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A Unique Way of Knowing: Children's Conceptions of the Nature of Science and its Relationship to Religion

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ABSTRACT

There is an increasingly rich body of developmental research on children's understanding of science and religion as ways of knowing. In this manuscript, I put this scholarship in conversation with applied research on science education and consider the potential implications for exposing children to instruction that addresses the relationship between science and religion. I begin by outlining three bodies of literature that can inform our understanding of how learners – especially young learners – make sense of potentially conflicting explanatory frameworks from the domains of science and religion: 1) the literature on testimony, which provides insight into how children learn about science and religion; 2) the literature on epistemological reasoning, which examines how learners think knowledge is conceptualized in different ways of knowing (in this case, science and religion); and 3) the bodies of literature on situated cognition and collateral learning, which posit that the experience of actively grappling with conflicting testimony is emotionally charged and connected to issues of culture and identity. After synthesizing the literature in these three areas, I turn to the science education literature to consider the implications for classroom culture and pedagogy, where I argue that the reviewed research supports the practice of making room for ideas that sit outside the traditional bounds of science as a powerful pedagogical tool. Specifically, I posit that students' questions and ideas about concepts that fall outside these typical domain boundaries can be leveraged by science teachers for deeper understanding – not just about the intended scientific content goals, but also about concepts such as disciplinarity and perspective taking – and for a more inclusive classroom environment that invites all students to engage in scientific thinking, regardless of their cultural or religious backgrounds.

Keywords: children, science and religion, testimony, epistemological reasoning, situated cognition, collateral learning

Editors' Comment

Dr. Megan Powell Cuzzolino, Ed.D., (2015-2017 Fellow), *is the Senior Project Manager at the Next Level Lab, a research group at the Harvard Graduate School of Education that draws on research from the learning sciences to address emerging and urgent issues in education and workforce development. Her doctoral research investigated the role of the emotion of awe in scientific learning and discovery. In this contribution to the special issue, Dr. Cuzzolino presents a thorough examination of the literature on learners' understanding of science and religion and how they make sense of conflicting ideas presented by each. She then makes clear the pedagogical importance of understanding students' ideas about science and religion in order to more successfully teach religiously sensitive science content and, therefore, the need to incorporate this need into science teacher preparation. She also makes clear that, to accomplish such goals, there must be a shift in the mindset of academics regarding the importance of research into* *students' beliefs about supernatural phenomena. We feel this manuscript establishes the importance of understanding learners' beliefs about science and religion and sets the stage for the subsequent shorter contributions about specific interactions between religion and science teaching.*

Introduction

"*Science investigations begin with a question."* This sentence appears in the Next Generation Science Standards (NGSS) as an "Understanding of the Nature of Science" at the Kindergarten-Grade 2 level (NGSS Lead States, 2013), and sure enough, this was how most investigations began in my classroom during my years as an elementary school science teacher. Some questions were more notable than others, but few were as memorable as the line of inquiry that began one morning as I sat on the carpet with a class of first graders, when a conversation about states of matter suddenly turned existential. One student interrupted my review of solids, liquids, and gases to inquire about why matter existed in the first place. Her classmates perked up, and soon others were joining in with questions about when the first matter came into being and whether someone or something was responsible for creating it. Before my eyes, the carpet full of six-year-olds had erupted into a full-scale debate about the nature of the universe.

The NGSS also state that "*Science is a unique way of knowing, and there are other ways of knowing.*" Although this standard is intended for high school students, I felt it was critical, in this moment of organic curiosity, to share the sentiment with my first graders. From the origins of matter and the evolution of life to the risks of global climate change and the exploration of deep space, it is no exaggeration to state that some of humanity's most pressing issues sit at the intersection of science, philosophy, ethics, and faith. I wanted my students to know that the questions they were asking were complex, enormous, and important, and that it would likely take more than science alone to answer them.

I was fortunate to teach in a unique independent school where students were empowered to ask questions and teachers were granted the flexibility to deviate from the planned curriculum. Childhood curiosity, however, is far from unique; in classrooms everywhere, students are likely pondering questions that sit outside the traditional bounds of science, whether they express them or not. These questions, if asked, may reveal valuable information about a student's current understanding of a particular concept or of their broader understanding of the nature of science – information that might lead a teacher to revisit a lesson or reframe a concept to build on the learner's prior knowledge. Yet, in many classrooms, these conversations do not happen. A teacher may be unsure of how to answer, or may fear the consequences of acknowledging concepts that delve into spiritual or religious territory; in other situations, the classroom climate may be such that questions simply linger in students' minds, unasked.

My own experiences as a teacher led me to wonder what could be gleaned from existing research to inform thoughtful pedagogy that takes into consideration children's early conceptions about science and its relationship to other ways of knowing. I was particularly interested in children's ideas about the relationship between science and religion, as this is likely a largely unexplored topic in most public school classrooms despite the fact that it is a present (and often significant) feature of many students' lives outside of school. To explore these ideas, I have conducted a review of the research, asking the following guiding questions of the literature:

1. *What does the extant research suggest are the cognitive, developmental, and sociocultural factors that shape how young learners develop conceptions of science and its relationship to religion?*
2. *What are the potential implications for exposing children to instruction that addresses the relationship between science and religion?*

Methods and Organization of Paper

In conducting this review, I have used academic databases including Academic Search Premier, ERIC, Google Scholar, and PsycINFO to seek out relevant research. I also used a snowballing technique to gather additional references. Given my interest in younger learners, I primarily limited my search to studies that focused on children ages twelve and under, though I occasionally incorporated research on older learners to inform my understanding in areas where the literature on young learners was scarce, particularly with regards to research on students' engagement with school science. It is also important to note that the literature on science and religion in schools is primarily an exploration of American Christian contexts (Hanley et al., 2014). As such, this paper is largely a review of studies conducted in the United States, many of which used language that explicitly or implicitly invoked Christian or Judeo-Christian conceptions of religion. The paper does include occasional references to European research, especially because some of the studies reviewed took a comparative approach with samples from the United States and other countries.

I rely on working definitions offered by Sinatra and Nadelson (2011) to characterize the domains of science and religion for the purposes of this paper. *Religion* is considered to be "a set of commonly held beliefs and practices often codified through specific religious doctrine or religious law" (Sinatra & Nadelson, 2011, p. 176). This generic sort of definition is how the term "religion" is typically discussed in the education policy sphere (given the global nature of the language in the establishment clause of First Amendment), making it appropriate for the context of this paper. For the term *science*, Sinatra and Nadelson cite the definition used by the National Academy of Sciences: "the use of evidence to construct testable explanations and predictions of natural phenomena, as well as the knowledge generated through this process" (National Academy of Sciences, 2008, p. 10). Additionally, when I use the term *instruction*, I am referring primarily to formal school learning settings, which are distinguished from informal learning contexts in important ways as I discuss sources of information and the familiarity and cultural relevance of particular explanatory frameworks.

I begin this piece with a brief overview of how the relationship between science and religion has been framed theoretically in the literature and introduce the connection I seek to make between this conceptual framing and the implications for education. I then unpack three bodies of literature that can inform our understanding of how learners – especially young learners – make sense of potentially conflicting explanatory frameworks from the domains of science and religion:

1. The literature on *testimony* provides insight into how children learn about scientific and religious phenomena that they cannot perceive firsthand and explores the cognitive process of grappling with counterintuitive and often conflicting explanatory framework offered by various sources.
2. The literature on *epistemological reasoning* examines how learners think knowledge is conceptualized in different ways of knowing (in this case, science and religion), and suggests that being able to reason about epistemology is necessary for making sense of scientific and religious explanations.
3. The bodies of literature on *situated cognition* and *collateral learning* posit that the experience of actively grappling with conflicting testimony is emotionally charged and connected to issues of culture and identity, thus implying that a *cold* model of conceptual change (Pintrich et al., 1993) that does not account for affect and social context is insufficient for understanding the learning process.

After reviewing the literature in these three areas, I turn to the science education literature to consider the implications for classroom culture and pedagogy, where I argue that the reviewed research supports the practice of making room for ideas that sit outside the traditional bounds of science as a powerful pedagogical tool. Specifically, I posit that students' questions and ideas about concepts that fall outside these typical domain boundaries can be leveraged by science teachers for deeper understanding – not just about the intended scientific content goals, but also about concepts such as disciplinarity and perspective taking – and for a more inclusive classroom environment that invites *all* students to engage in scientific thinking, regardless of their cultural or religious backgrounds.

Overview of Conceptual Background

There is a rich body of theoretical literature focused on the relationship between science and religion as epistemologies (e.g., Barbour, 1966; Coleman, 2014; Gould, 1999; Wilson, 1998). One of the most commonly cited frameworks comes from Ian Barbour, who posited four models of the relationship between science and religion: *conflict, independence, dialogue,* and *integration* (Barbour, 1988). In contemporary American rhetoric, conflict seems to be the most regularly evoked model. There is a common assumption embedded in much of our popular discourse that religious beliefs inhibit understandings of, and positive attitudes towards, science (Evans & Evans, 2008; Gauchat, 2015). These ideas are regularly reflected in the results of public opinion polls that inquire about Americans' views on science and religion, though some of these polls also begin to hint at the complexity of individuals' real beliefs. For instance, a Pew Forum survey (Pew Forum, 2009) found that while 55% of participants responded affirmatively to the question "Are science and religion often in conflict?", only 36% said yes to the follow-up question, "Does science sometimes conflict with your own religious beliefs?"

