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Conceptual Change and Evolutionary Biology: A Developmental Analysis

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Evolution, in a way, contradicts common sense (Mayr, 1982, p. 309)

Given the reputation of the United States as a world leader in science, it is ironic that its scientific establishment is experiencing a public backlash. The most acrimonious manifestation of this backlash has been the U.S. public's reaction to the Darwinian theory of evolution. With only 40% of the U.S. public accepting evolutionary explanations for human origins, the United States ranks second to last in acceptance rate among 34 industrialized nations. The rate in most of Europe, in contrast, ranges from 70% to 80%, whereas Japan's is 78% (Miller, Scott, & Okamoto, 2006). Explanations for this phenomenon abound, ranging from religious belief to poor scientific training to politicization. According to Mazur's (2005) analysis of several national U.S. samples, *Christian religiosity*, especially fundamentalism, significantly outweighs other contributing factors, including educational level and political orientation. Further, after controlling for these factors, including religiosity, Mazur (2005) found that acceptance of evolution was *not* independently related to other measures of science knowledge, dogmatism (closed-mindedness), geographical locale, or ethnicity.

In this chapter, these overt largely *creationist* rejections of evolutionary origins will be linked to a parallel phenomenon, well known to science teachers and science education researchers, which is students' misunderstanding of natural selection (e.g., Bishop & Anderson, 1990). A developmental framework will be used to help explain the emergence of both sets of ideas in communities with different religious orientations and differing degrees of scientific expertise. By invoking a developmental perspective, cognitive scientists and science educators who are interested in the emergence of early scientific ideas can pinpoint the critical junctures at which commonsense, scientific, and religious reasoning meet, and trace the ensuing conceptual changes (e.g., Duschl, Schweingruber, & Shouse, 2006; Vosniadou, 1994; Vosniadou & Ioannides, 1998).

A recent developmental approach that aligns well with formal science instruction is a description of human reasoning as a series of naïve or folk theories, which map onto fundamental domains of human knowledge, from biology to psychology to physics (Gopnik & Wellman, 1994; Hirschfeld & Gelman, 1994; Wellman & Gelman, 1998). Naïve theories provide the *commonsense* intuitions that first come to mind when humans seek everyday explanations for natural phenomena, from the workings of the human psyche to the movements of celestial objects. Conceptual change, from this perspective, may consist of the elaboration of intuitive concepts embedded in a particular explanatory framework or a more radical shift from one intuitive theory to another, to explain a particular phenomenon, such as from a naïve psychology to a naïve biology (e.g., Carey, 1985). Intuitive theories are not so much discarded as reworked.

In this chapter a synopsis of creationist thought will be followed by a developmental analysis of creationist and evolutionary ideas, utilizing the intuitive theory approach. The ways in which this approach could be integrated with that of domain-general theories will also be described. The premise of this chapter, however, is that a domain-specific explanatory framework is necessary (if not sufficient) to clarify why evolutionary ideas are counterintuitive, and creationist ones contagious (Sperber, 1996). Without it, the public resistance to evolution can only be understood in a piecemeal fashion. Such a framework, informed by a detailed developmental analysis, should also explain why conceptual change in evolutionary biology arouses existential fears. In brief, the basic claim, elaborated in the concluding section, is that an understanding of Darwinian evolution requires a radical shift from an intuitive psychological framework to a naturalistic biological one.

SCIENCE, CREATION SCIENCE, AND INTELLIGENT DESIGN

Creationists exploit the public's uneasiness about questions of origins and their misunderstanding of science to saddle evolution with the problems of a materialistic culture and to claim the imminent demise of evolutionary theory. From a creationist perspective, the failures of evolutionary theory stem from evolutionary biologists' naturalistic explanations for questions of origins, in particular, their acceptance of the mutability of species. Creationists argue that this materialistic world view excludes the supernatural, exposing the public to the misery of a Godless and immoral world (Scott, 2004). These criticisms have been addressed in detail in the media and in several books (e.g., Miller, 1999; Pennock, 2001; Ruse, 2006; Scott, 2004). In this chapter I shall provide enough background material to speak to a few of the core issues: the nature of creationist thought, the public reaction to the creation-evolution debate, and related *nature of science* questions.

