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Teleological Minds

HOW NATURAL INTUITIONS ABOUT AGENCY AND PURPOSE INFLUENCE LEARNING ABOUT EVOLUTION

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Natural selection is one of the core mechanisms of evolution, a unifying principle in biology, and the process responsible for the functional adaptation of biological organisms. Despite its centrality to understanding biological complexity and diversity and its key practical relevance to medicine, biotechnology, and agriculture, natural selection remains one of the most widely misunderstood concepts of contemporary science. Misconceptions about the process not only persist among the high school students and undergraduates who are the usual targets of instructional units focused on natural selection and evolution but, disturbingly, also among many of the postsecondary teachers who have been trained to instruct them on the topic (e.g., Brumby, 1979, 1984; Bishop & Anderson, 1990; Clough & Wood-Robinson, 1985; Deadman & Kelly, 1978; Evans, Legare, & Rosengren, 2011; Greene, 1990; Jungwirth, 1975, 1977; Nehm, Kim, & Sheppard, 2009; Nehm & Schonfeld, 2007; Shtulman, 2006; Shtulman & Calabi, this volume).

In this chapter, I will review some of these misunderstandings and argue that many of them have their roots in cognitive biases that are observable in preschoolers and elementary school children. Central among these is the teleological tendency to explain phenomena by reference to function. I will describe developmental work exploring this tendency and also review recent findings, largely from my own lab, concerning the possible origins of the bias. The chapter concludes with a discussion of the implications of this and other developmental research for instructional practice in evolutionary education.

Teleological Thinking in Students' Reasoning about Natural Selection

Stated in the rudimentary, nonspecialist terms adopted throughout this chapter, natural selection occurs because random variations in the heritable characteristics exhibited by members of biological populations means that certain individuals have a greater likelihood of survival than others (e.g., because of greater access to finite resources such as food). Because advantaged organisms are more likely to survive and produce offspring who inherit their beneficial traits, cumulatively, over multiple cycles and generations of differential reproductive success, those successful traits become dominant in the animal population.

This is the straightforward, elegant mechanism that Darwin identified as underlying biological adaptation. However, in the multitude of studies exploring older students' and adults' reasoning about natural selection, specific persistent misconceptions about the mechanism recurrently occur even after instruction (e.g., Bishop & Anderson, 1990; Brumby, 1979, 1984; Clough & Wood-Robinson, 1985; Evans, 2005; Greene, 1990; Nehm, Kim, & Sheppard, 2009; Nehm & Reilly, 2007; Nehm & Schonfeld, 2007). At the core of many of these misunderstandings is a teleological belief that organisms have the traits that they currently possess because those traits perform functions that aid survival (e.g., Deadman & Kelly, 1978; Jensen & Finley, 1995, 1996; Jungwirth, 1977; Pedersen & Halldén, 1994; Tamir & Zohar, 1991).

Importantly, the belief in function as a primary engine in adaptation is not necessarily, in itself, a major issue unless it reflects one of two underlying problems. The first, more mildly egregious one is an inaccurate "naive adaptationist" conviction that function is the *only* explanation of why traits evolve. The concern here is that, aside from making people vulnerable to spurious "just so" accounts of all traits (e.g., women evolved two breasts as optimal flotation devices; see Pinker & Bloom, 1990), such a view is also false because traits can emerge for other reasons, for example, as byproducts of other traits (Gould & Lewontin, 1979).

Concerns about naive adaptationism pale, however, in contrast to the second problem: students' attraction to functional explanations of traits usually reflects confused or significantly mistaken underlying causal assumptions about how natural selection works. Research over the last 30 years involving elicitations of students' explanations of adaptation (see Gregory, 2009, for review) suggest that, crudely speaking, these mistaken explanations can be categorized into three types of views: "basic function-based," "basic need-based," and "elaborated need-based." Each of these has potentially different instructional prognoses given the different levels of causal-mechanical elaboration and explanatory depth that they reflect (Wilson & Keil, 1998). For reasons to which I will return later, it may be of particular concern that one of these overarching categories (elaborated need-based) is probably systematically underdiagnosed.

"Basic function-based" and "basic need-based" views are the least causally elaborated and the distinction between them is subtle. While basic function-based explanations make no explicit reference to any underlying antecedent causes at all, explanations in the basic need-based category at least allude to them. Specifically, basic function-based explanations are stated in ways that suggest a trait's current ability to perform a beneficial function is the only factor needed to explain why that trait came into being (e.g., "giraffes have long necks *so that* they can reach high food"). Such explanations therefore involve the backwards logic of positing a trait's present consequence or effect as its own historical cause—the problem of reverse logic classically associated with teleological explanation and the one that has also rendered its validity in science highly controversial (see edited volumes by Allen, Bekoff & Lauder, 1998; Sober, 1984).

By contrast, explanations in the basic need-based category avoid the reverse causality problem by going one temporal step further back in terms of causal reference and appealing to an animal's antecedent physiological need as the historical factor that prompted its physical structure to change (e.g., "giraffes got long necks because *they needed them* to reach high food"). As in the basic function-based category, however, these explanations do not elaborate any actual mechanism of change. This is true even though a biological survival need (e.g., requiring sustenance) is invoked as an antecedent causal trigger. Absent any explicit reference to underlying mechanism, basic need-based explanations therefore carry the implication that an animal's biological need has an intrinsic power to bring a heritable trait into existence by having direct transformational effects on an animal's underlying (genetic) nature.

By comparison to both these other categories, explanations in the "elaborated need-based" category invoke more theoretically cohesive notions of mechanism. This sounds like a positive quality except that, because they are elaborations of an already flawed need-based rationale, these explanations are far from the "consequence etiology" (Wright, 1976) that has somewhat salvaged the legitimacy of teleological explanation for the evolutionary sciences. Specifically, for biologists and philosophers of science, apparently reverse causal teleological statements like "mammals evolved kidneys to filter blood" can be scientifically warranted given the underlying causal assumption that contemporary blood-filtering kidneys exist because of the differential reproductive success of earlier animals whose progenitor organs happened to offer marked, heritable, blood-filtering benefits (e.g., Wright, 1976; Neander, 1991; see Sober, 1984).