Though opinion polls tend to focus on adults' beliefs, the conflict narrative is perhaps most salient in the American public school classroom.[1] The most well-known example is likely the Scopes *Monkey Trial* (Scopes Case, 1927), in which the classroom teaching of evolution was debated in a dramatic and widely publicized court case, but it is just one of many legal and cultural battles that have contributed to the image of science and religion as being at odds in the educational context. Psychological research indicates that adult perceptions of science and religion have origins in early childhood (Bloom & Weisberg, 2007), and, as with adults, it seems unwise to assume that young learners intuitively gravitate toward the conflict model. As the anecdote in the introduction suggests, children's questions do not always fall neatly within domain boundaries. Research indicates that children use parallel strategies to make sense of scientific and supernatural explanations for phenomena (Harris & Koenig, 2006), and that the conflict model fails to fully account for the complex processes that students use as they develop beliefs and attitudes toward science and religion (Koul, 2006; Abo-Zena & Mardell, 2015). Thus, in this paper I seek a more nuanced understanding of how children reason about the nature of science and its relationship to religion, especially in the context of concepts that are widely seen as relevant to both domains.

Children's Reliance on Testimony from Others

The Role of Testimony in Conceptual Development

Historically, the research on how natural and supernatural reasoning coexist in the mind has been somewhat limited. Legare et al. (2012) posit that this lack of existing research may be because researchers did not traditionally see it as appropriate to empirically investigate supernatural thinking. However, cognitive developmental literature has emerged over the past ten to fifteen years that has begun to shine a light on the development of religious or spiritual conceptions and their relationship to other modes of reasoning.

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[1]As noted previously, though the potential for the conflict narrative to arise exists across many religious denominations, coverage of this topic in the United States tends to be focused on Christianity (Hanley et al., 2014).

This research suggests that from an early age, there are parallels between the processes for how children learn about scientific and religious concepts. In both domains, there are numerous phenomena and entities that cannot be understood through first-hand experience; to learn about such concepts, children frequently rely on testimony presented by other, typically more knowledgeable individuals (Harris, 2002). In the domain of science, there are many concepts that are difficult or impossible for learners – especially young learners – to observe directly, often because they operate on very large or small spatial or temporal scales, and may involve causal relationships that are outside of the learner's attentional frame (Grotzer & Solis, 2015). For instance, few children have the opportunity to view the shape of the earth (Nussbaum, 1985; Vosniadou & Brewer, 1992), perceive the causal mechanisms underlying magnetic attraction (Lesser, 1977), or witness the biological processes involved in death (Harris & Giménez, 2005). Likewise, although some research suggests that children are "intuitive theists" (Kelemen, 2004, p. 295), testimony likely still has a large impact on their conceptions of spiritual matters, including the existence of a higher power and an afterlife, as well as the efficacy of prayer (Harris & Koenig, 2006).

Counterintuitive phenomena, in particular, are often hard to conceptualize and impossible or challenging to verify through first-hand experience, and the research suggests that similar factors influence the acceptance of counterintuitive phenomena in both natural and supernatural domains (Lane & Harris, 2014). These factors include the developmental capacity of the recipient to conceptualize the idea, the context in which the information is presented, the demonstrated expertise of the informant, and the qualities of the information itself (such as whether or not the information as affective appeal, or the range of phenomena that an explanation covers). Thus, for both scientific and religious concepts, young learners are heavily dependent on the information provided by external sources, and the features of that informational transaction significantly influence understanding.

On some occasions, children may hear testimony – either from different sources, or from the same source in different contexts – that presents both scientific and religious explanations for the same concept. In these instances, the learner may compartmentalize these explanations as isolated concepts, or he or she must decide how to reconcile the potentially conflicting explanatory frameworks, whether by selecting one as the preferred explanation, choosing to apply one or the other depending on the context, or generating a new framework that combines or synthesizes the disparate claims. Children do seem to distinguish between scientific and religious domains in certain ways; notably, they typically express greater confidence about the existence of scientific entities. This may stem from the fact that discourse around scientific entities tends to take their existence for granted, while language used to discuss special beings often includes assertions of belief or faith, which may lead children to recognize that some people doubt the existence of these beings. Alternatively, children may be aware of the lack of consensus amongst adults discussing special beings, leading to less confidence in their own assertions (Harris & Koenig, 2006). It is important to note that the majority of this research is focused on scientific phenomena that are typically deemed uncontroversial (e.g., atoms, germs); the parallels between scientific and religious reasoning patterns may perhaps be even more pronounced for topics that tend to evoke a greater sense of controversy or uncertainty for many people, such as climate change or human origins.

Children also appear to employ strategies (whether consciously or subconsciously) for connecting the explanations they are familiar with to new scenarios; namely, when discussing concepts that have both scientific and religious explanations, children tend to offer context-appropriate accounts. For instance, when asked to provide an explanation for a character's death in a narrative, a child who hears about the character's corpse will likely apply a biological model, while a child who hears about ancestral rituals in the character's community is more apt to apply a spiritual model (Harris & Koenig, 2006). Harris and Koenig (2006) also found that children who grow up in a community where conflicting testimony is frequently presented are likely to acknowledge the possible existence of multiple correct beliefs. However, they do not typically engage in a process for evaluating the relative merit of each belief, nor are they often capable of proposing methods for doing so. Thus, when faced with the challenge of making sense of potentially contradictory statements, children may require explicit guidance about how to adjudicate between different types and sources of information. I will return to this notion below in the section on epistemology.

The Nature of Testimony to Young Learners on Science and Religion

Before children are of school-age, much of the early testimony they hear about both science and religion comes from parents, caregivers, and other members of their local community, often by way of spontaneous or informal discussions as well as more formal rituals. The literature on how adults talk to young children about science is somewhat limited, as compared to other domains like language and mathematics (Vlach & Noll, 2016). To date, the bulk of the research in this area has examined the types of explanations that children hear while engaged with adults in science talk at museums (e.g., Crowley et al., 2001; Haden, 2010) and in laboratory settings (e.g., Luce et al., 2013), though several studies have looked at scientific and causal language used in more naturalistic settings (e.g., Callanan & Oakes, 1992).

Based on this existing research, it seems that many parents and caregivers regularly engage in what could be considered informal science talk as they explore and explain causal relationships, make connections to other experiences, and introduce new vocabulary with their young children (Callanan et al., 2013).[2] Though science learning may not be the primary purpose in such interactions, these everyday conversations are often more likely to be tailored to the interests and experiences of the particular child (Callanan et al., 2013). On the other hand, talking to children about science may pose a particular set of challenges. While in many domains, adults intuitively talk to children in ways that are developmentally appropriate and beneficial to their learning, science may be an exception, given that adults tend to have less practice talking about scientific concepts with conversation partners of any age (Vlach & Noll, 2016).

Adults seem to believe that they should adjust their language when talking to children about science, but they may not always know how to do this effectively. Vlach and Noll (2016) found that when asked to explain science concepts to a range of listeners, college-age adults provided more varied types of explanations to five-year-old children than to adults. These explanations included higher frequencies of beneficial features, such as analogies and connections to prior knowledge, but they also included higher frequencies of potentially disadvantageous or confusing features, such as personification and references to magic. However, when asked to reflect on their explanations, the study participants assessed their explanations to children as being more accurate than their explanations to adults. Vlach and Noll (2016) hypothesize that adults employ a greater number of explanatory features in their science talk with children because they are more concerned with correct instruction than they might be with adult interlocutors. They also posit that the inclusion of more disadvantageous features, such as magical or supernatural explanations, may reflect the belief that a secondary goal of explaining science to children is to make it more fun and engaging; this hypothesis is speculative at this point and warrants further empirical testing, especially given that if this is indeed a common belief among adults, there may be implications for how science is typically framed for young children in other educational settings.

In considering how children think about concepts that sit at the boundary of science and other domains, it is noteworthy that issues of morality often seem to spontaneously emerge in parent-child discussions about science. In three studies (one laboratory study with children in grades 3-5, and two

[2] It is important to note that the parents and caregivers included in the samples of these studies are the ones who have chosen to take their children to a research lab or a museum, and thus are not necessarily representative of the population as a whole. This limitation in the sample points to the need for further research in naturalistic, more inclusive settings.

museum studies with children aged 3-10 years), Callanan et al. (2014) recorded conversations between parents and their children about a variety of science topics, including climate change and gender differences. The conversations were coded for instances in which moral issues were mentioned. The authors identified four categories of moral issues: avoiding harm or promoting care, promoting justice or fairness, being a good or responsible person, and tolerating differences or accepting essential truths. Callanan et al. (2014) found that topics of socialization and morality emerged throughout the discussions of science-related topics, with parents and children "often slipping back and forth between notions of ideas that are factually 'right' versus morally 'right'" (p. 121). However, the nature of the discussions about morality varied greatly based on the content domain at hand; i.e., parents and children introduced concepts of morality in different ways when talking about a physical domain than a social domain. Sometimes, references to moral issues were driven by the parent, in an apparent effort to seize the opportunity to attend to their child's character development. In other cases, the discussion of morality stemmed from the child, who raised questions or expressed the adoption of a particular moral stance related to the topic at hand.

