# Priming Counterintuitive Scientific Ideas

**Andrew Shtulman (shtulman@oxy.edu)**
Department of Psychology, Occidental College

**Daniel Meller (danielpaulmeller@gmail.com)**
Department of Psychology, Occidental College

## Abstract

Intuitive explanations for natural phenomena are typically our default explanations, even after we have learned more accurate, scientific explanations (Shtulman & Valcarcel, 2012). The current study examined whether priming students with scientific images improves their ability to verify counterintuitive scientific statements, like "bacteria need nutrients" and "bubbles have weight." Participants (100 college undergraduates) verified scientific statements interspersed with images relevant to the predicates of those statements; the images depicted either schematic diagrams (scientific primes) or everyday scenes (intuitive primes). Scientific primes increased the accuracy of participants' responses, relative to intuitive primes, but not the speed of those responses, indicating that scientific primes facilitate a preference for scientific ideas over intuitive ones but do not eliminate the initial conflict between them.

**Keywords:** scientific reasoning; intuitive theories; conceptual change; folk biology; folk physics; explanatory coexistence

## Introduction

Does grass respire (i.e., breathe)? Do tornados? Grass is alive and tornados are not, so the correct answers are yes and no, since all living things—and only living things—respire. Still, our perception that tornados move but grass does not can lead to a moment's hesitation—hesitation we would not experience if asked whether giraffes respire or whether boulders respire. That hesitation belies a conflict between an intuitive, self-constructed theory of biology and a scientific, formally instructed theory (Shtulman, 2017). Bypassing that conflict might lead to more assured and more accurate responses, which, in turn, might facilitate science learning. This study uses a statement verification task, similar to the opening questions, to assess whether the conflict between scientific and intuitive responses can be bypassed using scientific primes.

Conflict between science and intuition is a byproduct of early conceptual development. Children do not wait until school to piece together an understanding of the natural world; they develop intuitive theories to make sense of early observations and experiences (Baillargeon et al., 2008; Vosniadou, 1994). When reasoning about biological phenomena, children initially associate life with motion. They assume that anything that moves on its own is alive, leading them to misclassify animate phenomena like rivers and tornados as alive and misclassify seemingly inanimate organisms like flowers and trees as not alive (Stavy & Wax, 1989). When reasoning about physical phenomena, children initially associate matter with perceptibility. They assume that anything that can be seen or felt is material, leading them to misclassify perceptible phenomena like rainbows and shadows as material and misclassify imperceptible forms of matter like gasses and vapors as not material (Smith, 2007).

Intuitive theories were once thought to be replaced by, or assimilated into, later-acquired scientific theories, through a process of conceptual change. However, recent evidence indicates that scientific theories supplement intuitive theories rather than supplant them (Babai et al., 2009; Dunbar et al., 2006; Kelemen & Rosset 2009; Barlev et al., 2016). Intuitive theories coexist alongside scientific ones, yielding competing interpretations of the same phenomena (Shtulman & Lombrozo, 2016; Legare & Shtulman, 2018; Ohlsson, 2009).

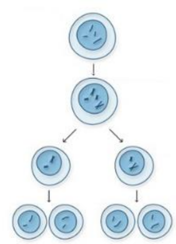
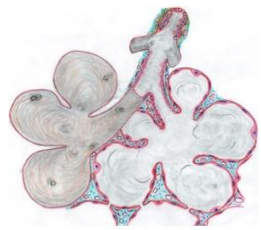
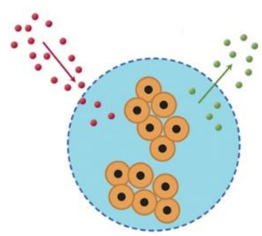
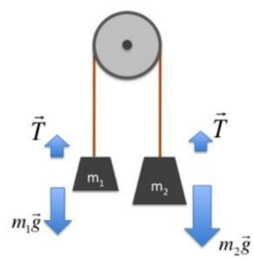
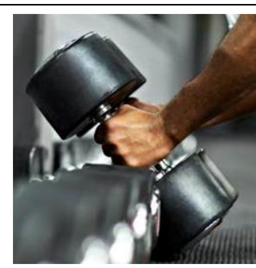
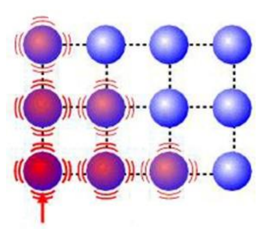
In previous studies using statement-verification tasks or category-judgment tasks, participants exhibited delayed responses and greater inaccuracy when making judgments that pit scientific ideas against intuitive ones (Potvin et al., 2015; Young et al., 2018). For instance, participants take longer to classify plants as alive than to classify animals as alive, and they make errors for plants relative to animals (Goldberg & Thompson-Schill, 2009). Convergent findings come from brain imaging studies that show increased activity in areas involved in inhibitory control when reasoning about counterintuitive scientific ideas, presumably because intuitive responses must be inhibited to arrive at the correct answer (Masson et al., 2014, Foisy et al., 2015). Recent imaging studies suggest that intuitive misconceptions like "moving things are alive" remain encoded in the brain long after we have acquired a scientific (i.e., biochemical) understanding of life (Skelling-Desmeules et al., 2021).