Studies indicate, however, that the sets of causal beliefs underpinning students' elaborate need-based views of adaptation are far less Darwinian in nature. One subtype of elaborated need-based view is the "effort-based" theory that individual animals acted in goal-directed ways to meet their needs and that, through their efforts, their bodies were genetically transformed to "grow" or produce the functional part. A classic example of this is the notion that giraffes acquired long necks through repeatedly trying to eat highly placed leaves or fruit on trees (e.g., Clough & Wood-Robinson, 1985; Demastes, Settlage, & Good, 1995; Evans et al., 2010; Jensen & Finley,1995; Kampourakis & Zogza, 2008). Another subtype of elaborated need-based view is the potentially interconnected "design-based" intuition that a personified "Mother Nature" or "Evolution" responded to the animals' functional needs by generating or conferring the functional part with a view to preserving the animal's survival. An example of this is the idea that giraffes have long necks because Natu[illegible]ansformed, "evolved," or "adapted" them so they could reach food on the tops of trees to survive (e.g., Kampourakis & Zogza, 2008; Moore et al., 2002; see also Gregory, 2009).

One further thing to note about need-based rationales in general—whether they fall within the basic need-based or elaborated need-based category—is that while they may differ in explanatory elaboration, these kinds of rationale tend to share some important mistaken corollary assumptions. First, adaptation is viewed as resulting from transformational changes of biological or genetic makeup within an animal's lifetime. Second, the traits acquired through these transformations are then seen as being genetically heritable ("soft inheritance," or naive Lamarckism). That is, animals acquire functionally necessary traits as a result of their need, and all their offspring inherit their parents' acquired traits in a straightforward genetic handover. This view leaves little room for notions of variability given that all animals in a population experience the need that prompts them to change, and then genetically pass those traits on (see Shtulman, 2006). Aspects of this soft inheritance assumption probably apply in some degree to basic function-based explanations also. In consequence, the different packages of assumptions involve misconceptions that leave little opportunity for envisaging change through a cumulative process of differential survival, reproduction, and inheritance: adaptation is ontologically miscategorized as an event in the life of each individual rather than a process that affects populations of individuals over generations (Chi, 2008).

It may be noticed from this brief overview that students' inaccurate ideas about natural selection are somewhat extensive whether their causal understanding is classified as basic function-based, basic need-based, or elaborated need-based. As a result, it might seem odd to characterize some of these views as more preferable than others from an instructional perspective. However, based on an assumption that it is easier to effect conceptual change when the task involves confronting a relative absence of conceptual knowledge (i.e., promoting more of a novice-to-expert shift) than when it involves challenging a more tightly coherent network of preconceived ideas (i.e., promoting theory change or alternative theory elaboration) (Carey, 1985; see also Sinatra, Brem, & Evans, 2008), individuals in the elaborated need-based category seem likely to be at a disadvantage relative to individuals whose explanations are in the less causally elaborated basic function-based or basic need-based categories (for preliminary evidence see Evans, Legare, & Rosengren, 2011). This is despite the fact that all of these views appear to embody substantial and potentially robust specific misconceptions about adaptation as involving individual level genetic transformation that is handed down the generations. They therefore reflect a general lack of recognition that a multistep causal chain is required to use functional effects as explanations in evolutionary biology. Nevertheless, students who harbor "elaborated need-based" perspectives may be hampered even further than those in the other categories not only because their reasoning shows greater coherence but also because their ideas may be contaminated by causal notions from outside the biological realm.

More specifically, insofar as basic function-based or basic and elaborated need-based rationales appeal to a survival relevant function as playing some kind of causal role in a trait's origins, such explanations can be characterized as having biological content: That is, the allusions to biological need suggest that students' understanding of natural selection is appropriately located within a framework of theoretical assumptions specific to their understanding of biological phenomena (e.g., Evans et al., 2011). However, the effort- and design-based subtypes of elaborated need-based views additionally invoke mechanisms more characteristic of the domain of intentional action than the domain of biology. For example, they involve reference to repetitive seeking to achieve a goal (effort-based) or foresightful manipulation by an agentive force (design-based). To the extent that these kinds of naive psychological ideas are also present in these students' reasoning, they introduce further ontological complications for biological conceptual change (see Carey, 1985; Chi, 2008).

Unfortunately, at the present time, it is difficult to determine the frequency with which psychologically elaborated need-based views are held relative to more basic function- and need-based views; perhaps for understandable pragmatic reasons, people rarely use the overtly intentional language of "intentions," "wants" and "desires" when answering questions that explicitly evaluate their understanding of evolution (see Evans et al., 2011, for evidence). Furthermore, most of the research on students' understanding of natural selection has adopted explicit, open-ended questionnaire or interview elicitation methods that, while descriptively illuminating, can be limited in their abilities to fully reveal students' causal beliefs, especially the influence of their latent or tacit assumptions. This is because students will often give shorthand responses to open-ended questions due to pragmatic assumptions of shared understanding with their audience, concerns about being evaluated, or because they are not provided with probes sufficient to unpack their logic. In consequence, while a review of studies adopting interview or open-ended questioning techniques might suggest that students predominantly fall into the causally superficial basic function-based and basic need-based views of natural selection, it is difficult to know just how accurate this assessment is. Arguably, the robust persistence of students' misunderstandings about natural selection even in the face of significant instructional exposure (e.g., Brumby, 1984, on medical biology students; Nehm, Kim, & Sheppard, 2009, on biology teachers; Nehm & Reilly, 2007, on biology majors) might suggest the theoretical depth of students' misconceptions is far deeper than their overt linguistic statements indicate.

Research using more indirect experimental methods has certainly produced results consistent with the interpretation that students' basic function- and need-based views are more elaborated than they might superficially appear. Recent findings suggest they might be embedded within a framework of intuitions characterizing Nature as a designing agent. For example, as part of a large multifaceted project exploring adults' reasoning about natural phenomena (Kelemen, Rottman, & Seston, 2011), we asked 81 undergraduates to complete the 40-item multiple choice Conceptual Inventory of Natural Selection (CINS), which assesses students' understanding of adaptation and evolution (Anderson et al., 2002).

Independently, the same students were also asked to rate their agreement with a number of statements about their religious, scientific, and quasi-scientific beliefs, including "I believe Earth is driven to preserve living things"—a statement assessing their construal of Nature as a nurturant, protective, self-regulating intentional agent, a being sometimes referred to as "Gaia" in informal religious circles (but see also Lovelock, 2000; Lovelock & Margulis, 1974, for usage of "Gaia" in a more scientific context).

