, B. D., & Anggoro, F. K. (2019). Relational scaffolding enhances children's understanding of scientific models. *Psychological Science*, *30*, 1287–1302.

Jee, B. D., Uttal, D. H., Spiegel, A., & Diamond, J. (2015). Expert—novice differences in mental models of viruses, vaccines, and the causes of infectious disease. *Public Understanding of Science*, *24*, 241–256.

Johnson, S. (2007). *The ghost map: The story of London's most terrifying epidemic and how it changed science, cities, and the modern world*. Riverhead Books.

Johnson, S. G. B. & Nagatsu, M. (this volume). Individual and structural explanation in scientific and folk economics.

Kahneman, D. (2011). *Thinking, fast and slow*. Farrar, Straus & Giroux.

Kalish, C. W. (1996). Preschoolers' understanding of germs as invisible mechanisms. *Cognitive Development*, *11*, 83–106.

Keil, F. C. (2003). Folkscience: Coarse interpretations of a complex reality. *Trends in Cognitive Sciences*, *7*, 368–373.

Kelemen, D., Rottman, J., & Seston, R. (2013). Professional physical scientists display tenacious teleological tendencies: Purpose-based reasoning as a cognitive default. *Journal of Experimental Psychology: General*, *142*, 1074–1083.

Legare, C. H., & Gelman, S. A. (2008). Biology, bewitchment, or both? The coexistence of natural and supernatural explanatory frameworks across development. *Cognitive Science*, *32*, 607–642.

Legare, C. H., & Shtulman, A. (2018). Explanatory pluralism across cultures and development. In J. Proust & M. Fortier (Eds.), *Interdisciplinary approaches to metacognitive diversity* (pp. 415–432). Oxford University Press.

Lewis, D. (2021). COVID-19 rarely spreads through surfaces. So why are we still deep cleaning? *Nature*, *590*, 26–28.

McCloskey, M., & Zaragoza, M. (1985). Misleading post-event information and memory for events: Arguments and evidence against memory impairment hypotheses. *Journal of Experimental Psychology: General*, *114*, 1–16.

Mukherjee, S. (2020, March 26). How does the coronavirus behave inside a patient? *The New Yorker*. Retrieved from: www.newyorker.com/magazine/2020/04/06/how-does-the-coronavirus-behave-inside-a-patient

National Center for Health Statistics (2019). *Immunization statistics*. Center for Disease Control and Prevention. Retrieved from: www.cdc.gov/nchs/fastats/immunize.htm

Ohlsson, S. (2009). Resubsumption: A possible mechanism for conceptual change and belief revision. *Educational Psychologist*, *44*, 20–40.

Palus, S. (2020, April 30). Stop yelling at runners for not wearing masks! *Slate*. Retrieved from: https://slate.com/technology/2020/04/runners-masks-coronavirus.html

Preston, J., & Epley, N. (2009). Science and god: An automatic opposition between ultimate explanations. *Journal of Experimental Social Psychology*, *45*, 238–241.

Raman, L., & Gelman, S. A. (2004). A cross-cultural developmental analysis of children's and adults' understanding of illness in South Asia (India) and the United States. *Journal of Cognition and Culture*, *4*, 293–317.

Raman, L., & Winer, G. A. (2004). Evidence of more immanent justice responding in adults than children: A challenge to traditional developmental theories. *British Journal of Developmental Psychology*, *22*, 255–274.

Rottman, J., & Young, L. (2019). Specks of dirt and tons of pain: Dosage distinguishes impurity from harm. *Psychological Science*, *30*, 1151–1160.

Rozenblit, L., & Keil, F. (2002). The misunderstood limits of folk science: An illusion of explanatory depth. *Cognitive Science*, *26*, 521–562.

Rozin, P., Haidt, J., & McCauley, C. R. (2008). Disgust. In M. Lewis, J. M. Haviland-Jones, & L. F. Barrett (Eds.), *Handbook of emotions* (pp. 757–776). The Guilford Press.

Rozin, P., Millman, L., & Nemeroff, C. (1986). Operation of the laws of sympathetic magic in disgust and other domains. *Journal of Personality and Social Psychology*, *50*, 703–712.

Samarapungavan, A. (1992). Children's judgments in theory choice tasks: Scientific rationality in childhood. *Cognition*, *45*, 1–32.

Shabad, R. (2020, Oct. 12). Trump chief of staff Mark Meadows refuses to speak to reporters with mask on. *NBC News*. Retrieved from: www.nbcnews.com/politics/white-house/trump-chief-staff-mark-meadows-refuses-speak-reporters-mask-n1242990

Shtulman, A. (2013). Epistemic similarities between students' scientific and supernatural beliefs. *Journal of Educational Psychology*, *105*, 199–212.

Shtulman, A. (2017). *Scienceblind: Why our intuitive theories about the world are so often wrong*. Basic Books.

Shtulman, A., & Harrington, K. (2016). Tensions between science and intuition across the lifespan. *Topics in Cognitive Science*, *8*, 118–137

Shtulman, A., & Legare, C. H. (2020). Competing explanations of competing explanations: Accounting for conflict between scientific and folk explanations. *Topics in Cognitive Science*, *12*, 1337–1362.

Shtulman, A., & Lombrozo, T. (2016). Bundles of contradiction: A coexistence view of conceptual change. In D. Barner & A. Baron (Eds.), *Core knowledge and conceptual change* (pp. 49–67). Oxford University Press.

Shtulman, A., & Valcarcel, J. (2012). Scientific knowledge suppresses but does not supplant earlier intuitions. *Cognition*, *124*, 209–215.

Sigelman, C. K. (2012). Age and ethnic differences in cold weather and contagion theories of colds and flu. *Health Education & Behavior*, *39*, 67–76.

Solomon, G. E., & Cassimatis, N. L. (1999). On facts and conceptual systems: young children's integration of their understandings of germs and contagion. *Developmental Psychology*, *35*, 113–126.

Spelke, E. S. (2000). Core knowledge. *American Psychologist*, *55*, 1233–1243.

Stricker, J., Vogel, S. E., Schöneburg-Lehnert, S., Krohn, T., Dögnitz, S., Jud, N., . . . & Grabner, R. H. (2021). Interference between naïve and scientific theories occurs in mathematics and is related to mathematical achievement. *Cognition*, *214*, 104789.

Teovanović, P., Lukić, P., Zupan, Z., Lazić, A., Ninković, M., & Žeželj, I. (2020). Irrational beliefs differentially predict adherence to guidelines and pseudoscientific practices during the COVID-19 pandemic. *Applied Cognitive Psychology*, *35*, 486–496.

Thagard, P. (1999). *How scientists explain disease*. Princeton University Press.

Thompson, H. (2012, March 22). Early exposure to germs has lasting benefits. *Nature News*. Retrieved from: www.nature.com/news/early-exposure-to-germs-has-lasting-benefits-1.10294

Vosniadou, S. (1994). Capturing and modeling the process of conceptual change. *Learning and Instruction*, *4*, 45–69.

Wicker, B., Keysers, C., Plailly, J., Royet, J. P., Gallese, V., & Rizzolatti, G. (2003). Both of us disgusted in My insula: the common neural basis of seeing and feeling disgust. *Neuron*, *40*, 655–664.

Zamora, A., Romo, L. F., & Au, T. K. F. (2006). Using biology to teach adolescents about STD transmission and self-protective behaviors. *Journal of Applied Developmental Psychology*, *27*, 109–124.

Zaragoza, M. S., & Lane, S. M. (1994). Source misattributions and the suggestibility of eyewitness memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *20*, 934–945.