More research is needed to determine the impact of these discussions of morality in the context of scientific explanations. Callanan et al. (2014) note that in regular conversation, we employ two distinct meanings for the word *right* – an epistemological definition, in which something is evaluated for factual correctness, and a moral definition, in which something is evaluated for whether or not it is just or virtuous – and it may be that discussions such as the ones described above cause these definitions to get conflated in children's minds. However, the authors also suggest that opportunistic discussions about morality could potentially be more impactful than strategic ones, as children may take particular note of topics that they interpret as being significant enough to warrant an interruption to the flow of conversation. Callanan et al. (2014) also posit that cultural or philosophical differences in worldview might impact the nature of discussions of morality that arise within conversations about science topics and the ideas that children take away from these conversations. The epistemological perspectives that parents implicitly or explicitly endorse are likely to impact their children's ideas about how to answer questions and evaluate evidence (Luce et al., 2013).

These findings merit further research to explore the potential impact of exposing children to the idea that morality is relevant to scientific issues. Notably, the topic of morality is often at the heart of religious conversations with young children, especially given that they are frequently learning about religion in the context of parables that lead to moral conclusions. It is possible that hearing about morality in both religious and scientific contexts may lead children to see connections between the two domains (e.g., by linking a stewardship narrative of the earth to concepts of ecology and environmentalism). Alternatively, if the concept of morality is discussed differently in the scientific context than the religious context, a child may perceive further distinctions between the two domains.

The Developmental Trajectory of Processing Scientific and Religious Testimony

Many of the ideas that young children form about science and religion persist into adulthood. To some extent, supernatural explanatory frameworks seem rooted in human cognitive architecture. Though the developmental literature has traditionally argued that supernatural explanations are supplanted by natural explanations over time, it is clear that supernatural explanations do remain prevalent in adult cognition across cultures (Legare et al., 2012). Moreover, the generalized preference for teleological explanations exhibited by children seems to carry over into an adult tendency to perceive an inherent purpose in significant life events (Banerjee & Bloom, 2014). Teleological intuitions, including those about natural phenomena, persist even for adults who do not identify as religious – and in fact, even among those who claim aversion to religion (Järnefelt et al., 2015). Regardless of age, religion, or cultural identity, individuals show a tendency to default to teleological explanations for phenomena when placed under time pressure, which supports a dual process theory hypothesis that intentional explanations are largely due to inherent aspects of human cognition (Järnefelt et al., 2015). This may account for the apparent universality of both natural and supernatural belief systems across societies, leading the coordination among these various explanatory frameworks to be deemed a "general cognitive problem" (Evans et al., 2011, p. 114).

However, the process of grappling with these domains also appears to follow a developmental trajectory, with the influence of caregivers, community members, and other external sources of information holding different weight at different stages. In early childhood, exposure to religious ideas is correlated with children's tendencies to believe in, and invoke, supernatural explanations. Corriveau et al. (2015) found a sharp distinction between kindergarteners with and without systematic exposure to religion (through school or church), with the children raised in a religious environment conceiving of a notably broader range of plausible phenomena than their secular peers. This discrepancy – and the fact that secular children relied on references to religion as justification for deeming phenomena to be pretend – suggests that a religious upbringing seems to override children's natural tendencies to doubt unlikely causal phenomena (rather than the converse notion that a secular upbringing overrides a predisposition toward credulity). Additionally, in early childhood, the tendency to invoke creationist explanations for the origins of species corresponds to the child's religious background. In interviews with children and adults from fundamentalist and non-fundamentalist communities about the origins of various species, Evans (2008) found that children aged 5-7 provided a mix of responses categorized as spontaneous generationist (suggesting that the species simply appeared) or creationist (referencing a supernatural power), with children from fundamentalist communities providing a higher frequency of creationist responses.

By middle childhood, however, children are more likely to receive a diversity of messages from various sources, and they begin to formulate individual ideas about the world that may reflect new developmental capacities as well as their attempts to account for multiple explanatory frameworks. In the interview study with fundamentalist and non-fundamentalist individuals described above, 8–10-year-olds tended to endorse creationist ideas regardless of their community background. Evans (2008) suggests that at this age, children are beginning to confront existential questions (Evans et al., 2001) and are developing the ability to reason about the possible existence of an intelligent designer, whereas younger children are not likely to accept the premise that animals and artifacts are impermanent and therefore struggle to reason about origins. While this reasoning pattern does not reflect a scientific worldview, the ability to conceive of impermanence does indicate that children at this age may be prepared to begin thinking about evolutionary concepts if they are introduced (e.g., Kelemen et al., 2014), or at the very least, to recognize that there are multiple possible explanatory frameworks.

Grappling with Multiple Explanations

As children's worlds expand and they are exposed to ideas from a variety of sources, they begin to face the cognitive challenge of reconciling conflicting testimony. Memory research suggests that information – whether true or false – is filed in the brain "without being 'tagged' as to source or credibility" (DiMaggio, 1997, p. 267). When the information is later retrieved, the individual must therefore infer these features and make a determination about whether or not it is believable; this task becomes more challenging when multiple explanations must be weighed against each other and reconciled. Ultimately, an individual may choose to adopt one explanation over the other, or to permit both explanations to mentally coexist, either by compartmentalizing them or integrating them in some way. Both compartmentalization and integration are likely to require metacognitive abilities and cognitive adaptability (Legare et al., 2012).

Legare et al. (2012) refer to the process of holding multiple explanatory frameworks as *coexistence thinking*. There are a number of features that characterize concepts that tend to invoke coexistence thinking, including the involvement of hidden or unobservable causal agents, association with strong emotions, and a relationship to existing cultural practices that pre-date formal science (Legare et al., 2012). Unsurprisingly, coexistence thinking occurs frequently with phenomena for which both natural and supernatural explanations are presented.

Individuals may invoke a variety of frameworks for reasoning about the coexistence of natural and supernatural explanations for a given phenomenon (Legare et al., 2012). In *target-dependent* thinking, the conflict remains unresolved in one's mind; one explanation or the other is recruited to account for a particular aspect of the phenomenon based on the context at hand. Elkana (1981) suggests that although people often use context to determine which source of knowledge is appropriate, "in the event of a serious clash, the knowledge source with the greatest personal legitimacy and value (scope and force) will prevail" (Cobern, 1996, p. 594-5). In *synthetic* thinking, on the other hand, the two different explanations are loosely integrated into one framework, though without explicit consideration of how they fit together. Finally, in *integrated* thinking, the two different explanations are more thoroughly interwoven, often in a model that relies on each domain for a different level of analysis (e.g., one might cite a natural proximate cause and a supernatural ultimate cause). Synthetic and integrated models, which are constructed to resolve a state of cognitive (and sometimes emotional) conflict, are likely closely held and may be particularly challenging to abandon or adjust (Evans et al., 2011). Evans and Lane (2011) argue that holding blended models also requires the activation of system 2 reflective processing (Stanovich & West, 2000; Kahneman, 2003), in that individuals who endorse a hybrid of scientific and religious conceptions are demonstrating the ability to "rapidly shift between different reasoning patterns" and ultimately taking an analytic (rather than purely intuitive) approach (p. 156).

Coexistence thinking can also arise out of a need to make sense of counterintuitive information. Evaluating counterintuitive information entails a great deal of cognitive load, as the individual must engage in the process of shifting back and forth between one's own perception of how things appear and the conflicting representation of how things are asserted to be (Lane & Harris, 2014). Lane and Harris (2014) note that most prominent models of belief formation (originating from philosophers such as Descartes and Spinoza) are based on the premise that the learner begins by creating a mental representation of a given claim. Thus, these models fail to account for scenarios in which the learner has difficulty developing a cognitive representation, such as with counterintuitive concepts. In these cases, the learner may exhibit a tendency to disbelieve the claim that is not easily represented. Lane and Harris (2014) posit that the tendency to accept counterintuitive explanations is influenced by the developmental capacity of an individual to produce these mental representations. This is supported by research demonstrating that young children are particularly skeptical of evidence that conflicts with their personal experience and beliefs (Lane & Harris, 2014). As such, children may struggle to reckon with testimony that presents an explanatory framework running counter to earlier explanations and/or first-hand experiences, which often occurs for children who are not exposed to scientific models until they enter school (Billingsley et al., 2014).

Epistemological Understanding

The Developmental Trajectory of Epistemological Understanding

Making sense of the relationship between scientific and religious explanatory frameworks as described above requires an understanding of each domain's epistemology – their conception of the nature of knowledge and knowing. The discussion of multiple epistemologies is not uncommon among academics and clergy, many of whom see it as a professional responsibility to acknowledge and respond to potential areas of conflict that arise from differences between the epistemological lenses of their domain and other ways of knowing (e.g., Gottlieb & Wineberg, 2012). While any given discipline or domain tends to have some overarching unifying epistemological principles that distinguish it from other fields, individuals also hold their own conceptions of the nature of knowledge, what Burr and Hofer (2002) refer to as *personal epistemology*. Less research has been done about how individuals, especially those in the lay public, reason about epistemology (Evans et al., 2011), but the existing literature suggests that epistemological understanding follows a developmental trajectory, with children beginning to draw on multiple epistemological frameworks as early as 3-5 years of age (Legare et al., 2012).

In the literature, the earliest stage of epistemological development is typically described as a dualist or absolutist perspective, in which the individual believes in a sense of right and wrong and the notion that truth can be known with certainty. As most of the research on epistemological development has been conducted with adolescents and adults, little is known about the earliest stages of the developmental process or whether there are any stages that precede dualism. Some have posited that there is a pre-dualistic stage of naïve realism, in which children believe that there is no possible perspective other than their own. For instance, Burr and Hofer (2002) found that very young children (around age 3) struggle to complete an epistemology task in which they have to explain why a character lacks knowledge that they possess. Young children's difficulty with theory of mind tasks may also support the idea of a naïve realism stage (Burr & Hofer, 2002). However, in a review of the theory of mind literature, Wellman (2014) points to evidence that 3-year-olds do demonstrate the ability to distinguish between individuals holding different beliefs.