Results revealed that undergraduates' mean level of agreement (100% = strong agreement, 0% = no agreement) with the scientifically unwarranted statement "I believe Earth is driven to preserve living things" was relatively high (59%), as was their mean agreement with highly correlated statements such as "I believe the Earth is alive" (64%); "I believe that Nature is a powerful being" (73%); "The Earth is driven to provide optimal conditions for Life" (62%). In general then, these students who strongly endorsed natural selection as an explanation of both human (M = 82%) and nonhuman origins (M = 81%), had a marked tendency to view the Earth as a powerful, protective, controlling being. More importantly, this agentive view of Nature was found to be highly correlated with students' rather high tendency (M = 43% incorrect) to endorse inaccurate (e.g., need- and function-based) answer options on the CINS ($r(81) = 0.45$, $p < 0.05$).

Findings suggesting that underlying beliefs about natural agency exert nonobvious influence on students' biological reasoning are potentially less surprising when considered in a broader context of research which suggests that such immanent agentive ideas influence adults' scientifically incorrect ideas about living and nonliving nature more generally. For example, in contrast to their ratings of belief in God, students' ratings of the Gaia notion that "Earth is driven to preserve living things" has been found to strongly predict undergraduates, promiscuous (but often covert) tendencies to teleologically explain not only living but also nonliving natural phenomena in terms of a purpose: That is, an agentive construal of nature provides a significant reason why American undergraduates find scientifically inaccurate teleological statements such as "the sun makes light so that plants can photosynthesize" highly believable even after extensive high school and college level tuition in both the physical and life sciences (Kelemen, Rottman, et al., 2012; also Kelemen & Rosset, 2009).

In sum, students' teleological beliefs about adaptation are prevalent, are potentially embedded in a framework of implicit underlying intentional assumptions about nature, and represent a significant departure from a scientific understanding of how animals change via natural selection. So, how do these nonscientific ideas about natural selection take root and why are they so resistant to change even in the face of instruction (Brumby, 1985; Kelemen & Rosset, 2009; Kelemen, Rottman, et al., 2012; Nehm, Kim, & Sheppard, 2009; Nehm & Reilly, 2007)?

Multiple factors seem implicated. One candidate is the nature of student instruction. As noted earlier, research findings suggest that many postsecondary teachers misunderstand natural selection (Greene, 1990; Jungwirth, 1975; Nehm &

Shonfeld, 2008) and do not feel confident in their ability to teach it (Nehm & Reilly, 2007). Furthermore, scientific experts and instructional materials such as textbooks often compound problems by using teleological and anthropomorphic language when describing natural selection and related concepts (Jungwirth, 1977; Moore et al., 2002). Another factor is students' emotional resistance to instruction (Sinatra & Pintrich, 2003). Because natural selection is a central evolutionary mechanism, it can potentially evoke complex emotional reactions in students with particular religious commitments despite the fact that the topic of adaptation is less religiously controversial than the topic of speciation, and the relationship between accepting and understanding evolutionary mechanisms is far from straightforward (e.g., Evans et al., 2011; Sinatra, Brem, & Evans, 2008).

These variables doubtlessly have a role to play, and other chapters in this volume will address them in substantial detail. But one further factor holds central importance—not least because it is likely to be at the root of some of the other candidate explanations just described, particularly teachers' misconceptions and errors by textbook writers. Specifically, it is the existence of various deep-seated cognitive tendencies—for example, teleological, intentional, and essentialist biases—that students bring to the learning situation. Cognitive developmental research suggests these everyday intuitive reasoning biases emerge early in development, persist covertly and sometimes overtly into adulthood (e.g., Kelemen & Rosset, 2009; Gelman, 2005; Legare & Gelman, 2008; Rosset, 2008; Shtulman, 2006), and represent default assumptions likely to influence the construction and persistence of students' scientifically in accurate causal theories about natural phenomena. Crucially, if they are unchallenged from early childhood, ideas derived from these deeply rooted biases may become so entrenched that their habitual nature creates a significant ongoing impediment to scientific literacy.

Given its central role in students' misconceptions about natural selection, and the fact that it is the focus of my own research, in the sections that follow I will focus on children's development of one of these biases in particular: the teleological bias. After describing children's highly generalized tendencies to ascribe purpose to living and nonliving natural phenomena, I will then turn to research exploring the potential origins of their broad teleological bias, paying attention to two cognitive accounts in particular. One of these accounts is that children broadly view natural phenomena as existing for a purpose because of underlying intuitions that natural phenomena and natural order derive from intentional design. If this account holds true—and it is also assumed that there is some degree of conceptual continuity between children and adults—then older students' elaborated design-based misconceptions about natural selection may not only be an underdiagnosed problem in evolutionary education but one that presents particular instructional obstacles. This is because of their potential theoretical coherence, mixed intentional/biological ontology, and many years of entrenchment from early development onward.

The alternative account is that children's generalized tendency to ascribe functions to natural entities results from a far more basic, low-level cognitive mechanism: one that is sensitive to agents' goals and automatically ascribes purposes to any objects that seem to achieve them. In other words, children come to teleologically view entities as "for" a purpose based on little more than cues about functional utility. If this account holds true, then children's teleological construal results from causal assumptions whose theoretical coherence and depth is on a par with that involved in older students' basic function-based and basic need-based views of natural selection. As a result—and assuming conceptual continuity between children and older students—research indicating that children's teleological bias is rooted in this goal-driven mechanism suggests a more optimistic scenario regarding the potential malleability of older students' misconceptions about natural selection and their likely responsiveness to well-targeted instruction.

Young Children's Ideas about Function in Nature: "Promiscuous Teleology"

Piaget famously concluded that children are "artificialists" who egocentrically view all things as made by people for a purpose (Piaget, 1929). He suggested that this tendency arose, in significant part, because young children are deficient at representing physical mechanical causes and therefore rely on their subjective experience of their own and their parents' intentional actions as a basis for explanation. Nowadays, there are many reasons to think that this specific proposal is wrong. First, contrary to Piaget's suggestion of representational deficiency, contemporary cognitive developmental research indicates that children are able to reason in terms of physical mechanical causes from infancy, discriminating physical and intentional causation from quite early on (e.g., Bloom, 2004; Carey, 2009; Spelke & Kinzler, 2007; Spelke, Phillips, & Woodward, 1995). Second, contrary to the suggestion that children generalize from experiences of their own or their parents' creative powers to view human actions as the source of everything, research has also shown that 4- and 5-year-old children know that, while people make artifacts such as tables and chairs, they do not make animals, oceans, and planets (Gelman & Kremer, 1991; Kelemen & DiYanni, 2005).