The coexistence of competing explanatory frameworks is a potential problem for science education. Science students tend to default to their intuitive knowledge, especially when burdened or pressured (Shtulman & Valcarcel, 2012; Kelemen et al., 2013; Barlev et al., 2017), implying that this knowledge is accessed first, as our default interpretation of natural phenomena. The resilience of intuitive misconceptions complicates science education, as strategies intended to eliminate such misconceptions can be counterproductive. More effective strategies are those that shift the balance from intuitive reasoning to scientific reasoning (Potvin, 2017). An abundance of scientific coursework can help shift that balance (Goldberg & Thompson-Schill, 2009; Masson et al., 2014), as can higher education in general (Kelemen et al., 2013; Shtulman & Harrington, 2016). Still, it's unclear whether education helps students prioritize science over intuition or students who are initially better at prioritizing science are more likely to pursue additional education.



In J. Culbertson, A. Perfors, H. Rabagliati & V. Ramenzoni (Eds.), *Proceedings of the 44th Annual Conference of the Cognitive Science Society*. 

Table 1: Sample statements and primes, organized by domain and statement type: (1) intuitively true, (2) intuitively false, (3) counterintuitively true, (4) counterintuitively false

| Concept | Type | Sample statement | Sample scientific prime | Sample intuitive prime |
|---|---|---|---|---|
| Reproduction | 1 | Spiders reproduce |  |  |
| | 2 | Tables reproduce | | |
| | 3 | Coral reproduces | | |
| | 4 | Fire reproduces | | |
| Respiration | 1 | Pelicans respire |  |  |
| | 2 | Forks respire | | |
| | 3 | Grass respires | | |
| | 4 | Tornados respire | | |
| Nutrition | 1 | Zebras need nutrients |  |  |
| | 2 | Rugs need nutrients | | |
| | 3 | Algae need nutrients | | |
| | 4 | Robots need nutrients | | |
| Weight | 1 | Gold has weight |   |  |
| | 2 | Minutes has weight | | |
| | 3 | Clouds have weight | | |
| | 4 | Heat has weight | | |
| Temperature | 1 | Steel has a temperature |  |  |
| | 2 | Dreams have a temperature | | |
| | 3 | Dust has a temperature | | |
| | 4 | Shadows have a temperature | | |
| Spatial extent | 1 | Bricks occupy space |  |  |
| | 2 | Numbers occupy space | | |
| | 3 | Air occupies space | | |
| | 4 | Rainbows occupy space | | |

In a direct test of how scientific training impacts scientific reasoning, Young et al. (2018) used targeted tutorials to teach students counterintuitive ideas that later appeared in a statement-verification task. They found that training increased the accuracy of students' verifications, though not their speed. Similarly, Wheeldon (2017) found that instructing chemistry teachers on specific misconceptions about energy helped them avoid those misconceptions and feel more confident in their knowledge. But the effects of interventions targeted at specific misconceptions often fade with time (Venkadasalam et al., 2019) and may need to be repeated at regular intervals.

An alternative to training is priming, which may be less resource-demanding and could be achieved more regularly, in contexts where scientific primes could be made ubiquitous, such as science museums or the science classroom. Priming also bypasses the issue of "teaching to the test" inherent in the evaluation of targeted instruction. Ideally, priming a scientific mindset would allow students to circumvent the need to inhibit intuitive misconceptions by activating only scientific ideas. If students can be primed to think scientifically from the outset, then competition between intuitive and scientific interpretations of the material could be avoided.