Creationism and Science: A Cultural Clash?

Most cultures have a creation myth (see Campbell, 1972). Creationism is the most well known in the West because it draws its support from the King James Bible. Biblical literalists believe that God created each kind of animal with a unique essence, about 6000 to 10,000 years ago (Numbers, 1992, 2003). A cornerstone of this approach is the immutability of living kinds: Each kind has a fixed boundary and only God can create new kinds (Evans, 2001; Kehoe, 1983, 1995). Although the inerrancy of the Bible is a notable feature of Christian fundamentalist thought, it is also found among other religious groups, with about 30% of the U.S. population accepting the Bible as the actual word of God (Doyle, 2003). Fundamentalists from other monotheistic religions also reject evolution, for similar reasons, but the focus of this chapter is on the more explicit challenges posed by Christian Fundamentalism. Clearly, their viewpoint is at odds with that of contemporary evolutionary biologists many of whom regard *species* boundaries as entirely mutable, with ancestor and descendent species linked in one entangled web, in a common ancestry of naturalistic origin (e.g., Doolittle, 2000).

The media coverage of the evolution-creationist controversy obscures what is actually a broad range of opinions on this topic (Miller, 1999; Ruse, 2005; Scott, 2004). The Gallup polls tend to focus fairly narrowly on the question of human origins and their questions rarely address this kind of complexity. Nevertheless, they do show a fairly consistent pattern over the past twenty years, with approximately 46% of their national sample endorsing the Biblical version of human origins. Only 13% accept the notion of common ancestry, with no reference to God. Importantly, though, 36% appeared to be theistic evolutionist, in that they accept evolution, but under God's guiding hand (Gallup, 2007).[1] The latter is in keeping with the beliefs of theologians from most non-fundamentalist Western religions who happily accept the theory of evolution as the embodiment of God's powers (Ruse, 2006). Indeed, many contemporary scientists reconcile science and religion as "nonoverlapping magisteria" (Gould, 1997) or consider that "God … exists outside of space and time" (Francis Collins, interviewed by Biema, 2006). This kind of analysis indicates that the two worldviews part company at their extremes, with Biblical literalists in one camp, and scientists, such as Dawkins, who extol the benefits of atheism (Biema, 2006), in the other. Towards the center, however, there appear to be several ways of reconciling these apparently incommensurable positions.

Creation science preceded the more recent intelligent design movement, though both are manifestations of earlier creationist ideas (Evans, 1991, 1994/1995; Mayr, 1982; Scott, 2004). For this reason, the term *creationism* will be used in this chapter in a generic sense to refer to all groups who accept a *direct* role for God in the creation of species. Creation science was a 20th century movement. It emerged along with the publication of several prominent books by creation scientists John C. Whitcomb and Henry M. Morris, which reestablished the importance of the Noachim flood, so-called flood geology, and a literalist view of the Bible (Evans, 2001; Morris & Parker, 1982; Numbers, 1992; Whitcomb, 1972, 1988). Contemporary ideas about intelligent design, in contrast, secede from this literalist viewpoint to accept the geologist' view of the age of the earth. What both creation science and intelligent design have in common, though, is a rejection of a materialist view of the world, including a denial of naturalistic explanations for the origins of species (Scott, 2004). Moreover, both claim that a materialist Western science endorses a purposeless, Godless world. Scott (2004) points out that with methodological naturalism Western science cannot make any kind of statement about the existence, or not, of the supernatural, but this nuanced view is lost on creationists (and even some contemporary scientists).