Having said all of this, to state a slightly tired refrain within developmental psychology: Piaget was not all wrong. There is evidence to suggest that children are inclined to think of natural phenomena as intentionally created, albeit not by a human agent (Evans, 2000a, 2000b, 2001)—findings I will briefly describe shortly. Furthermore, children do evidence a tendency to broadly construe all kinds of natural objects and events as occurring for a purpose, displaying the "promiscuous teleological bias" that is the focus of this section (Kelemen, 1999a, 1999b, 2003, 2004).

Children's broad tendency to categorize and explain natural phenomena by reference to purpose has been revealed in studies adopting a variety of methods. Current data suggests that this pattern emerges sometime in the early preschool years. For example, in one study, preschoolers were charged with helping a puppet become smart by answering questions for him about what living things (e.g., tiger), artifacts (e.g., clock), nonliving natural objects (e.g., mountain), and their physical parts were "for" while also being careful to identify for him when the question was a "silly question" to ask, that is "a question that has no answer." Despite showing a capacity to withhold functional answers on control items, in contrast to adults who generally selectively treated the "what's X for?" question as only appropriate to biological traits (e.g., ear), artifacts (e.g., pants), and their parts (e.g., pocket), children responded by stating a function for almost every kind of object and part. For instance, mountain peaks were "to climb," plants were "to grow," and lions were "for walking" (Kelemen, 1999a, Study 1).

A further study then explored whether children really viewed these functions as teleological explanations of the entities' existence or whether they thought they were simply activities that the objects could characteristically do or be used to do. Preschoolers and adults listened to two characters discuss the functional status of artifacts, living things, and nonliving natural things and decided whether, for example, a tiger is "made for something" like "walking and being seen at a zoo" "and that's why it is here" or whether a tiger "isn't made for anything," "it can do lots of things" like "walking and being seen at a zoo" but "that's not why it is here." Once again, while adults were selectively teleological, preschool children agreed that entities of all kinds are "made for something" and broadly assigned purposes to entities of all kinds (Kelemen, 1999a, Study 2).

Finally, a further study designed in response to spontaneous statements by kindergarten children found that, when told about living and nonliving natural entities that can no longer perform certain functional activities (e.g., a mountain that can no longer be climbed), 5- and 6-year-olds endorsed the view that they are broken and hence in need of repair or replacement (DiYanni & Kelemen, 2005).

This "promiscuous teleological" bias persists and shows signs of strengthening in elementary school children. For instance, when asked to conduct a "science" task and decide whether prehistoric animals and natural entities (e.g., rocks) have certain properties (e.g., points) because of a physical process (e.g., "the rocks were pointy because bits of stuff piled up for a long period of time"), or because they perform a function, American 6- to 9-year-olds differed from adults by tending to endorse teleological explanations. This was true whether the teleological explanations invoked "self-survival" functions (e.g., "the rocks were pointy so that animals would not sit on them and smash them") or "artifact" functions (e.g., "the rocks were pointy so that animals could scratch on them when they got itchy"). Furthermore, among early elementary school-age children, this teleological preference occurred even when children had been primed to think in terms of simple physical-causal mechanisms and had also been explicitly told to think "like scientists" (Kelemen, 1999b, 2003; Kelemen, 2012, for preliminary results with 4-year-olds; but see Keil, 1992; Greif, Kemler Nelson, Keil, & Gutierrez, 2006).

Finally, when asked about the first origins of living and nonliving natural entities (e.g., "Why did the first ever river occur?"), British 6- to 9-year-old elementary school children were also more likely to spontaneously account for them in terms of the "functions" they perform (e.g., "so animals could drink from them") than either physical-causal mechanisms (e.g., "it rained and rained") or purely intentional-causal antecedents (e.g., "someone made them") (Kelemen & DiYanni, 2005).

Explanations of Promiscuous Teleology: Contextual Factors

PARENTAL EXPLANATION

Why does this bias occur? As noted earlier, there are many possible explanations, each possessing slightly different implications for how this bias might be best approached in science instruction. One obvious explanation is that the tendency is caused by parents and their ways of responding to their children's incessant "why" questions. However, a diary study of explanations given by Mexican-descent parents in response to their 3- to 4-year-old children's questions and a case study analysis of approximately two years of conversations between a father and his young son suggest that parents are unlikely to be the source of this bias, at least not in any straightforward sense (Kelemen, Callanan, Casler, & Pérez-Granados, 2005). Specifically, these studies revealed that parents are more likely to offer causal rather than teleological explanations in response to their children's "why" queries about the social and natural world. In fact, they do this to a surprising extent: Our research found that even when children asked about domains of phenomena, such as the biological or social behavioral domains (e.g., "Why do women have breasts?" "Why do you go to work?"), for which a purpose-based response would have been highly appropriate, parents showed a bias to offer causal (e.g., "because they grow them;" "because I want to") rather than purpose-based responses (e.g., "to feed babies;" "to earn money").

CULTURAL RELIGIOSITY

But, perhaps parents are the wrong level of analysis and it is something in the broader cultural environment that is responsible for the promiscuous teleology effects. One factor might be cultural religiosity: All of the initial studies documenting children's purpose bias occurred in different regions of the United States—a country widely recognized as a religious exception among Western industrialized nations because of its relatively high levels of theist belief, strong sense of civil religion, and the prevalence of "God talk" in popular discourse (e.g., Bellah, 1967). This raises the possibility that children's broad beliefs about natural purpose are a culture-specific effect driven by exposure to ambient cultural ideas invoking benevolent design and divine intervention. However, studies with British children suggest that this is not the case.

Britain is highly similar to the United States on many dimensions likely to be relevant to the development of purpose-based thinking (e.g., popular media, social customs, literacy practices). However, it differs significantly on the relevant dimension of religiosity. To place this cultural difference in perspective, studies have found that while 79% of American adults in their prime child-rearing years (18 to 34 years) identify as having some degree of religious conviction, the same is true of only 25% of British young adults. They are more likely (42%) to actively label themselves as nonreligious even if they are willing to offer up a nominal religious affiliation when asked (Bruce, 1999; Kelemen, 2003). Despite this religiosity difference, however, when British 6- to 9-year-olds' preferences for teleological explanations of natural phenomena were compared to those of American children, the two groups did not significantly differ beyond some subtle variations in the kinds of teleological explanations that they preferred. Furthermore, when tested on their beliefs about first origins of natural objects and events (e.g., "Why did the first ever mountain happen?"), British children also showed a strong teleological bias: They were more likely to spontaneously invoke purpose-based explanations of the origin of natural phenomena than any other kind of explanation (Kelemen & DiYanni, 2005).