Previous research suggests that priming can indeed shift the balance between scientific reasoning and intuitive reasoning in the context of religion. Scientific primes increase the use of biological concepts when explaining illness, while religious primes engender greater use of supernatural concepts (Legare & Gelman, 2008; Busch et al., 2016). Scientific primes also increase the endorsement of scientific explanations, whereas religious primes have the opposite effect (Preston & Epley, 2009). Computational simulations of these effects imply that they are pervasive, reflecting a habitual attempt to establish coherence between abstract causal principles and concrete situations (Friedman & Goldwater, 2019).

Here, we explored whether priming might help students prioritize scientific ideas over intuitive ones in an educational context rather than a religious context. We asked college undergraduates to verify counterintuitive scientific statements under three conditions: scientific priming, intuitive priming, and no priming. We hypothesized that exposing participants to scientific primes, in the form of statement-relevant images, would facilitate access to scientific interpretations of those statements, thus increasing the speed and accuracy of their verifications. Whether, and how, intuitive primes would affect scientific reasoning was less clear. If intuitive theories are a default mode of reasoning, then priming them may not interfere with scientific reasoning any more than usual.

## Method

Our Our study employed a mixed 2x3 factorial design. Statement type (intuitive vs. counterintuitive) was varied within participants, and prime type (intuitive vs. none vs. scientific) was varied between participants.

### Participants

One-hundred undergraduate students completed the study for extra credit in a psychology class. Participants were mostly female (72%) and approximately 20 years old ($M$ = 21.2, $SD$ = 2.5); 15% were freshmen, 21% sophomores, 23% juniors, and 31% seniors.

### Materials

We probed the conflict between science and intuition using a statement verification task, similar to that used by Shtulman and Valcarcel (2012). Participants decided, as quickly as possible, whether two types of statements were true or false: intuitive statements, designed to elicit agreement between scientific and intuitive interpretations, and counterintuitive statements, designed to elicit disagreement.

Half the statements of each type were true, and half were false, ensuring that statement type (intuitive vs. counterintuitive) was not confounded with truth-value. Intuitively true statements were true from both a scientific perspective and an intuitive perspective ("bricks occupy space"); intuitively false statements were false from both a scientific perspective and an intuitive perspective ("numbers occupy space"). Counterintuitively true statements were true from a scientific perspective but false from an intuitive perspective ("air occupies space"), and counterintuitively false statements were false from a scientific perspective but true from an intuitive perspective ("rainbows occupy space"). Sample statements are displayed in Table 1.

Statements covered two domains: life and matter. Statements about life covered the concepts of reproduction, respiration, and nutrition, and statements about matter covered the concepts of weight, temperature, and spatial extent. Within each domain, one of 80 entities was matched with one of three predicates to produce 20 intuitively true statements, 20 intuitively false statements, 20 counterintuitively true statements, and 20 counterintuitively false statements.

Participants were randomly assigned to one of three priming conditions: scientific priming ($n$ = 34), intuitive priming ($n$ = 32), or no priming ($n$ = 34). The primes were images presented for two seconds between each statement and were intended to convey either a scientific interpretation of the statement or an intuitive interpretation. Scientific primes consisted of models or diagrams, similar to those found in a science textbook, whereas intuitive primes were photographs of everyday situations, typically involving people. For instance, scientific primes for statements about weight ("[x] has weight") were force diagrams, where weight was represented as a downward-pointing vector, consistent with the scientific sense of weight as the product of mass and gravity. Intuitive primes for these same statements were images of barbells, dumbbells, and scales, consistent with the intuitive sense of weight as heft. Participants in the no-priming condition were shown a fixation cross for two seconds between each statement.

## Procedure

The task was administered in 6 blocks of 80 statements, for a total of 480 statements. All statements within a block contained the same predicate, such as "respires" or "has weight." Statements were presented in a random order, as were the blocks. Participants were not given a time limit, but they were encouraged to answer as quickly as possible. The task was administered using MediaLab v1.21.

# Results

We explored the effect of priming across domains and then assessed the consistency of this effect within domains. Participants verified 86% of statements correctly overall, and their mean response time was 1145.2 ms (*SD* = 1077.0 ms). Response times greater than two standard deviations above the mean were excluded from analysis, as were response times less than 250 ms (a time too short for participants to have read the statement and responded meaningfully). We further excluded response times for incorrect responses, though the results do not change if those times are included.