In contrast to this contemporary angst, a brief glimpse of the history of Western science often shows science and religion working hand in hand, with scientists revealing God's guiding hand as they investigate the mysteries of the natural world (Evans 2000b; Shapin, 1996). The methods they used, however, were naturalistic, including experimentation; only naturalistic methods could be used to investigate natural phenomena. One of the reasons why creation science is often declared an oxymoron is because science cannot be used to investigate the supernatural (Numbers, 1982; Scott, 2004). That is the realm of religion.

All the major scientific and research organizations in the United States have issued policy statements defending the teaching of evolution in the nation's science classrooms and rejecting the idea that creation science or intelligent design should be taught alongside evolution (NSTA, 2003). Moreover, the law is on the science teacher's side. Despite many attempts, neither creation scientists nor leaders of the intelligent design (ID) movement have yet convinced the nation's lawmakers that creationism can be taught in the *science* classroom (Scott, 2004). The trump card, according to Judge Jones in the 2005 Dover trial, is that "ID violates the centuries-old ground rules of science by invoking and permitting supernatural causation" (p. 34, Mervis, 2006). This does not prevent creationists from attempting to impose their beliefs on local or state school boards, who are less susceptible to the legal or scientific arguments.

Is Evolution Immoral?

Leaving aside the question of the authenticity of the scientific account of evolution and of its legal status, many members of the public still feel uneasy about evolutionary theory (Brem, Ranney, & Schindel, 2003). Is it immoral? "If we are merely animals then how should we behave to one another" was one parent's question and another said, "I don't know what to believe, I just want my kids to go to heaven." (Evans, 1994/1995, 2001). Evolutionary theory is, of course, mute on this point; this is the realm of religion, not science. Yet, some members of the public, including science teachers, associate evolution with a variety of negative ideas and effects, which contributes to their rejection of evolutionary theory (Griffith & Brem, 2004; Hahn, Brem, & Semken, 2005).

One factor in this rejection is the discredited attempt to associate Darwinism with the social inequality of the 19th century, the implication being that such inequality was genetically determined (Scott, 2004). Another is a successful attempt, mostly by creationists, to brand evolutionary theory with outcomes that harm society. A major political figure blamed the Columbine disaster on the teaching of evolution (Krugman, 2003). Others noted that the increased teaching of evolution in the schools *caused* a rise in teenage pregnancy and venereal disease (Chick, 2000). Teenage pregnancy rates are now declining, yet the teaching of evolution continues unabated. It would be just as misleading to state that the teaching of evolution caused the recent decline. This illusory correlation is one of the many ways that creationists use science to mislead the public and associate evolution with a host of contemporary evils.

Creationism and the Nature of Science

In addition to its supposed immorality, an oft-repeated criticism of evolution is that evolution is *only a theory* (Bybee, 2004; NAS, 1998, 1999; Scott, 2004). This criticism again relies on a misuse of science to bolster the case against evolution, but it does raise some interesting nature of science issues. In this case, creationists are using the term *theory* in its everyday sense, as an idea that can easily be discarded.

What does having a theory mean to a scientist? As do many areas of specialization, science incorporates terms commonly used in general discourse and proceeds to give them highly specialized meanings. In everyday language, theory means an idea, or a hunch about something. For scientists, however, a theory is an organized body of knowledge, which explains a set of interrelated facts. It has a great deal of support. In the face of evidence that does not quite fit into the theory, the theory is more likely to be amended than overturned. It takes a lot of counter evidence to overturn a theory. On the other hand, the term *hypothesis*, as used by scientists, is probably closer in meaning to the everyday use of theory. When scientists conduct experiments, it is usually to test whether or not a specific hypothesis can be supported, not an entire theory.

Creationists' belittling of evolution is also tied to ongoing disputes within the scientific community. Richard Dawkins and the late Steven Jay Gould are two leading evolutionary biologists who have had long battles over specific evolutionary hypotheses, though both are staunch anticreationists. Dawkins argues, for example, that natural selection occurs at the level of the gene, whereas Gould considered it to operate at the level of the species, as well. Creationists have long publicized such arguments as evidence that evolutionary theory is in crisis and will soon be overturned. But, from a scientific point of view, it is just a sign that evolutionary theory is alive and well. New data will be collected to resolve such disputes over these specific hypotheses, which will end up strengthening the predictive power of the theory.