The ability to reason about categories of knowledge also improves developmentally. Even very young children comprehend the distinctions between factual and opinion-based judgments; they understand, for instance, that reasoning about the physical world involves a higher degree of certainty than reasoning about matters of aesthetic preference (Hofer et al., 2011). By age four, children begin to demonstrate the ability to make judgments about expertise that rely on cognitive schema representing abstract domain categories (Lutz & Keil, 2002). For instance, many children at this age can recognize that a doctor would be more likely to possess knowledge within the domain of biology, while an automotive technician would be more likely to possess knowledge within the domain of physical mechanics. However, four- and five-year-olds struggle to abstract knowledge clusters to broader disciplines when the experts in question are unfamiliar (e.g., an eagle expert or a bicycle expert). In a study of children in Kindergarten through Grade 6, Danovitch and Keil (2004) found that younger children tended to select expert consultants for a task based on their reported topic knowledge, while older children were more likely to select consultants based on their understanding of deeper disciplinary relationships. Children likely struggle to characterize knowledge by discipline because this task requires being sensitive to deep structural relationships between concepts rather than attending simply to surface-level features (Danovitch & Keil, 2004).

As children get older, their capability to reason about domain differences improves, but they still demonstrate different patterns of epistemological thinking than adults. For instance, children have different ideas about the relationship between knowledge or belief and the individual expressing that knowledge or belief. In a series of experiments, Heiphetz et al. (2014) presented adults and children aged eight to ten with a set of characters who made various factual, opinion-based, or religious statements. Participants were asked whether each statement offered more information about the world or about the person making the statement. Both children and adults reported that they learned more about the world than about the individual from statements of correct factual belief. However, upon hearing an individual make a statement about religious beliefs, adults reported that they had learned more about the individual making the statement than about the nature of the world, whereas children reported the reverse. Heiphetz et al. (2014) suggest that the difference between how children and adults perceive religious statements may stem from the fact that adults have had more exposure to religious diversity and disagreements, though they also note that children do seem to understand the concept of a lack of consensus around theological claims. The authors conclude that there is still "much to learn … about how children situate religious beliefs within a larger epistemological framework" (Heiphetz et al., 2014, p. 27).

Implications of Epistemological Understanding for Science Learning

There is an extensive body of research on the nature of science that explores how students understand science as a way of knowing and considers the implications for how science is taught in the classroom (see Lederman, 1992 for a review of the literature). A number of studies have also specifically examined how students understand science in relationship to other ways of knowing, though most of the existing literature focuses on older learners. Several researchers have proposed typologies or frameworks to characterize how features such as knowledge, evidence, and certainty are viewed through scientific and religious epistemological lenses. For instance, Sinatra and Nadelson (2011) suggest that the epistemological assumptions promulgated by science and religion as institutions can be seen as existing at opposite ends of four continua: source of knowledge, justification of knowledge, certainty of knowledge, and structure of knowledge. Elsewhere, based on their research of science instruction in British secondary schools, Hanley et al. (2014) developed a typology to characterize student engagement with topics pertaining to science and religion. The typology was developed based on students' views across several dimensions, including the value they placed on evidence versus belief, their open-mindedness, and their tolerance of uncertainty. Though a focus group of teachers reported that their students did not hold any views that were irreconcilable with scientific explanatory frameworks, surveys and interviews with students about their understanding of the origin of life revealed that many did in fact hold epistemological stances that were serving as roadblocks to scientific understanding.

Shtulman and colleagues (e.g., Shtulman & Valcarcel, 2012; Shtulman, 2013; Shtulman & Harrington, 2016) have also conducted extensive research on how students, especially college students, reason about scientific principles that run counter to intuitive beliefs, as well as the students' explanations for why they hold particular conceptions. Shtulman (2013) found in a study of undergraduates that the most common form of justification for both scientific and supernatural beliefs was through deference to the opinions and conclusions of others, echoing the findings of Harris and Koenig (2006) with younger children. Moreover, individuals' reported confidence in their beliefs in both scientific and supernatural phenomena was more strongly associated with perception of consensus about the explanation than with the acknowledgement of available evidence. Shtulman's (2013) findings also reveal a correlation between students' understanding of the nature of science and their tendency to offer evidential justifications for their beliefs (as opposed to deferential or subjective justifications), though Shtulman suggests that more research is needed to understand the nature of this relationship.

Brain imaging research provides an interesting accompaniment to these findings. For instance, Fugelsang and Dunbar (2005) found that when people were presented with information that was consistent with their prior theories about a scientific concept, the parts of their brain associated with learning showed increased activity. In contrast, when people were given data that contradicted their prior theories, they showed activation in the parts of their brain involved in error detection, conflict monitoring, effortful processing, and working memory. As noted by Dunbar, Fugelsang and Stein (2007), the fact that information inconsistent with one's prior conceptions is neurologically processed as an error points to the significant challenges and complexity inherent in conceptual change.

One factor that may confound learners who are trying to make sense of scientific explanations is the many diverse uses of the terms *knowledge* and *belief* within science education and in everyday talk (Southerland et al., 2001). In particular, a number of researchers have argued that the common usage of the word belief, which in everyday language can imply the existence of doubt, causes confusion regarding the scientific approach to theories (e.g., Cobern, 2000; Smith, 1994; National Academy of

Sciences, 1998). For instance, a statement that scientists believe in the theory of evolution may be interpreted by a layperson to mean that this belief is tentative or uncertain (Southerland et al., 2001). Southerland et al. (2001) posit that much of science education research is based on the epistemological position of fallibility. Within a fallibilist epistemology (Siegel, 1998), certainty is not a condition of knowledge; the fallibilist stance maintains that explanations can be compared and judged for quality despite the premise that human knowledge is imperfect. Beliefs, in contrast, are held by fallibilists to be subjective, personal truths that do not rely on evidence and are often laden with emotion. Thus, Southerland et al. (2001) propose that drawing a distinction between knowledge and belief may lie in identifying the "type and number of warrants" that a person holds for a given piece of information (p. 336). In other words, if an individual produces a limited number of justifications, or if the justifications would be deemed weak by scientific epistemological standards (e.g., thinking something is true because a friend said so), then the piece of information should be considered a belief rather than knowledge.[3] Using this framework, one can understand how the same statement could be knowledge to one person and a belief to another.

To avoid conflating inaccurate ideas with ideas that are non-empirically based, some researchers advocate for the use of the term *alternative conception* (e.g., Wandersee et al., 1994) to refer to ideas that are not beliefs but rather incorrect, but empirically grounded, explanations (Southerland et al., 2001). Additionally, Smith and his colleagues have proposed that the term *acceptance* more appropriately represents the scientific process of evaluating evidence and concluding that a theory is the best possible explanation given the available information (Smith et al., 1995). This distinction between acceptance and belief foregrounds the epistemological lens of science, in which validity is based on the evaluation of evidence rather than personal opinion.

Many researchers and educators have made the distinction between understanding and belief as potential aims of science education, suggesting, for instance, that while students should be required to understand the theory of evolution, it is inappropriate and likely impossible to require them to believe it. Southerland et al. (2001) group acceptance with belief; though they acknowledge that the idea of acceptance implies more agency on the part of the learner than does belief, they argue that both agency and belief should be seen as goals of science education rather than requirements, as students cannot make an informed choice to believe or accept a given theory until they have achieved a deep understanding of the evidence.

While the goals of science education remain an open question in the literature, it seems safe to conclude that an awareness of epistemological assumptions inherent to science and how those differ from other ways of knowing is a necessary condition for understanding and evaluating conflicting explanatory frameworks. However, it is not sufficient to pursue this as a purely intellectual endeavor. In the following section, I will explore the social and affective components that factor into the process of engaging in thinking that runs counter to intuitive or culturally familiar ideas.

Science Learning in Context

The Need for "Hot Conceptual Change"

The research described in the sections above provides insight into the cognitive processes that occur as learners acquire and make sense of information derived from scientific and religious ways of knowing. Of course, learning happens in context, and the nature of the learning environment must factor in to any consideration of how conceptual understanding develops. Notably, learners undergo

[3] It is important to note that beliefs are typically based on rationales; the claim is simply that these rationales are not empirical (Southerland et al., 2001). They may instead be grounded in other types of reasoning, such as a community consensus or the reliance on a trusted authority figure.

a shift when they enter school and begin to receive formal science instruction. For any learner, thinking about science in a school setting may present certain challenges, but this transition can be particularly difficult for learners for whom the classroom approach to science is entirely novel or misaligned with their prior experience.

Geary (2008) describes formal schooling as "a central interface between evolution and culture" (p. 179): schools are a cultural innovation designed to close the gap between children's *folk knowledge* and the information required to be successful in adult society. For many students, this gap is particularly evident in science education, where intuitive ideas and early testimony provided by families and communities may regularly conflict with the concepts presented in the classroom. In addressing such conflicts, learners must decide whether to maintain or revise deeply held beliefs, and they must come to terms with the implications embedded in the new conceptions being presented, which are often both personal and existential.