We analyzed participants' responses for effects of statement type (intuitive vs. counterintuitive) and prime type (intuitive vs. none vs. scientific) using mixed-factor analyses of variance (ANOVAs). Statement type was collapsed across truth-value and analyzed within participants; prime type was analyzed between participants.

## Response Accuracy

Participants' accuracy at verifying intuitive and counterintuitive statements is displayed in Figure 1 by priming condition. Accuracy varied by statement type ($F(1,97) = 414.77$, $p < .001$, $\eta_p^2 = .81$) and prime type ($F(2,97) = 3.98$, $p = .022$, $\eta_p^2 = .08$), with no interaction between them ($F(2,97) = 0.95$, $p = .39$, $\eta_p^2 = .02$).

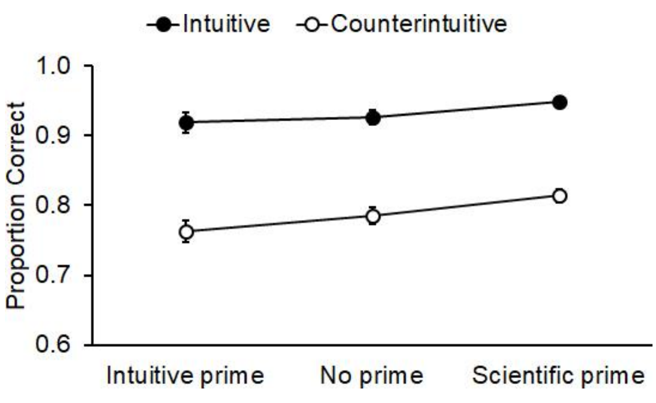



Figure 1: Mean proportion of intuitive and counterintuitive statements verified correctly for each type of prime.

Post hoc comparisons with Bonferroni corrections revealed that participants were more accurate when primed with scientific images than when primed with intuitive images (*M* = .84 vs. *M* = .88, $t = 2.79$, $p = .019$). Accuracy for the no-prime condition fell between the two priming conditions (*M* = .86) and did not differ significantly from either.

To explore the effect of priming more thoroughly, we performed contrast analyses by priming condition for each type of statement. These analyses revealed that accuracy for the counterintuitive statements increased linearly across conditions, from intuitive primes to no primes to scientific primes ($t = 2.93$, $p = .004$). No such trend was observed for the intuitive statements ($t = 1.79$, $p = .076$), indicating that priming selectively affected accuracy for counterintuitive statements, designed explicitly to elicit cognitive conflict.

## Response Latency

Participants' speed at verifying intuitive and counterintuitive statements is displayed in Figure 2. Speed varied by statement type ($F(1, 97) = 374.93$, $p < .001$, $\eta_p^2 = .79$) but not prime type ($F(2,97) = 0.00$, $p > .99$, $\eta_p^2 = .00$), and there was no interaction between these factors ($F(2, 97) = 2.89$, $p = .061$, $\eta_p^2 = .06$). Participants responded more quickly to intuitive statements than counterintuitive statements but did not respond more quickly when primed with scientific images relative to intuitive images (or no images at all).

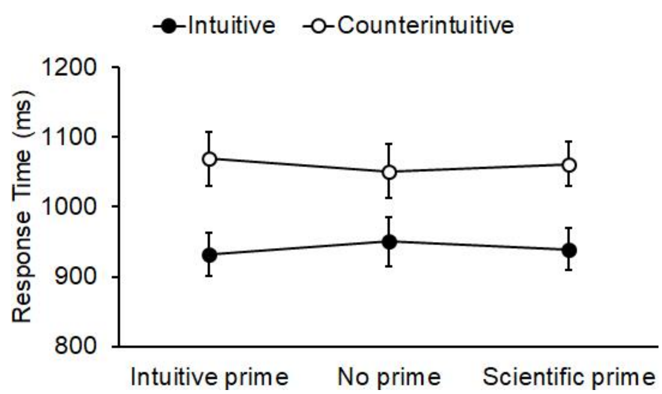



Figure 2: Mean response times (in milliseconds) to intuitive and counterintuitive statements for each type of prime.

## Effects By Domain

Scientific primes increased the accuracy but not the speed of participants' responses. We next explored whether these effects held for each domain or were driven by one domain in particular. In the biological domain, response accuracy varied both by statement type ($F(1, 97) = 120.56$, $p < .001$, $\eta_p^2 = .55$) and by prime type ($F(2,97) = 3.53$, $p = .033$, $\eta_p^2 = .07$), but response latency varied only by statement type ($F(1, 97) = 115.93$, $p < .001$, $\eta_p^2 = .54$).