Collectively, this is good preliminary evidence against the notion that ambient religious representations cause children to develop a purpose bias. However, it should be noted that while the British/American comparison was conducted for specific theoretical reasons, it hardly represents a rich cross-cultural sampling. It remains possible that the development of explicit patterns of teleological endorsement may, indeed, differ in countries where there is a strong polarization of religious versus secular identity (e.g., Israel; see Diesendruck & Haber, 2009, for suggestive results) or ones where religion has been actively suppressed (e.g., China). Further research exploring this possibility is currently in progress.

STORYBOOK CONVENTIONS

A final possibility is that, children's bias toward purpose is in part a result of media exposure such as the potentially widespread storybook convention of presenting the natural world as a personified and purposeful place. That is, perhaps it is standard for authors to present children with contexts in which winds blow to help ships sail and rains fall to help farmers' crops grow. While preliminary, a study involving a content analysis of 12 typical, popular, teacher-identified first-grade books suggests that this is not the case. Out of the 69 natural event descriptions described in these books, only 10% were represented as happening for a purpose, with the vast majority (85%) described in neither teleological nor anthropomorphic terms (Donovan & Kelemen, 2003). Children would therefore need to have an unlikely bias to attend to a minority of their experience if exposure to storybook media and conventions are to be identified as the primary cause of their promiscuous teleological intuitions.

Explanations of Promiscuous Teleology: Cognitive Origins

Research reviewed in the section above suggests that external social forces are unlikely to provide a clear explanation of children's affinity for teleological explanation and their broad tendency to reason about objects in terms of a function. This therefore suggests that, while the details of children's beliefs are certainly going to be informed by cultural input, on balance, the preference is likely to have a more internal, cognitive origin. What might that internal origin be?

As outlined earlier, one possibility is that children are naturally biased to view nature as though it is intentionally created. On this view, children's ascriptions of purpose are underpinned by a relatively rich framework of theoretical assumptions about intentional causation and design. Another possibility, however, is that a mechanism with far greater conceptual simplicity accounts for children's broad function ascriptions, and I will address this simpler possibility first.

Goal Sensitivity and Hair-Trigger Function Ascriptions

What the last 25 years of research in cognitive development has established, maybe more than anything else, is that young children have an acute sensitivity to other agents' intentional goals and goal-directed actions and that this sensitivity emerges early, within the first year of life (e.g., Bloom, 2004; Carey, 2009, Gopnik, Meltzoff, & Kuhl, 2000; Tomasello, 2009; Woodward, Sommerville, Gerson, Henderson, & Buresh, 2009, for reviews). With respect to children's promiscuous teleology, this raises an interesting possibility: Perhaps children readily account for all kinds of entities by reference to function because they are sensitive to cues that those entities might fulfill a useful goal for someone. That is, if they see an agent act on an object in a goal-directed way that brings about a desirable outcome that is well fitted to the object's physical properties (e.g., seeing someone poke a hole with a pointy object), perhaps children are on a hair-trigger to enduringly decide that this activity is what the object is "for" and why it is here, without consideration of what kind of object it is (e.g., natural or artifact) and how it originated (e.g., by natural or intentional processes).

As described earlier, because the only causal antecedent required to trigger teleological reasoning about an object under this mechanism is an agent's intentional goal, the depth of causal reasoning involved in this functional explanation-based categorization process is relatively superficial. It is akin to the level involved in basic function-based and basic need-based teleological explanations of natural selection that treat current or need-fitting functional outcomes as the only explanations required to account for the existence and structure of current biological traits. In consequence, if children's promiscuous teleology is the result of this causally superficial hair-trigger mechanism, it might also help explain why they might be prone to generate causally superficial natural selection explanations as older students.

Why is it reasonable to propose that children might have this very automatic, basic, generalized, teleological construal mechanism—a mechanism that functionally categorizes any kind of object as long as it appears to fulfill an intentional goal? One reason is that we know that young children's goal sensitivity does put them on a hair-trigger when it comes to functionally categorizing novel artifacts (Casler & Kelemen, 2005, 2007; Phillips & Kelemen, 2011; Phillips, Kelemen, & Seston, 2011). That is, long before children seem to have any robust, coherent theoretical understanding that artifacts have functions because someone intentionally designed them (Kelemen & Carey, 2007; Kelemen, Seston, & Saint Georges, 2011), they will enduringly treat a tool as existing for a particular goal based on having briefly seen it intentionally used to achieve that purpose.

Evidence of this tendency derives from a number of studies that adopted a very simple method ("selective return method") (Casler & Kelemen, 2005, 2007; Phillips & Kelemen, 2011; Phillips et al., 2011). In this method, we present 2-year-old children with two physically distinct but functionally equivalent tools (see Figure 4.1) and spend equal time familiarizing them to both. For one of the tools ("the dax"), familiarization involves the experimenter pointing out the physical features of the object (e.g., its color, texture) and telling the child some facts about it (e.g., "This came from Peru"). For the other tool ("the blicket"), it involves her briefly—in some studies in less than 30 seconds—intentionally using it to achieve a goal (e.g., inserting it into the top of a box and dinging an internal bell). After pointing out the tools' physical equivalence (e.g., "these look really different but they have the same ends"), the test question procedure then begins. Over the course of two multi-trial sessions spread across two different days, children are repeatedly asked to choose between the original dax and blicket (or color variants) to ring the bell-box again or perform an alternative cookie-crushing task. The question of interest is whether children's brief exposure to an experimenter's intentional goal-directed use of the blicket leads them to selectively, enduringly, teleologically view it as "for" the bell-ringing task despite the ready availability of the equally good alternative "dax," and

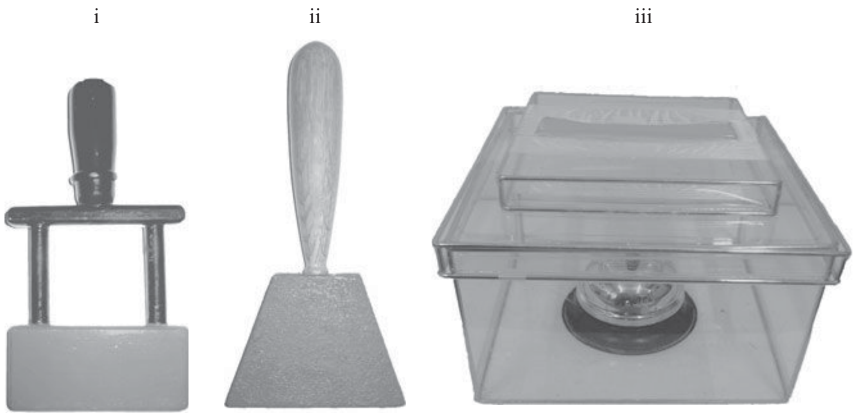

FIGURE 4.1 *Sample stimuli from tool function mapping studies (e.g., Casler & Kelemen, 2005, 2007). The model demonstrated how to insert the "blicket" tool (i) or (ii) into a bell box (iii). The alternative unused "dax" tool (ii) or (i) had interesting facts associated with it. The tools' physically equivalent features were pointed out to children.*

despite repeated questioning that usually prompts children to change their answers (e.g., Siegal, Waters, & Dinwiddy, 1988).