The sense-making process that learners must undergo in order to grasp new scientific explanatory frameworks, especially those that are complex or counterintuitive, is often understood through the lens of conceptual change. New information does not automatically trigger conceptual change; instead, for a learner to adopt a new conception, she must acknowledge that there is a conflict between the explanation she currently holds and the new explanation being presented, and she must be willing to seek resolution for that conflict (Strike & Posner, 1982). Thus, a critical first step in the conceptual change process is to reveal the learner's present understanding in order to hold it up to a contrasting model. For concepts that sit at the boundary of science and religion, the conceptual change process presents a unique set of challenges. In the course of unearthing one's current understanding about concepts such as cosmology or human origins, the learner may encounter ideas that are deeply entrenched and emotionally charged. For instance, Evans (2008) notes that it is critical to consider the emotional components to teaching evolutionary theory, as the ideas of impermanence and mutability of kinds may lead to "existential angst" (p. 283) for both children and adults (though this may be more the case when confronting the idea of human origins than with other species). Other topics introduced in the science classroom may bear similar implications for human identity and mortality. They may also cause learners to confront their existing beliefs in supernatural entities and phenomena, as well as their personal affiliations with religious or cultural communities (Evans et al., 2011; Gelman, 2011).

For the reasons just described, some researchers have suggested that conceptual change is limiting as a framework for understanding how learners engage with new concepts. For instance, Long (2013) argues that there is a tendency to view the purpose of education as correcting misconceptions one student at a time, which he believes fails to account for the social nature of conceptual development, in which learners construct knowledge through the process of engaging with other individuals whose ideas and perspectives interact with their own in complex ways. More specifically to science education, Cobern (1996) found through a series of interviews with a student and her teacher that improving conceptual change tactics is insufficient as a method for helping a learner whose worldview is causing resistance to what is being taught. Hanley et al. (2014) suggest that conceptual change is inappropriate for viewing the teaching of evolutionary theory, because it diminishes the affective dimension of the learning and presents all beliefs not supported by conventional Western science as misconceptions.

Many traditional arguments in the conceptual change literature take the perspective that this is a process that is disconnected from emotional or social factors. However, other researchers have made the case for a more nuanced understanding of conceptual development that accounts for the contextual nature of learning. The phenomenon of "hot cognition" (Abelson, 1963) is widely referenced in the literature and refers to the idea that reasoning is impacted by an individual's emotional state. Pintrich et al. (1993) extend this to suggest a "hot" model of conceptual change, acknowledging that whether or not conceptual change occurs is influenced by a variety of "personal, motivational, social, and historical processes" (p. 170). Additionally, the literature on situated cognition offers a lens for thinking about learning in the context of the physical setting where learning takes place and the community of practitioners who engage together in the learning process (Brown et al., 1989). Rather than relying on an approach to science education that views conceptual change as a process in which the learner abandons prior knowledge for another, more acceptable conception, some researchers in the situated cognition field have advocated for a model in which students learn to think and operate in both the formal science domain and their everyday notions of science, and to distinguish the contexts in which particular conceptions are appropriate (Hennessy, 1993).

Border Crossing and the Compartmentalization of Knowledge

For many students, the relationship between school science and the rest of their lives is complex, and navigating between these contexts does not always come easily. Cobern (1996) observes that there is an implicit argument that scientific literacy should be viewed as distinct from the "everyday world," despite the fact that this everyday world is presumably the context in which most people will make use of their scientific knowledge (p. 582). Yet, it is unwise to assume that students will naturally "approach their classroom learning with a rational goal of making sense of the information and coordinating it with their prior conceptions" (Pintrich et al., 1993, p. 173). In everyday life, individuals tend to satisfice, looking for information that will allow them to adequately explain and predict phenomena, rather than the optimal explanations and predictions that are sought through the process of scientific inquiry (Reif & Larkin, 1991). This everyday model of satisficing may more accurately represent the understanding that occurs in classroom contexts than the scientific conceptual change model, unless the classroom in question has a climate that encourages a commitment to deep understanding and is sensitive to the unique needs of the students present (Pintrich et al., 1993).

Research on the concept of worldviews informs the thinking about how students experience school science. Kearney (1984) defines worldview as "conceptually organized macrothought" (p. 1); an individual's worldview comprises the set of assumptions determining his or her behavior and decision making. Even when students do not experience a significant conflict between the various worldviews they have been presented, they will frequently compartmentalize *school knowledge* – especially school science – perceiving it as existing independently of their daily lives. They may retrieve the science they have learned in school as necessary for homework and exams, but do not think to apply it to situations in the outside world, and let go of it once the school requirements have been completed (Cobern, 1996). Moreover, students' prior knowledge may lead them to construct intentions and conclusions that do not align with the teacher's actual agenda (Hennessy, 1993). For instance, while science teachers tend to immediately evoke science when describing nature, students may more naturally conjure up "aesthetic, religious, pragmatic, and emotional concepts" (Cobern, 1996, p. 596).

The process of compartmentalization seems to be more pronounced for students who experience a discord between school science and their indigenous beliefs. For these students, the process of border crossing between the "microcultures" of their home life and the science classroom can be challenging and even traumatic; such students may go so far as to exhibit significant "creativity and intransigence" in order to avoid deep understanding or acceptance of science concepts (Aikenhead & Jegede, 1999, p. 275). Cobern (1996) argues that the goal often assumed in the science education literature of moving students toward a "scientific worldview" is problematic because it fails to acknowledge that for some students, this notion implies the need to reject their current deeply held conceptions. Instead, he suggests that the goal should be to help students develop a "scientifically compatible worldview," which accounts for the idea that an individual will only make use of scientific ideas if they align with how he already makes sense of himself and of the world.

Jegede (1995) puts forth the theory of collateral learning as a model that foregrounds the culture of the learner as critical to the process of understanding science. Though Jegede originally employed the theory in the study of African learners engaging with Western notions of science, the principles are useful in understanding American classroom contexts as well. In the process of collateral learning, individuals construct an understanding of concepts taught in school alongside the prior understandings they have developed from their home communities. Different categories of collateral learning exist along a continuum. At one end, *parallel collateral learning* occurs when the learner encounters a new idea which is in opposition to his or her prior understanding, but does not perceive disequilibrium between the two concepts, possibly because the learner does not have enough understanding or experience to consider how they might conflict. On the other end is *secured collateral learning*, in which the learner grapples with the cognitive conflict between two conceptions and works toward reconciliation of them within his or her broader worldview. Jegede (1995) argues that effective science education requires understanding learning through a conceptual ecocultural paradigm, "a state in which the growth and development of an individual's perception of knowledge is drawn from the sociocultural environment in which the learner lives and operates" (p. 124).

In sum, as is the case with any other form of learning, science learning does not happen in a vacuum. The research sends a clear signal that the process of science learning cannot be understood without careful consideration of how the learners' prior knowledge and cultural background interact with the material presented during formal science instruction. Any learner is apt to experience some amount of discomfort when studying counterintuitive concepts with potentially existential implications. For students whose prior experience with these topics has been largely or solely through religious frameworks, encountering these concepts in the school science setting is likely to be particularly jarring. Without careful instruction that provides the necessary time and space to grapple with conflict, learners may consciously or subconsciously avoid deep understanding.

Implications for Pedagogy

Much of the research synthesized above comes from the fields of cognition and development, where researchers tend to remain largely agnostic regarding the practical implications of the work. However, in the literature that comes out of the science education research space (such as Jegede's work on collateral learning), a number of concrete recommendations for classroom practice have been put forth. Overall, researchers seem to agree that there is pedagogical value in incorporating discussions of learners' religious beliefs as they interact with the scientific concepts being introduced in the classrooms, though there are differences in the recommendations for how these conversations unfold. In this section, I will outline some notable conclusions drawn from the research and highlight important areas of disagreement.

Helping Students Draw Connections to Prior Knowledge and Beliefs

One clear message from the literature is that teachers have an important role to play in encouraging their students to reveal their initial understandings, and, as necessary, helping them to navigate the process of border crossing between the science classroom and the rest of their lives. Callanan et al. (2013) argue for the importance of making intentional and meaningful linkages between students' informal science experiences and the more formal science learning that happens in school. In particular, they suggest that children "may need guidance to recognize the rich background they themselves bring to the science classroom by virtue of their participation in conversations and activities from their everyday lives" (Callanan et al., 2013, p. 46). Rather than striving to simply convert students from their inherent beliefs to the acceptance of scientific explanations, Jegede (1995) argues that school science should aim to help students identify contexts in which their prior understandings are valuable. If this is not achieved, Jegede (1995) cautions, a student may maintain a barrier between his or her various contexts, perhaps managing to perform successfully in school science without developing the inclination to apply these understandings outside the classroom.

Teachers can help their students constructively engage with topics at the boundary of science and religion by acting as a *culture broker* (Aikenhead & Jegede, 1999) who facilitates students' movement across domains. Of course, this requires teachers to deeply know their students, including those who may be in the silent minority (or even majority). Cobern (1996) argues that science educators must "understand the fundamental, culturally based beliefs about the world that students bring to class, and how these beliefs are supported by students' cultures; because, science education is successful only to the extent that science can find a niche in the cognitive and socio-cultural milieu of students" (p. 603). This task also entails establishing an environment in which students are comfortable sharing their ideas, even if they suspect that they may not align with scientifically accepted explanations. Hanley et al. (2014) suggest that science teachers should build classroom cultures that permit all students to participate "without risking self-censorship or estrangement" (p. 1225).