Likewise, in the physical domain, response accuracy varied both by statement type ($F(1, 97) = 429.08$, $p < .001$, $\eta_p^2 = .82$) and prime type ($F(2, 97) = 3.08$, $p = .05$, $\eta_p^2 = .06$), but response latency varied only by statement type ($F(1,97) = 277.59$, $p < .001$, $\eta_p^2 = .74$). No interaction effects were observed in either domain for either measure. In sum, priming affected accuracy in both domains but did not affect speed.

## Discussion

Explanatory coexistence poses a challenge to science education, as students must coordinate two theories of the same phenomena: the scientific theory being taught and an intuitive theory developed earlier in life. We predicted that exposing participants to scientific primes would facilitate access to the scientific theory, increasing the speed and accuracy of students' scientific reasoning. We found that priming had no effect on speed but did improve accuracy, at least slightly. Students verified counterintuitive statements like "clouds have weight" more accurately when these statements were interspersed with scientific depictions of weight (force diagrams) than when interspersed with intuitive depictions of the same concept (images of dumbbells and scales). These findings indicate that counterintuitive scientific ideas can be primed with the right contextual cues, which might, in turn, facilitate science learning. That is, scientific primes might help students better engage with the material, keep up with instruction, and alleviate confusion.

One prominent question raised by our findings is why priming improved accuracy but not speed. This finding is consistent with the training effects found by Young et al. (2018), described above, and suggests that explanatory conflict can be shifted in favor of one explanation over another but cannot be circumvented altogether. That is, scientific primes allowed students to privilege scientific interpretations of a statement over intuitive ones, but both interpretations may have been activated upon participants' initial reading, yielding cognitive conflict.

For instance, a statement like "clouds have weight" may have activated both a scientific sense of weight (which applies to all material substances, including clouds) and an intuitive sense (which does not apply to clouds) regardless of what primes participants saw. But scientific primes would prompt them to endorse the scientific sense of weight, judging the statement "true."

It's possible that scientific primes promoted accuracy at a higher level of reasoning—by activating a "scientific mindset" or by heightening participants' error-monitoring skills—but we suspect the effect was predicate-specific, similar to the effect of training observed by Young et al. (2018). Participants trained on the scientific properties of one domain, such as matter, showed no improvement in accuracy for statements about another domain, such as life. Still, future research could test for higher-level effects of priming by including scientific primes for some predicates and not others and then observing whether accuracy improves for all predicates or only those that were primed.

Relevant to the question of how priming affects reasoning, it's worth noting that both types of primes influenced accuracy. Participants were most accurate when primed with scientific images and least accurate when primed with intuitive ones, which suggests that the conflict between science and intuition is malleable and can be resolved in either direction. Intuitive primes could have yielded no effect on accuracy, if participants' default interpretation was an intuitive interpretation, but accuracy varied along a continuum, from intuitive primes to no primes to scientific primes.

This finding implies that students may benefit not only from instruction that emphasizes the scientific aspects of a natural phenomenon but also from instruction that deemphasizes its intuitive aspects. For example, analogies from scientific concepts to everyday life may be more harmful than helpful if the analogy primes an intuitive interpretation that cannot be rectified with the relevant scientific interpretation (Thagard, 1992). Likewise, instructional activities grounded in abstract, schematic representations may be more beneficial than those grounded in concrete, detailed representations if the latter primes intuitive ideas incompatible with the scientific ones being taught (Koedinger et al., 2008).

Our results also confirm the more general finding that intuitive theories of a domain coexist alongside—and interfere with—scientific theories, as revealed by the consistent gap in response accuracy and response latency between intuitive and counterintuitive statements. This gap was observed across statements and across domains and was only modestly affected by priming. Educators would thus benefit from recognizing that science students will experience cognitive conflict regardless of the instructional context. Educators would also benefit from recognizing that this conflict is not driven by ignorance but by a substantive, yet qualitatively different, theory of the same phenomena.