Our finding is that, across two days, 2-year-old children enduringly, selectively return to the demonstrated tool as for the briefly demonstrated bell-ringing task even when asked by a different experimenter or when making judgments for an absent party (Casler & Kelemen, 2007). Indeed, by 2.5 years of age, teleological construal of the demonstration tool is so specified that children will avoid using it for the alternative cookie-crushing function; a pattern that holds true even if their initial familiarization to both tools occurred indirectly via children surreptitiously eavesdropping on the experimenter from another room (Casler & Kelemen, 2005; Phillips et al., 2011). Importantly, however, children do not make this rapid function mapping to the tools if they see someone achieving the bell-ringing outcome by accident. It therefore appears that perception of goal-directedness is a critical component in this function-mapping mechanism (Kelemen, Phillips & Seston, 2012).

The early emerging tendency to rapidly teleologically categorize artifacts based on social cues to utility is interesting for many reasons, not least that this behavior seems likely to be species-specific (see Casler & Kelemen, 2005). Nevertheless, in order to know whether this basic mechanism is a potential source of children's promiscuous teleology, a central theoretical question is whether children's rapid function mapping only occurs with human-made objects or whether children map functions to any kind of object as long as it seems able to achieve some agent's goal. We explored this question in a recent study with 3.5-year-old children, selecting this age group because their bias to rapidly functionally categorize tools is extremely robust but occurs in the absence of a rich, causally elaborated understanding that tools exist because someone intentionally designed them for a purpose (Kelemen, Seston, & Saint Georges, 2011).

In this version of the selective return procedure, children saw two physically different but functionally equivalent hollow tube-shaped natural objects (actually a gourd and a cow trachea). which arrived in a box of objects that they were told had been "found outside." The box also contained other natural objects such as a rock, stick and pine cone. As in the original studies, children were then familiarized to both natural objects, having features and facts pointed out about one of them ("dax") while briefly seeing the other ("blicket") intentionally used to achieve a goal (funneling a seed into a deep-sided planting box). Their physical equivalence was also pointed out. As before, the testing procedure involved asking the children, over the course of two days, to choose between the blicket and dax (or color variants) to plant a seed or perform the novel, alternative task of covering a prickly plant. For thoroughness, in addition to this experimental condition, a separate group of children completed a control condition that had an identical procedure except that children saw handmade versions of the natural objects. These tools exactly paralleled the functional affordances of the natural object pair in the experimental condition yet differed by possessing the structural regularities, smooth contours and textures characteristic of the artifact domain. Also, in contrast to the natural objects, they initially arrived in a box of objects "from the store" that contained a hammer, digger and garden brush.

The results of this study were highly informative. As in previous work (e.g., Casler & Kelemen, 2005), when children in the control condition were presented with the functionally equivalent tools and repeatedly asked which one they needed to plant a seed, they consistently returned to the briefly demonstrated blicket tool as being for the demonstrated task. Likewise, they used the dax tool when asked to perform the alternative plant-covering task. By contrast, when children in the experimental condition were asked to choose between the two natural objects to plant a seed, they displayed a very different pattern. They showed no preference for the functionally demonstrated blicket over the alternative dax. They were also willing to use either natural object for covering the prickles on a plant. In short, when the instrumental entities were natural objects, children showed no tendency to stably categorize either of them as "for" any particular purpose (Kelemen, Seston, & Phillips, 2011).

What these results suggest is that young children are not on a hair-trigger to teleologically construe any kind of object simply on the basis of their sensitivity to salient goals and positive outcomes. As a result, children's promiscuous teleological intuitions about the functions of pointy rocks and rivers are not straightforwardly explained by a basic function ascription mechanism. This brings us back to the alternative possibility that something theoretically deeper and more coherent might drive their teleological intuitions, perhaps causal assumptions somewhat akin to those involved in older students' elaborated need-based reasoning about natural selection.

Children's Causal Assumptions about the Natural World

To recap, older students' elaborated need-based causal beliefs about natural selection seem based on notions that animals acquire functional properties either through the immanent agency of their own goal-directed efforts or through the more extrinsic personified agency of "Nature the Designer." Do similar inaccurate theoretical assumptions about agency in nature underpin young children's tendencies to broadly ascribe purposes to living and nonliving natural phenomena?

Preschool and elementary school children's tendencies to endorse animistically themed teleological explanations like "the rocks were pointy so that animals would not sit on them and smash them" are certainly suggestive that children have intuitions that natural objects have some kind of immanent, and potentially self-modifying, vital agency. In consequence, the hypothesis that animism is at least partially responsible for children's promiscuous teleology is a serious possibility and one that we are currently exploring in more detail.

In addition, for some time, we have also been pursuing the alternative, potentially complementary hypothesis that children tacitly construe some kind of extrinsic designing force as the cause of functionality in nature. More particularly, our question has been whether, lacking knowledge of scientifically valid physical-causal explanations of natural phenomena, children compensate by drawing on their knowledge of a domain that they know well—the domain of intentionally designed artifacts. Even as young children may know that natural phenomena are not literally caused by people (e.g., Gelman & Kremer, 1989), perhaps they nevertheless plug their explanatory gaps by treating nature as though it has been made for a purpose by some kind of underspecified nonhuman agent. This option, of course, implies that children's promiscuous teleology is underpinned by a rather "rich" theory-driven compensatory strategy, so what justifies the suggestion that children might do this rather than adopt some lower-level strategy?