One more *nature of science* issue often raised by creation scientists is that evolutionary theory is not science because it is based on undocumented inference, rather than observation. Classically, creationists point out that the fossil record is incomplete, therefore, it cannot be used as evidence that species have evolved. There are countless examples in science of inferences based on data that could not be directly observed. We now know that there is a space between nerve cells across which chemicals are released for cell communication. This space could not be observed until the advent of the electron microscope in the 1940s. Yet, prior to that date, in order to explain otherwise inexplicable findings about the transmission of information in the nervous system, scientists had determined that there must be a space (see Mazzarello, 2000 for an historical account). How did they know? They could not directly observe the space, but based on available data they made the inference that it must exist. It was the only reasonable explanation for their findings. Crucially, even though scientists can only indirectly observe these phenomena, they are using *naturalistic* methods to obtain data to test their hypotheses. They did not resort to supernatural explanation.

Finally, it turns out that evolution can be observed. Organisms that undergo rapid reproduction from viruses to fruit flies provide opportunities for the direct observation of natural selection in action (Futuyma, 1998). The fossil record, while not complete, does provide evidence of transitional forms between species, some of the most notable examples being those of the ancestors of whales, which, unlike modern whales, had the capacity to walk on land (Gingerich, Raza, Arif, Anwar, & Shou, 1994; Zimmer, 2005).

These criticisms of evolution have proven useful to the scientific community because they highlight some widespread misconceptions about the scientific method, which need to be addressed both in the educational system and in communication with the general public (e.g., NAS, 1998).

Creationism and the Mutability of Species

Beyond nature of science wars, creationist misunderstandings of evolution reveal some intriguing cognitive barriers to evolutionary thought. These biases are core to the intuitive theory approach to be developed in rest of this chapter. Darwinian evolution is not all of one kind. Essentially, it can be divided into two sorts of processes, which are interdependent: microevolution or small-scale evolution and macroevolution or large-scale evolution. *Microevolutionary* processes explain change in gene frequencies within a particular population or species. Given particular environmental pressures and sufficient numbers of generations, these microevolutionary processes eventually yield large phenotypic changes, such as the reptiles and mammals, which are derived from a common ancestor. This is known as *macroevolution* (Futuyma, 1998).

Creationists explicitly reject macroevolution and common descent. Such processes directly contradict the creationist belief that that each living kind was present during the Noachim Flood and has a God-given essence, meaning that it cannot change into a different living kind (Whitcomb, 1988). In contrast, by claiming that God built some diversity into the DNA of each living kind, creationists can accept microevolutionary processes such as variation and changes in gene frequency within a living kind (Greenspan, 2002; Morris & Parker, 1982). In a criticism of various evolution exhibits, a creationist claims:

> The evolution of HIV is not disputed by creationists. The only complaint that creationists have with this is the confusing use of the term "evolution" to describe both variation within a species and the origin of new kinds of life. … The fact that one can mix existing genes to get some variation in species doesn't prove that genes can arise naturally to create new kinds of creatures.' (Jones, 2005)

The following example, given by an adult museum visitor, illustrates this type of creationist reasoning in the museum going lay public (Evans et al., 2006):

> Ok, I believe um, God created a pair, a male and female of everything with the ability to diversify. So I guess what I meant at the time of the flood, I believe that's when the continents broke apart and so even though only a few of each things were saved in the flood, they had the genetic background to be able to diversify into all of the, like for instance, dogs, and all the different kinds that we have. And so um, does that help? Just a creationistic view.