One reason priming may have had a modest effect, relative to the effect of statement type, is that our primes were subtle, intended to evoke a scientific interpretation of the relevant predicates without explicitly encouraging them to do so or explaining how. More salient primes, involving videos or narratives, may have a stronger effect on accuracy and possibly also speed. Still, the finding that primes have a greater influence on accuracy than speed speaks to the general finding that the conflict between science and intuition is immediate and robust (Shtulman & Valcarcel, 2012; Shtulman & Legare, 2020). This conflict is likely an inherent byproduct of conceptual change and must be taken into account when teaching and communicating scientific ideas that challenge our intuitive understanding of the world.

## References


Babai, R., Sekal, R., & Stavy, R. (2010). Persistence of the intuitive conception of living things in adolescence. *Journal of Science Education and Technology*, *19,* 20-26.

Baillargeon, R., Li, J., Ng, W., & Yuan, S. (2008). An account of infants' physical reasoning. In Woodward, A., & Needham, A. (Eds.), *Learning and the infant mind* (pp. 66-116). Oxford University Press.

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.

Busch, J. T., Watson-Jones, R. E., & Legare, C. H. (2017). The coexistence of natural and supernatural explanations within and across domains and development. *British Journal of Developmental Psychology*, *35*, 4-20.

Dunbar, K. N., Fugelsang, J. A., & Stein, C. (2007). Do naïve theories ever go away? Using brain and behavior to understand changes in concepts. In M. Lovett & P. Shah (Eds.), *Thinking with data* (pp. 193–206). New York: Lawrence Erlbaum Associates

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

Foisy, L. M. B., Potvin, P., Riopel, M., & Masson, S. (2015). Is inhibition involved in overcoming a common physics misconception in mechanics? *Trends in Neuroscience and Education*, *4*, 26-36.

Friedman, S. E., & Goldwater, M. B. (2019). Simulating explanatory coexistence: Integrated, synthetic, and target-dependent reasoning. *Proceedings of the 41st Annual Conference of the Cognitive Science Society*, 351-357.

Kelemen, D., & Rosset, E. (2009). The human function compunction: Teleological explanation in adults. *Cognition*, *111*, 138-143.

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.

Koedinger, K. R., Alibali, M. W., & Nathan, M. J. (2008). Tradeoffs between grounded and abstract representations: Evidence from algebra problem solving. *Cognitive Science, 32*, 366-397.

Legare, C. H., & Gelman, S. A. (2008). Bewitchment, biology, or both: The co-existence of natural and supernatural explanatory frameworks across development. *Cognitive Science*, *32*, 607-642.

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

Masson, S., Potvin, P., Riopel, M., & Foisy, L. M. B. (2014). Differences in brain activation between novices and experts in science during a task involving a common misconception in electricity. *Mind, Brain, and Education*, *8*, 44-55.

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

Potvin, P., Masson, S., Lafortune, S., & Cyr, G. (2015). Persistence of the intuitive conception that heavier objects sink more: A reaction time study with different levels of interference. *International Journal of Science and Mathematics Education*, *13*, 21-43.

Potvin, P. (2017). The coexistence claim and its possible implications for success in teaching for conceptual change. *European Journal of Science and Mathematics Education*, *5*, 55-66.

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

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 Barner, D., & Baron, A. S. (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.

Skelling-Desmeules, Y., Foisy, L. M. B., Potvin, P., ... & Charland, P. (2021). Persistence of the “moving things are alive” heuristic into adulthood: Evidence from EEG. *CBE: Life Sciences Education*, *20*, article 45.

Smith, C. L. (2007). Bootstrapping processes in the development of students’ commonsense matter theories. *Cognition and Instruction*, *25*, 337-398.

Stavy, R., & Wax, N. (1989). Children’s conceptions of plants as living things. *Human Development, 32*, 88-94.

Thagard, P. (1992). Analogy, explanation, and education. *Journal of Research in Science Teaching*, *29*, 537-544.

Venkadasalam, V., Larsen, N., & Ganea, P. (2019). The importance of explanations in guided science activities. *Proceedings of the 41st Annual Conference of the Cognitive Science Society*, 3598.

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

Wheeldon, R. (2017). Improving preservice chemistry teachers’ content knowledge through intervention activities. *International Journal of Science Education*, *39*, 1238-1261.

Young, A., Laca, J., Dieffenbach, G., Hossain, E., Mann, D., & Shtulman, A. (2018). Can science beat out intuition? Increasing the accessibility of counterintuitive scientific ideas. *Proceedings of the 40th Annual Conference of the Cognitive Science Society*, 1238-1243.