Considering Religion through the Lens of Epistemology

It is evident from the literature that culture and religion are critical mediating factors that must be considered in any analysis of how students interact with school science (Hanley et al., 2014). Over the years, a number of researchers have advocated for the explicit acknowledgement and exploration of religion through historical and cultural lenses, even in public school settings. Sinatra and Nadelson (2011) claim that in such a highly religious country as the United States, calls for a rejection of religion in order to improve science education (e.g., Dawkins, 2006) are both implausible and unnecessary, and Postman (1995) makes a strong argument for advancing religious education based on its prominence in daily life and its interaction with other domains, including science. More recently, Long (2013) has argued that providing students with formal education about religion encourages them to embrace inclusivity, whether they choose to personally adopt a religious tradition or not. For educators who take a radical constructivist approach to learning, the act of "relegat[ing] beliefs to the outskirts of instruction" fails to account for the many types of reasoning that learners bring to the table, and may lead students to ask, "if science can't answer my question about this, what is it good for?" (Southerland et al., 2001, p. 344).

Yet, the majority of researchers in science education do seem to caution that introducing ideas about religion must be done carefully and strategically, so as not to imply that scientific and religious ways of knowing are interchangeable. The clearest path forward seems to be an increased focus on the nature of science and its epistemological similarities and differences to other domains. Many researchers align with Gould's (1999) model of non-overlapping magisteria, arguing that science and religion are capable of coexisting because the set of assumptions embedded within each way of knowing is distinct. Rather than conceiving of science and religion as conflicting domains, the two "should be viewed as epistemologies that have different roles and explain different aspects of the human condition" (Sinatra & Nadelson, 2011, p. 175). Explicitly differentiating between these two ways of knowing can provide learners with "a place to stand" (Southerland et al., 2001). To be able to explain why science and religion purport differing views on origins, for instance, students need to possess a high level of "epistemic insight" (Billingsley et al., 2014). In order to move towards this greater insight, Billingsley et al. (2014) suggest that students should have more opportunities to "consider and compare the natures of science and religion" (p. 1729). Cobern (1996) also recommends that science should be taught in conjunction with other academic disciplines for the purposes of helping students develop a "coherence view of knowledge" (p. 601) that more closely aligns with how knowledge is organized and used in one's daily life.

Researchers disagree about the most appropriate time and place to have these comparative discussions. Some have proposed that religion should be addressed in school, but not during science class. For instance, Evans et al. (2011) express a concern that incorporating discussions about religious explanatory frameworks into the science classroom may encourage students to construct inaccurate scientific models, though they do suggest that these conversations "might well have a role in the broader curriculum" (p. 131), given that children come to school with a wide variety of epistemological lenses. Sinatra and Nadelson (2011) suggest it is valuable to compare and contrast the epistemologies of science and religion, but they do not deem it appropriate for science teachers to present particular non-scientific explanations alongside scientific ones, as such an approach may lead students to believe that the alternative explanations are on par. However, they do propose that science teachers should welcome the discussion of historical and contemporary controversies *within* science (e.g., plate tectonics, the details of mass extinction events, etc.).

The critical exploration of these debates within science is likely to help students understand the nature and epistemology of the domain. On the other hand, in response to the fear that introducing the idea that some people might disagree with a particular concept will automatically undercut the science, Hanley et al. (2014) posit that a teachers' acknowledgement that a topic could be seen by some as controversial might provide an entry point into the discussion for certain students who would otherwise feel alienated. Others have argued that "quarantining" supernatural beliefs from the science classroom leads teachers and students to miss out on rich opportunities to explicitly consider the epistemological distinctions between the domains. Rather than being left out of classroom discussions, supernatural beliefs "should stand subject to the same kinds of empirical and theoretical scrutiny" as scientific beliefs (Shtulman, 2013, p. 208).

Of those who suggest that religious ideas can be productively acknowledged in science discussions, many recommend the strategy of "teaching the demarcation" – i.e., teachers should explore with students how science is in certain ways distinct from other ways of knowing and in other ways similar. As such, a critical understanding goal for science instruction should be that students are capable of identifying scientific approaches to a given topic, and distinguishing those from approaches that come from other domains (Ferrari & Taylor, 2010). Eflin et al. (1999) agree that science education should include the issue of demarcation, but they express concern that discussion of the subtle relationships between psychological, epistemological, and metaphysical issues "is likely to create more confusion than insight" for learners (p. 114).

Thus, while there seems to be some consensus around the idea that it is valuable to make some space for students' religious beliefs and supernatural explanations in a formal educational context, it remains inconclusive in the literature how this should be done or whether science classrooms are the appropriate location for these discussions – and given that every classroom is different, a universal set of *best practices* is unlikely to exist. However, I would argue that the research reviewed above makes a clear case against the status quo of acting as though students enter the classroom as blank slates without exposure to complex, and potentially conflicting, ideas about science and religion as ways of knowing.

Conclusions and Implications

Some additional insights and questions emerged from the literature that may hold promise for future research endeavors. First, and critically, more basic research is needed on religious and supernatural thinking, which seems to necessitate a change of mindset regarding the value of this work. Legare et al. (2012) express a hope to see future research that "treats supernatural cognition as an integral part of cognitive developmental theory and not as an early or primitive mode of thinking that is outgrown in the course of cognitive development" (p. 791). For instance, we do not yet have an understanding of why some children are better at developing integrated reasoning schemes than others. It is possible that some individual differences are due to influence from adults, but it is also plausible that that the differences are due to particular cognitive characteristics. Certain life events and the explanations that are subsequently presented to children may also prompt them to seek more integrated frameworks (Legare et al., 2012). Future research that can tease apart these distinctions would be valuable to the field of cognitive development, and also of great use to educators seeking to understand how these cognitive processes could inform pedagogy.

Another important question to consider moving forward is how teacher development could be informed by a better understanding of how learners think about science and religion. Researchers have been recommending that pre-service teachers study the philosophy and history of science since the 1960s, after a number of studies (e.g., Miller, 1963; Schmidt, 1967) found evidence that teachers lacked a solid understanding of the nature of science – in some cases, demonstrating even less understanding than their students (Lederman, 1992). However, there have not been similar recommendations for teachers to study religion or its relationship to other academic domains; at present, there is no explicit focus on religion in an overview of the research on programs for teacher development and preparation (Abo-Zena & Mardell, 2015; Ball & Tyson, 2011). This is particularly noteworthy because, compared to other professions, the population of teachers in the United States is a highly religious one. Not only is education a popular choice of major for incoming American college students who identify as religious, but majoring in education actually appears to be associated with an increase in reported religiosity over time (Kimball et al., 2009). Thus, it seems that it would be of value for teachers, including science teachers, to reflect on how their own ideas about religion may influence their teaching practice. For instance, Evans and Lane (2011) posit that science teachers tasked with teaching evolutionary theory could develop greater confidence in dealing with the various theological stances that students may bring to the classroom – as well as any religious conceptions of origins that the teachers themselves possess – if such ideas were explicitly addressed in teacher preparation programs.

Additionally, it appears evident that there is value to beginning these conversations at an early age. For instance, in a study examining the effectiveness of a storybook intervention designed to teach evolutionary mechanisms, Kelemen et al. (2014) found that five- to eight-year-olds demonstrated growth in their understanding of adaptation at the population level, and the older children in particular were capable of generalizing beyond the narrative to other species. In light of these findings, Kelemen et al. (2014) argue that is best to introduce students to counterintuitive scientific concepts at a young age, when they are less beholden to alternative commonsense explanations. From the perspective of religious education, Abo-Zena and Mardell (2015) found through a case study of a kindergarten classroom that young children were capable of, and very interested in, exploring issues of religion and spirituality with their classmates. Their research has implications for how schools might work with families to engage in thoughtful discussion of sensitive topics. Yet, most of the research on young children's development of scientific and religious conceptions exists in the domain of cognitive psychology, where an extra step is required to infer implications for classroom practice and the conclusions that can be drawn are limited outside the laboratory. Meanwhile, the educational research that exists is focused on secondary and higher education and on teachers. Research that focuses on how young children make sense of science and religion in instructional contexts would address a large and important gap in the literature.

Finally, there is more work to be done in the exploration of how children's ideas about science and religion connect to deeper understanding and engagement at a broader level. Ferrari et al. (2010) argue for the practice of "teaching for wisdom" – that is, infusing the curriculum with issues that carry deep and personal significance for students. In particular, they advocate for science classrooms in which students "learn to be intellectually honest and sophisticated in their thinking about the natural world and the human condition, without denying deep existential questions that authentically matter to how they personally live their lives" (Ferrari et al., 2010, p. 253). Connecting science to other issues, they argue – such as policy, ethics, and philosophy – can allow for the teaching of a rigorous science curriculum while simultaneously recognizing that "some ultimate mysteries remain beyond science" (Ferrari et al., 2010, p. 254).

Prior scholarship, mostly with older individuals, has pointed to the fruitfulness of using science to imbue learners with a sense of deeper meaning by emphasizing ideas like interconnectedness and the magnitude of time and space. In particular, recent research has indicated that leveraging learners' feelings of awe and wonder can be a powerful tool for engagement and motivation in science and can also facilitate the process of conceptual change (Cuzzolino, 2021; Gilbert & Byers, 2017; Valdesolo et al., 2017). Two powerful examples of this are the *Overview Effect* (White, 1998), a cognitive shift experienced by astronauts and cosmonauts who come to experience themselves and the world differently after viewing the Earth from space, and the *Science for Monks* program (Impey, 2014), in which His Holiness the Dalai Lama convened a group of Western scientists to introduce science to a class of Tibetan monks. In each of these cases, both experts and novices underwent a much more meaningful learning experience than they would have if the scientific principles without acknowledgement of their existential implications. It is intriguing to consider what would unfold if these same sorts of ideas were widely shared with young children. The research suggests that they are ready to learn.