Thus, when creationists reject evolution, by and large they are rejecting phylogenetic changes or macroevolution (Poling & Evans, 2004b). In the following example, a museum visitor was asked to explain why there were changes in the average size of beaks in populations of *Galapagos Finches* over several seasons. Although *evolution* is rejected, the visitor describes the microevolutionary process of differential survival with some accuracy (Evans, et al., 2006):

> That's a good question. I probably can't explain that. But like I said, because of my biblical world view, I don't believe in evolution. So I don't believe that they evolved because it takes too long. There are too many failures before they evolve into something that finally works, so I just reject that view. *Um, my guess would be that there probably were larger beaked finches but there weren't as many of them and the small beaked ones would have died out because they couldn't get the food.* [italics added]

The practical outcome of this distinction is that in the classroom the teacher could discuss microevolutionary processes without running into difficulties with creationist reasoners (Evans et al., 2007). Further, there is some evidence that the lay public similarly considers evolution to be common descent, without understanding that it also refers to changes in gene frequency in a population (Poling & Evans, 2004b).

One final issue raised by notions of the immutability, or not, of species is the definition of the term *species*, which is problematic for both the scientist and the layperson. For the creationist museum visitors described above, diversity within a specific *living kind*, such as birds or dogs, would not be considered evidence of speciation because the diverse dogs or birds continue to be *same* living kind. When a college-educated population was asked to define species, the majority thought of species as a group of animals that looked alike "'like mice or humans'; only 7% referenced reproductive isolation or common ancestry" (Poling & Evans, 2004b, p. 513). In that same study, even undergraduates who were creationist as well as those who were evolutionist were more likely to agree that highly similar animals (e.g., gorillas, monkeys) share a common ancestor than do dissimilar animals (e.g., rats, whales) (Poling & Evans, 2004b). (For an evolutionary biologist, all living things share a common ancestor.)

Such definitions are similar to the *generic-species* concepts found historically folk beliefs and in traditional societies across the world (Atran, 1990, 1999). This concept references an everyday understanding of species as living kinds that look alike and which are adapted to a specific environment; usually they are the only representative of a particular genus in that locale (e.g., zebras, lions). The field naturalist, in contrast, is likely to use reproductive isolation as a working definition of species (Futuyma, 1998; Mayr, 1991, 1997), whereas other biologists and philosophers often argue that there is no satisfactory definition that covers all phyla (Doolittle, 2000; Mishler, 1999).

CONCEPTUAL BARRIERS TO EVOLUTIONARY THINKING: A FRAMEWORK

Intuitive theories provide a conceptual framework that makes it possible for individuals to make sense of the everyday world, without any formal training (Atran, 1995, 1998; Wellman & Gelman, 1998). Intuitive reasoning works wonderfully on a day-to-day basis. It only causes difficulty when we try to understand ideas that are outside the realm of everyday experience, such as the theory of evolution. Three cognitive biases stemming from an everyday or intuitive biology (Medin & Atran, 2004; Gelman, 2003) and psychology (Wellman & Gelman, 1998) are particularly problematic: That living things are separate, stable, and unchanging (*essentialism*) and that animate behavior is goal directed (*teleology*) and intentional. Evolutionary concepts, it is claimed, are counterintuitive precisely because they challenge this everyday understanding (Evans, 1991, 1994/1995, 2000, 2001; Mayr, 1982), which tends to resonate better with a creationist ideology. These biases appear very early in human ontogeny (Wellman & Gelman, 1998).

Evolutionary theory provides us with a dynamic world in which all living kinds are related, through a common ancestry. If we could speed up time, we would "see" species as dynamic and biological change as contingent and non-directional; in effect, species would morph from one to another as environments change, or disappear entirely. Yet, everyday cognition, mired as it is in a particular time and place, appears to obstruct this view of a dynamic world. What is needed is the equivalent of a microscope or telescope, such as a time-machine that transcends human cognitive and perceptual limitations. Although the fossil record and molecular biology provide some of these tools, they lack the sense of immediacy and authenticity of the other instruments. The most potent constraint, though, is derived from an everyday psychology, our expertise at reading minds and understanding human goals and intentions. The powerful analogy provided by the creative abilities of the human, appears to underlie the concept of intelligent design, especially when reinforced by a cultural model of God as central planner of the natural world (Evans 2000a, 2001).