One reason for thinking that children might intuitively analogize to the intention-based artifact domain comes from existing research suggesting that, even though infants show precocious abilities to discriminate physical, mechanical causes from intentional causes (e.g., Spelke & Kinzler, 2007; Spelke et al., 1995), children nevertheless evidence a bias to privilege intentional explanations of events. This is a tendency that Rosset (2007, 2008) termed "the intentionality bias." For instance, when asked to judge involuntary actions like sneezes and hiccups, 4-year-old children's preliminary response is to say that they are under intentional control (Smith, 1978). Although children can subsequently revise this interpretation when given salient cues that the explanation is nonveridical, this more knee-jerk assertion can be quite striking. For example, children will even make this judgment after they have physically just experienced the nonvolitional nature of a particular action for themselves, such as after experiencing their own involuntary response to having their reflexes tested (Miller & Aloise, 1989; Montgomery & Lightner, 2004; Piaget, 1932; Rosset, 2007, 2008; Shultz, Wells, & Sarda 1980, for review and adult research). In elementary school children (and adults), the bias has also been found to color tacit moral interpretations of events. They react to an agent who accidentally and unknowingly distributes unequal rewards to two people as though she were no different than someone who has engaged in an act of intentional unfairness (Donovan & Kelemen, 2011; see also Young, Cushman, Hauser, & Saxe, 2007, for related findings).

A second reason for proposing that children might draw on an "artifact analogy" derives from work by Evans (2000a, 2000b, 2001), which suggests that children have a bias to endorse intentional accounts of how species originate. Specifically, Evans asked 5- to 10-year-old American children from Christian Fundamentalist or non-fundamentalist communities, how different kinds of entities (e.g., sun bears) came to be here on the earth. She found that regardless of religious home background, children favored "creationist" origins explanations when asked to rate different explanations such as (1) God made it; (2) a person made it; (3) it changed from a different kind of animal that used to live on earth; (4) it appeared; or (5) it came out of the ground. Indeed, while 11- to 13-year-olds tended to voice the dominant beliefs of their own community, 8- to 10-year-olds from both communities showed the creationist bias very strongly. This was the case whether they were responding on a rating scale or answering open-ended questions about origins (for other relevant research, see Gelman & Kremer, 1991).

Finally, our own research has yielded direct evidence of a link between children's intuitions about purpose in nature and notions of intentional causation. In a study in which we asked British elementary school children to speculate on the origins of living and nonliving natural phenomena, we found that children's tendencies to teleologically explain those origins correlated with their independently assessed beliefs that some kind of intentional agency is at work in nature. The relationship between purpose and assumptions of intentional cause could also be seen in children's spontaneous explanations. Children quite often mentioned "God" or "He," or even a mysterious "they," when explaining a natural object or event in terms of a purpose. For example, in the words of one British 7-year-old, the first ever mountain existed "because *they* made mountains…so people can look at them" (Kelemen & DiYanni, 2005).

Findings that elementary school children's ideas about purpose in nature pattern with their ideas about intentional causation in nature are significant and relevant. However, the proposal that children's promiscuous teleology results from overextensions of their understanding of the domain of intentionally designed artifacts would be substantially strengthened if we could establish some level of developmental relationship between children's promiscuous teleology and their knowledge of artifact design. In other words, do children's highly generalized teleological intuitions about nature only robustly emerge once children have a causally coherent understanding that artifacts are not just entities that are intentionally created, but entities that are intentionally created *for a purpose*?

The question of when children adopt this kind of "design stance" on artifacts is something that has been much debated in the literature (see Kelemen & Carey, 2008, for review). However, on the basis of our own findings as well as those of others (e.g., Asher & Kemler Nelson, 2008; Kemler Nelson, Herron, & Morris, 2002; but see Defeyter & German, 2003; German & Johnson, 2002), it seems that children begin to robustly exhibit this theoretical view of artifacts from around 4 years of age. For example, when told about a novel artifact that was made by someone for one purpose (e.g., stretching out clothes shrunk in the washer) but given to someone else who uses it everyday for another task (e.g., exercising a bad back), 4- and 5-year-olds, but not 3-year-olds, tend to judge the artifact as "for" the designer's intended function. They also view it as belonging with objects that have a similar goal (i.e., it belongs in the laundry room, not the gym) (Kelemen, 1999a, 2001). Furthermore, by 4 years of age, children are also able to reason in quite sophisticated terms about the mind of an artifact designer. Thus, when asked to guess which of two novel artifacts is likely to be the one that a designer built for fulfilling a particular goal (e.g., crushing popcorn), 4-year-olds but not 3-year-olds show a robust tendency to state that the creator is more likely to have made the tool that is physically optimal for the goal (when presented with a physically optimal and physically suboptimal tool) or to have made an object that is physically specific to the goal (when presented with two equally optimal tools that differ in the number of goal relevant parts) (Kelemen, Seston, & Saint Georges, 2011).

In short, by 4 years of age, children are quite knowledgeable about purposeful design and the domain of intentionally created artifacts (see also DiYanni & Kelemen, 2008). Interestingly, current research also suggests that it is also at around 4 years of age that children first show marked signs of promiscuous teleology on the kinds of verbal tasks described earlier (Kelemen, 1999a, 2001, 2010). Although this apparent developmental association might be entirely coincidental, one further result is also suggestive of a developmental relationship between children's emerging understanding of artifact design and their emerging promiscuous teleological intuitions. In the previous section on children's hair-trigger function ascriptions, I described recent findings that children at the "pre-design stance" age of 3.5 years rapidly map functions to tools but not natural objects after briefly witnessing them used for a goal (Kelemen, Phillips & Seston, 2010). This pattern suggests that young children do not possess a basic generalized tendency to rationalize objects in terms of function just on the basis of salient cues to utility (see Lombrozo et al., 2007; Keil, 1992). Interestingly, however, we found a different pattern of results when we tested 5-year-old children—children whose understanding of artifact design is likely to be relatively robust—on the same rapid function-mapping task. After briefly witnessing someone intentionally use one of two equally good objects to plant a seed, children in this age group rapidly and enduringly construed the object as existing for that specific function. Furthermore, they did so whether the demonstrated object was a tool (control condition) or a natural object (experimental condition) (Kelemen, Phillips, & Seston, 2011). Although indirect, this behavioral evidence of promiscuous function mapping by 5-year-olds, but not 3-year-olds, provides further food for thought when evaluating the claim that promiscuous teleology may originate because children's intentional bias leads them to draw on their understanding of artifacts as apotentially enduring basis for understanding nature.