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References

Abelson, R.P. (1963). Computer simulation of "hot cognition." In S. S. Tomkins & S. Messick (Eds.), *Computer simulation of personality: Frontier of psychological theory* (pp. 277- 302). New York, NY: Wiley.

Abo-Zena, M. M., & Mardell, B. (2015). When the children asked to study God, what did the parents say: Building family engagement around sensitive topics. *Religion & Education*, *42*(3), 289-307. https://doi.org/10.1080/15507394.2014.977716

Aikenhead, G. S., & Jegede, O. J. (1999). Cross-cultural science education: A cognitive explanation of a cultural phenomenon. *Journal of Research in Science Teaching, 36*(3), 269-287. https://doi.org/10.1002/(SICI)1098-2736(199903)36:3<269::AID-TEA3>3.0.CO;2-T

Ball, A. F., & Tyson, C. A. (2011). *Studying diversity in teacher education*. Lanham, MD: Rowman & Littlefield.

Banerjee, K., & Bloom, P. (2014). "Everything happens for a reason": Children's beliefs about purpose in life events. *Child Development, 86*(2), 503-518. https://doi.org/10.1111/cdev.12312

Barbour, I. G. (1966). *Issues in science and religion*. Englewood Cliffs, N.J.: Prentice-Hall.

Barbour, I. G. (1988). Ways of relating science and theology. In R. J. Russell, W. R. Stoeger, & G. V. Coyne (Eds.), *Physics, philosophy, and theology: A common quest for understanding* (pp. 21-48). Vatican City: Vatican Observatory.

Billingsley, B., Riga, F., Taber, K. S., & Newdick, H. (2014). Secondary school teachers' perspectives on teaching about topics that bridge science and religion. *Curriculum Journal, 25*(3), 372-395. https://doi.org/10.1007/s11165-012-9317-y

Bloom, P., & Weisberg, D. S. (2007). Childhood origins of adult resistance to science. *Science, 316*(5827), 996-997. https://doi.org/10.1126/science.1133398

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*(1), 32-42. https://doi.org/10.3102/0013189X018001032

Burr, J. E., & Hofer, B. K. (2002). Personal epistemology and theory of mind: Deciphering young children's beliefs about knowledge and knowing. *New Ideas in Psychology, 20*(2), 199-224. https://doi.org/10.1016/S0732-118X(02)00010-7

Callanan, M., Luce, M., Triona, L., Rigney, J., Siegel, D., & Jipson, J. (2013). What counts as science in everyday and family interactions? In B. Bevan, P. Bell, R. Stevens, & A. Razfar (Eds.), *LOST opportunities*: *Learning in out-of-school time* (pp. 29-48). Dordrecht, Netherlands: Springer.

Callanan, M.A., & Oakes, L.M. (1992). Preschoolers' questions and parents' explanations: Causal thinking in everyday activity. *Cognitive Development, 7*(2), 213-233. https://doi.org/10.1016/0885-2014(92)90012-G

Callanan, M., Valle, A., Luce, M., & Rigney, J. (2014). Discussions of moral issues emerging in family conversations about science. In C. Wainryb & H. Recchia (Eds.), *Talking about right and wrong: Parent-child conversations as contexts for moral development* (pp. 193-216). Cambridge, UK: Cambridge University Press.

Cobern, W. W. (1996). Worldview theory and conceptual change in science education. *Science Education, 80*(5), 579-610. https://doi.org/10.1002/(SICI)1098-237X(199609)80:5<579::AID-SCE5>3.0.CO;2-8

Cobern, W. W. (2000). The nature of science and the role of knowledge and belief. *Science & Education, 9*(3), 219-246. https://doi.org/10.1023/A:1008747309880

Coleman, R. J. (2014). *State of affairs: The science-theology controversy*. Eugene, Oregon: Cascade Books.

Corriveau, K. H., Chen, E. E., & Harris, P. L. (2015). Judgments about fact and fiction by children from religious and nonreligious backgrounds. *Cognitive Science, 39*(2), 353-382. https://doi.org/10.1111/cogs.12138

Crowley, K., Callanan, M. A., Jipson, J. L., Galco, J., Topping, K., & Shrager, J. (2001). Shared scientific thinking in everyday parent-child activity. *Science Education*, *85*(6), 712-732. https://doi.org/10.1002/sce.1035

Cuzzolino, M. P. (2021). "The awe is in the process": The nature and impact of professional scientists' experiences of awe. *Science Education*, *105*(4), 681-706. https://doi.org/10.1002/sce.21625

Danovitch, J. H., & Keil, F. C. (2004). Should you ask a fisherman or a biologist?: Developmental shifts in ways of clustering knowledge. *Child Development, 75*(3), 918-931. https://doi.org/10.1111/j.1467-8624.2004.00714.x

DiMaggio, P. (1997). Culture and cognition. *Annual Review of Sociology, 23*(1), 263-287. https://doi.org/10.1146/annurev.soc.23.1.263

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

Eflin, J. T., Glennan, S., & Reisch, G. (1999). The nature of science: A perspective from the philosophy of science. *Journal of Research in Science Teaching*, *36*(1), 107. http://dx.doi.org/10.1002/(SICI)1098-2736(199901)36:1<107::AID-TEA7>3.0.CO;2-3

Elkana, Y. (1981). *A programmatic attempt at an anthropology of knowledge.* Dordrecht, Netherlands: Springer Netherlands.

Evans, E. M. (2000). Beyond Scopes: Why Creationism is here to stay. In K. Rosengren, C. N. Johnson, & P. L. Harris (Eds.), *Imagining the impossible: The development of magical scientific and religious thinking in contemporary society* (pp. 305-333). Cambridge, UK: Cambridge University Press.

Evans, E. M. (2008). Conceptual change and evolutionary biology: A developmental analysis. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 263-294). New York, NY: Routledge.
Evans, J. H., & Evans, M. S. (2008). Religion and science: Beyond the epistemological conflict narrative. *Annual Review of Sociology*, *34*(1), 87-105. https://doi.org/10.1146/annurev.soc.34.040507.134702
Evans, E. M., & Lane, J. D. (2011). Contradictory or complementary? Creationist and evolutionist explanations of the origin(s) of species. *Human Development, 54*(3), 144-159. https://doi.org/10.1159/000329130
Evans, E. M., Legare, C., & Rosengren, K. (2011). Engaging multiple epistemologies: Implications for science education. In M. Ferrari & R. Taylor (Eds.), *Epistemology and science education: Understanding the evolution vs. intelligent design controversy* (pp. 111-139). New York, NY: Routledge.
Evans, E. M., Mull, M., & Poling, D. (2001, April). Confronting the existential questions: Children's understanding of death and origins. *Biennial Meeting of the Society for Research in Child Development.* Minneapolis, MN.
Ferrari, M. & Taylor, R.S. (2010). Teach the demarcation: Suggestions for science education. In M. Ferrari & R. Taylor (Eds.), *Epistemology and science education: Understanding the evolution vs. intelligent design controversy* (pp. 271-285). New York, NY: Routledge.
Ferrari, M., Lee, P., & Taylor, R.S. (2010). Teaching evolution in a historical context: From the wisdom of the ancient Greeks to genetic algorithms. In M. Ferrari & R. Taylor (Eds.), *Epistemology and science education: Understanding the evolution vs. intelligent design controversy* (pp. 243-267). New York, NY: Routledge.
Fugelsang, J. A., & Dunbar, K. N. (2005). Brain-based mechanisms underlying complex causal thinking. *Neuropsychologia*, *43*(8), 1204-1213. https://doi.org/10.1016/j.neuropsychologia.2004.10.012
Gauchat, G. (2015). The political context of science in the United States: Public acceptance of evidence-based policy and science funding. *Social Forces, 94*(2), 723-746. https://doi.org/10.1093/sf/sov040
Geary, D. C. (2008). An evolutionarily informed education science. *Educational Psychologist, 43*(4), 179-195. https://doi.org/10.1080/00461520802392133
Gelman, S. A. (2011). When worlds collide – or do they? Implications of explanatory coexistence for conceptual development and change. *Human Development, 54*(3), 185-190. https://www.jstor.org/stable/26765004
Gilbert, A., & Byers, C. C. (2017). Wonder as a tool to engage preservice elementary teachers in science learning and teaching. *Science Education*, *101*(6), 907-928. https://doi.org/10.1002/sce.21300
Gottlieb, E., & Wineberg, S. (2012). Between *veritas* and *communitas*: Epistemic switching in the reading of academic and sacred history. *The Journal of the Learning Sciences, 21,* 84-129. https://doi.org/10.1080/10508406.2011.582376
Gould, S. J. (1999). *Rocks of ages: Science and religion in the fullness of life*. New York: Ballantine Publishing Group.
Grotzer, T. A., & Solis, S. L. (2015). Action at an attentional distance: A study of children's reasoning about causes and effects involving spatial and attentional discontinuity. *Journal of Research in Science Teaching*, *52*(7), 1003-1030. https://doi.org/10.1002/tea.21233
Haden, C. A. (2010). Talking about science in museums. *Child Development Perspectives*, *4*(1), 62-67. https://doi.org/10.1111/j.1750-8606.2009.00119.x

Hanley, P., Bennett, J., & Ratcliffe, M. (2014). The inter-relationship of science and religion: A typology of engagement. *International Journal of Science Education, 36*(7), 1210-1229. https://doi.org/10.1080/09500693.2013.853897

Harris, P.L. (2002). What do children learn from testimony? In P. Carruthers, S. Stitch, & M. Siegal (Eds.), *The cognitive basis of science* (pp. 316-334). Cambridge, UK: Cambridge University Press.