Next, I shall focus on the basic claim in this chapter, which is that this network of intuitive beliefs constrains human cognition such that creationist ideas are attractive and easier to spread, whereas evolutionary ideas are less contagious.

Essentialism

A group of well-educated adults bursts into laughter as a leading creation scientist describes the apparently absurd idea entertained by evolutionary biologists that whales originally walked on land (Evans, 1994/1995). On the face of it this does appear to be an odd idea: a land mammal the ancestor of an ocean dweller? Similarly, if children are asked if such a transformation is possible, they are likely to reply "you've got to be kidding" (Evans et al., 2005). What underlies this strong intuition that animal kinds are unique and cannot be transformed into different kinds? Such ideas are widespread. Historians have documented them in early Western philosophers (Mayr, 1982) and they are also found in children (Gelman, 2003). This psychological essentialism (Medin & Ortony, 1989) gives rise to essentialist beliefs in the unique identity of each living kind. Humans act as if each living kind has an underlying essence that makes it what it is. A tiger, for example, is always a tiger, even if you paint out its stripes and remove its legs; it is a deformed tiger, but a tiger, nonetheless. These essentialist beliefs may well have several functions. They appear to help us view the world as stable and unchanging. This is a very useful aspect of everyday reasoning in that we ignore the dynamic aspects of the world around us and focus on the stability. It is much easier for young children, for example, to work out what is happening in a world that is perceived as essentially the same from day to day. Essentialist thinking may also underlie our ability to categorize and make inferences based on those categories (Gelman, 2003; Shipley, 1993). Once a child is told that the three-legged white animal is really a tiger, he or she can easily infer a lot of tiger properties: Its offspring will be tigers, it eats meat, it lives in forests and is dangerous. This categorization ability reduces the amount of information we have to process every time we learn new things. Everyday essentialist reasoning is, however, a significant barrier to evolutionary thinking, in which living kinds are ever changing.

Teleology

A glance at the behavior of an ant colony or a beehive will convince most people that ant and bee activities are purposeful. These insects systematically search for food and bring it back to their home base to fuel the next generation. The human tendency to view behavior as directed towards a goal is very powerful and seen in infancy (Tomasello, Carpenter, Call, Behne, & Moll, 2005). Yet, insects, even ants, cannot reason about goals, because they cannot *think*. They aren't wondering where the next meal is coming from or how to satisfy the voracious appetites of their young. Their behavior only appears to be goal-directed; in reality, insects are responding to environmental cues and internal signals, acquired over their evolutionary history. It is very difficult, however, to describe animal behavior without referring to its purpose or function (Kelemen, 1999, 2004; Keil, 1994, 1995). Why might such teleological (or purposive) thinking be useful?

A reasonable hypothesis is that it helps people tell the difference between living and non-living things (e.g., Medin & Atran, 2004). If we see a rock plummeting down a mountain-side, we will look for something that might have pushed it. That is part of an everyday naïve physics. Conversely, if we see a cat bounding down the same terrain, one might wonder about its goal — pursuit of a rabbit, fleeing a predator? Even infants can distinguish between these two kinds of movement, one resulting from a physical cause and the other apparently satisfying a function or goal (Tomasello et al., 2005). It could well be that the ability to detect purposeful activity is important to human survival, as it is a signal that an object is a living thing and it might be a source of food or of danger. Researchers hypothesize that along with essentialist reasoning, teleological reasoning forms the basis of our everyday naive biology (Medin & Atran, 2004), and appears early in childhood (Inagaki & Hatano, 2002; 2006). This again raises a barrier to evolutionist reasoning. Evolution is adaptive in the sense that it is contingent on particular environmental conditions, but it is not directed towards the goal of adapting to those conditions.