Implications for Science Education

In the first part of this chapter, I described some of the teleologically based misconceptions about adaptation that have been repeatedly identified in science education research over the last 30 years (Gregory, 2009, for review). Much of that research suggests that while involving a number of inaccurate ideas, students' causal explanations of natural selection are generally shallow. This is a characterization that, if accurate, offers a more positive prognosis for instructional success relative to a scenario in which students maintain somewhat theoretically coherent views of natural selection that combine both naive biological and psychological ideas. I suggested, however, that the latter, more challenging, scenario may be more prevalent than we think, given the resilience of students' misconceptions in the face of instruction and recent findings suggesting that adults' reasoning about nature is, in general, tacitly influenced by notions of goal-directed natural agency (Kelemen & Rosset, 2009; Kelemen, Rottman et al., 2012).

In the second part of this chapter, I then traced the developmental roots of older students' misconceptions and showed that they potentially extend well into early childhood. From around late preschool, children display a promiscuous teleological tendency to construe natural phenomena in terms of purposes. Furthermore, echoing "elaborated need-based" characterizations of older students' evolutionary misconceptions, there is recent developmental research which suggests that children's broad teleological ideas do not simply arise because of a basic, atheoretical tendency to categorize objects by reference to useful goals. Rather, there is evidence to suggest that they stem from a theoretically deeper strategy informed, in part, by their understanding of design and purpose in the artifact domain. Not only are elementary school children's ideas about purpose in nature linked to their ideas about intentional agency in nature, but also the onset of preschool children's promiscuous ascriptions of function occurs at around the same time as they are elaborating their causal understanding of how intentional creation produces function in the artifact domain (Kelemen, Seston et al., 2010). Around 4 years of age then, children may already be elaborating coherent, intuitive theoretical ideas about natural phenomena that, unchallenged from early childhood, become robust, resilient impediments to the construction of scientifically accurate ideas in later years.

What does this developmental account imply for evolutionary education? Because of its conceptual complexity, educational standards guidelines (e.g., AAAS, 2001; NRC, 1996) currently advocate a very gradualist approach to teaching about natural selection. While substantial preparatory instruction on relevant component ideas (e.g., structure-function environment fit) takes place during Grades K–8, it is generally recommended that exposure to a comprehensive, theoretically integrated explanation of how natural selection leads to biological adaptation be delayed until Grades 9–12 (see also Catley, Lehrer, & Reiser, 2005).

The justification for these recommendations is understandable: Grasping natural selection involves incorporating knowledge about numerous facts and distinct processes. Unfortunately, however, one side effect of delaying comprehensive exposure to the theory until 13- to 18-years of age is that inaccurate intuitive ideas are, by then, likely to have become deeply entrenched by being left largely unchallenged for a long period of developmental time. Inevitably, this is likely to negatively impact students' responsiveness to instruction; the whole process becomes additionally complicated by students' need to rethink and reconstruct conceptions that are both highly natural and highly habitual. Necessarily then, one route for confronting the challenges that students are likely to face as they comprehensively learn about natural selection is to directly educate them about the misconceptions that they are likely to hold as they receive instruction (AAAS, 2009; Sinatra & Pintrich, 2003).

Another, as yet largely untried, route, however, is to acknowledge that some of these misconceptions have their roots in early emerging cognitive biases and address them at their source, by tackling them early. Stated more explicitly, it seems likely that students' chances of enduringly learning natural selection would be significantly enhanced if they received recurrent exposure to the full logic of the theory of natural selection—and not just its component parts—from a far earlier developmental point than is currently advocated. Through this early, comprehensive exposure, evolutionary explanation might therefore become familiar enough to have some chance of competing with the kinds of embryonic intuitive theories that children seem biased to construct. Even if full conceptual revision of more cognitively natural ideas is not attainable via this strategy of early, recurrent exposure, at the very least such a habituation approach would, over time, aid children's ability to inhibit their intuitively based misconceptions thus increasing their chances of reasoning accurately when called on to engage productively in "thinking for science."

One justifiable reaction to this suggestion of early intervention is that it is both naive and untenable given the complex, multifaceted nature of the natural selection mechanism and the obvious limits both of young children's information processing capacities and knowledge base. In response to this, I would argue that natural selection is amenable to description in highly simplified terms and that existing developmental research already provides significant indicators that young children have a knowledge of relevant isolated facts that is far richer than might be automatically assumed (see also Kindergarten through Eighth Grade Committee on Science Learning, 2007). For example, children's early-arising teleological orientation is such that long before they receive formal schooling on the matter (Grades 3–8), they know that the properties of living things have functions, and these functional parts have broad "survival" consequences for the animals that possess them (Jaakkola & Slaughter, 2002; Keil, 1991, 1995; Kelemen, 1999a, 1999b, 2003; Kelemen, Widdowson, Posner, Brown, & Casler, 2003). Similarly, 4- and 5-year-old children know that ecological resources such as food or clean air, are critical to animal well-being and that without them, animals' bodies deteriorate and cease to move and grow (Inagaki & Hatano, 2002; Nguyen, 2008; Toyama, 2000). Finally, many 4- to 6-year-old children rudimentarily understand several key facts of birth and biological inheritance. For example, they know that babies come from inside mothers (Bernstein & Cowan, 1975; Springer, 1995) and that offspring tend to physically resemble their birth parents (Gelman & Wellman, 1991; Giménez & Harris, 2002; Hirschfeld, 1995; Johnson & Solomon, 1997; Solomon, 2002; Springer & Keil, 1989). They also tend to believe that babies inherit traits with functional consequences from their parents (Springer & Keil, 1989).

Although this knowledge base is far from complete, in combination these facts provide a skeletal framework on which children can build a basic understanding that: (1) animals with differentially functional body parts have differential health and survival; (2) the survival benefits of parental traits will pass to future progeny. Indeed, the assertion that children as young as 5 years of age can grasp a simplified, comprehensive explanation of adaptation via natural selection is currently going beyond the realm of mere conjecture. Preliminary studies testing this proposition are providing substantial reasons for optimism (Kelemen, Seston, & Ganea, 2009; Kelemen, Ganea, & Seston, 2012). It remains for ongoing research to explore the full scope of these initial promising signs.

In summary, in this chapter I have outlined why young children's intuitive teleological bias provides one of the many major instructional challenges to secondary and postsecondary educators in the evolutionary sciences. Despite the many reasons for pessimism, however, there are also many reasons for optimism. This is especially true in an intellectual climate where synergies between psychological science and science education are becoming ever more potent.

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