Harris, P. L., & Giménez, M. (2005). Children's acceptance of conflicting testimony: The case of death. *Journal of Cognition and Culture*, *5*(1)*,* 143-164. https://doi.org/10.1163/1568537054068606

Harris, P. L., & Koenig, M.A. (2006). Trust in testimony: how children learn about science and religion. *Child Development*, *77*(3), 505-524. https://doi.org/10.1111/j.1467-8624.2006.00886.x

Heiphetz, L., Spelke, E. S., Harris, P. L., & Banaji, M. R. (2014). What do different beliefs tell us? An examination of factual, opinion-based, and religious beliefs. *Cognitive Development, 30,* 15-29. https://doi.org/10.1016/j.cogdev.2013.12.002

Hennessy, S. (1993). Situated cognition and cognitive apprenticeship: Implications for classroom learning. *Studies in Science Education, 22*(1), 1-41.

Hofer, B. K., Lam, C. F., & DeLisi, A. (2011). Understanding evolutionary theory: The role of epistemological development and beliefs. In M. Ferrari & R. Taylor (Eds.), *Epistemology and science education: Understanding the evolution vs. intelligent design controversy* (pp. 95-110). New York: Routledge.

Impey, C. (2014). *Humble before the void: A Western astronomer, his journey East, and a remarkable encounter between Western science and Tibetan Buddhism.* West Conshohocken, PA: Templeton Press.

Järnefelt, E., Canfield, C. F., & Kelemen, D. (2015). The divided mind of a disbeliever: Intuitive beliefs about nature as purposefully created among different groups of non-religious adults. *Cognition, 140,* 72-88. https://doi.org/10.1016/j.cognition.2015.02.005

Jegede, O. J. (1995). Collateral learning and the eco-cultural paradigm in science and mathematics education in Africa. *Studies in Science Education, 25,* 97-137. https://doi.org/10.1080/03057269508560051

Kahneman, D. (2003). Maps of bounded rationality: Psychology for behavioral economics. *The American Economic Review, 93*(5), 1449-1475. https://doi.org/10.1257/000282803322655392

Kearney, M. (1984). *Worldview.* Novato, CA: Chandler & Sharp Publishers.

Kelemen, D. (2004). Are children "intuitive theists"? Reasoning about purpose and design in nature. *Psychological Science*, *15*(5), 295-301. https://doi.org/10.1111/j.0956-7976.2004.00672.x

Kelemen, D., Emmons, N. A., Schillaci, R. S., & Ganea, P. A. (2014). Young children can be taught basic natural selection using a picture-storybook intervention. *Psychological Science, 25*(4), 893-902. https://doi.org/10.1177/0956797613516009

Kimball, M. S., Mitchell, C. M., Thornton, A. D., & Young-Demarco, L. C. (2009). Empirics on the origins of preferences: The case of college major and religiosity. NBER working paper, no. 15182. Cambridge, MA: National Bureau of Economic Research. https://doi.org/10.3386/w15182

Koul, R. (2006). Religious outlook and students' attitudes towards school science. *Journal of Beliefs & Values, 27*(3), 251-267. https://doi.org/10.1080/13617670601000936

Lane, J. D., & Harris, P. L. (2014). Confronting, representing, and believing counterintuitive concepts navigating the natural and the supernatural. *Perspectives on Psychological Science, 9*(2), 144-160. https://doi.org/10.1177/1745691613518078

Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching, 29*(4), 331-359. https://doi.org/10.1002/tea.3660290404

Legare, C. H., Evans, E. M., Rosengren, K. S., & Harris, P. L. (2012). The coexistence of natural and supernatural explanations across cultures and development. *Child Development, 83*(3), 779-793. https://doi.org/10.1111/j.1467-8624.2012.01743.x

Lesser, H. (1977). The growth of perceived causality in children. *The Journal of Genetic Psychology*, *130*(1), 145-152. https://doi.org/10.1080/00221325.1977.10533241

Long, D. E. (2013). Finding Jesus's magic pineapple: Or, improving science education by improving religious education. *Cultural Studies of Science Education, 8*(2), 389-398. https://doi.org/10.1007/s11422-013-9491-x

Luce, M. R., Callanan, M. A., & Smilovic, S. (2013). Links between parents' epistemological stance and children's evidence talk. *Developmental Psychology, 49*(3), 454-461. https://doi.org/10.1037/a0031249

Lutz, D. J., & Keil, F. C. (2002). Early understanding of the division of cognitive labor. *Child Development, 73*(4), 1073-1084. https://doi.org/10.1111/1467-8624.00458

Miller, P.E. (1963). A comparison of the abilities of secondary teachers and students of biology to understand science. *Iowa Academy of Science, 70,* 510-513.

National Academy of Sciences (1998). *Teaching about evolution and the nature of science.* National Academy Press, Washington, DC.

National Academy of Sciences. (2008). *Science, evolution, and creationism.* Washington, DC: National Academy Press.

NGSS Lead States. (2013). *Next generation science standards: For states, by states.* Washington, DC: The National Academies Press.

Nussbaum, J. (1985) The earth as a cosmic body. In R. Driver, E. Guesne, & A, Tiberghian (Eds.), *Children's ideas in science* (pp. 170-192). Philadelphia: Philadelphia Open University Press.

Pew Forum. (2009). *Public praises science; Scientists fault public, media*. Retrieved from http://www.people-press.org/2009/07/09/public-praises-science-scientists-fault-public-media/.

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research*, *63*(2), 167-199. https://doi.org/10.3102/00346543063002167

Postman, N. (1995). *The end of education.* New York: Alfred A. Knopf.

Reif, F., & Larkin, J. H. (1991). Cognition in scientific and everyday domains: Comparison and learning implications. *Journal of Research in Science Teaching*, *28*(9), 733-760. https://doi.org/10.1002/tea.3660280904

Schmidt, D.J. (1967). Test on understanding science: A comparison among school groups. *Journal* of *Research in Science Teaching, 5*(4), 365-366. https://doi.org/10.1002/tea.3660050411

Scopes Case, 289 S.W. 363, 154 Tenn. 105, 154 Tennessee 105 (Supreme Court 1927).

Shtulman, A. (2013). Epistemic similarities between students' scientific and supernatural beliefs. *Journal of Educational Psychology, 105*(1), 199-212. https://doi.org/10.1037/a0030282

Shtulman, A., & Harrington, K. (2016). Tensions between science and intuition across the lifespan. *Topics in Cognitive Science, 8*, 118-137. https://doi.org/10.1111/tops.12174

Shtulman, A., & Valcarcel, J. (2012). Scientific knowledge suppresses but does not supplant earlier intuitions. *Cognition, 124*, 209-215. https://doi.org/10.1016/j.cognition.2012.04.005

Siegel, H. (1998). Knowledge, truth, and education. In D. Carr (Ed.), *Education, knowledge and truth: Beyond the postmodern impasse* (pp. 19-36). London, UK: Routledge.

Sinatra, G. M., & Nadelson, L. S. (2011). Science and religion: Ontologically different epistemologies? In M. Ferrari & R. Taylor (Eds.), *Epistemology and science education: Understanding the evolution vs. intelligent design controversy* (pp. 173-193). New York, NY: Routledge.

Smith, M. U. (1994). Counterpoint: Belief, understanding, and the teaching of evolution. *Journal of Research in Science Teaching, 31*(5), 591-597. https://doi.org/10.1002/tea.3660310512

Smith, M. U., Siegel, H., & McInerney, J. D. (1995). Foundational issues in evolution education. *Science & Education*, *4*(1), 23-46. https://doi.org/10.1007/BF00486589

Southerland, S. A., Sinatra, G. M., & Matthews, M. R. (2001). Belief, knowledge, and science education. *Educational Psychology Review*, *13*(4), 325-351. https://doi.org/10.1023/A:1011913813847

Stanovich, K.E. and West, R.F. (2000). Individual differences in reasoning: Implications for the rationality debate? *Behavioral and Brain Sciences, 23*(5), 645–665. https://doi.org/10.1017/S0140525X00003435

Strike, K. A., & Posner, G. J. (1982). Conceptual change and science teaching. *European Journal of Science Education*, *4*(3), 231-240. https://doi.org/10.1080/0140528820040302

Valdesolo, P., Shtulman, A., & Baron, A. S. (2017). Science is awe-some: The emotional antecedents of science learning. *Emotion Review, 9*(3), 215-221. https://doi.org/10.1177/1754073916673212

Vlach, H. A., & Noll, N. (2016). Talking to children about science is harder than we think: characteristics and metacognitive judgments of explanations provided to children and adults. *Metacognition and Learning, 11*, 317-338. https://doi.org/10.1007/s11409-016-9153-y

Vosniadou, S., & Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive psychology*, *24*(4), 535-585. https://doi.org/10.1016/0010-0285(92)90018-W

Wandersee, J. H., Mintzes, J. J., & Novak, J. D. (1994). Research on alternative conceptions in science. *Handbook of research on science teaching and learning*, *177*, 210.

Wellman, H.M. (2014). *Making minds: How theory of mind develops.* New York: Oxford University Press.

White, F. (1998). *The overview effect: Space exploration and human evolution*. AIAA.

Wilson, E.O. (1998). *Consilience: The unity of knowledge*. New York: Knopf.