Intentionality

Humans are a social species exquisitely attuned to shades of meaning. We read human minds and behaviors more easily and earlier than we read books. Unfortunately, it also leads us to assume intentions where none are meant. One child kicks another. Did he or she mean to do it? Was it intentional or accidental? Here's where we get to creationist versus evolutionist reasoning. A watchmaker creates a perfect instrument exquisitely attuned to the measurement of time (Dawkins, 1987). This artifact has been built to satisfy human goals and intentions. Creationists, it would appear, transfer their intuitive understanding of the human as a manufacturer of tools, such as watches, and apply it to objects that have arisen naturally, such as the human eye. They use the artifact analogy to reason that anything as perfect as the human eye must have had a designer, a supernatural creator in this case; this is the crux of the intelligent design argument. The eye could not have arisen naturally. Some researchers argue that creationism and intelligent design are so appealing because they elicit the well honed human capacity for intentional and purposive or goal-directed reasoning –a naïve theory of mind (Evans, 1994/1995, 2000, 2001; Kelemen, 2004).

Conceptual Change

Evolutionary theory is probably one of the most counterintuitive ideas the human mind has encountered, so far. Some historians believe that is why it took such a long time before anyone could discern a natural solution to the problem of "Where did we come from?" (Mayr, 1982).

That is, a solution that did not involve the direct intervention of a supernatural designer. Even when Darwin had solved the problem, it took him many years to assemble a watertight argument, one that would convince every critic (Mayr, 1991). To appreciate evolutionary arguments requires a radical conceptual change. We have to set aside or reconfigure our intuition that species were designed for a purpose, just like artifacts, and that they have unique essences. Specifically, we have to switch from a naïve psychological explanation to a naturalistic explanation that eschews purpose and endorses the idea that living things undergo radical change.

On the surface, it would seem that evolution may be too difficult for children to grasp. But we cannot assume this to be the case. In some ways children are more flexible than adults. An understanding of evolution does not require complex ideas that take years to acquire, such as mathematical reasoning or an understanding of genetics. Darwin and his contemporaries had no knowledge of Mendel's work on genes (Mayr, 1991). It was not until the 20th century that Darwinian evolution and Mendelian genetics were united. In the next section, I shall outline what we know about the development of evolutionary concepts in children and describe the most typical ideas of youth of different ages.

So far the focus has been on conceptual barriers to an understanding of evolution rather than on difficulties understanding the *nature of science*. Although both are important, I shall argue later that the latter are secondary rather than primary. The public misunderstanding of science and its uneasiness about questions of origins are exploited by creationists. The intuition that animals are immutable and that animate behavior is purposive increases susceptibility to a creationist worldview. For such ideas to spread with ease the cognitive contingencies must already be in place (Sperber, 1996). Darwinian evolution, on the other hand, is unsettling and more difficult to reconcile with these basic intuitions. Although it is clearly the case that the public misunderstands the nature of science, that does not explain why antipathy towards the theory of evolution is stronger than to other scientific theories, such as the theory of gravity..

CONCEPTUAL CHANGE AND EVOLUTIONARY BIOLOGY: A DEVELOPMENTAL ANALYSIS

The Emergence of Evolutionist and Creationist Ideas in Different Communities

If human cognition is subject to constraints in the form of intuitions that increase resistance to evolutionary thinking, then the developmental evidence should provide the most powerful support for such a hypothesis (Evans, 2000a, 2001). Such constraints should appear early on, change systematically over development, and persist into adulthood, even when modified by cultural input.

In sum, we should expect to see developmental change in children's understanding of evolutionary ideas, which parallel children's emerging understanding of human minds and of nature. Young children should be highly resistant to the idea that animals can change and quite accepting of the idea that animate motion is purposeful (Evans, 2000a, 2001). Further, the extensive work on children's theory of mind should provide evidence of changes in their everyday psychology that relate to children's understanding of intelligent design. In a series of studies that examined the early emergence of ideas about the origins of species in diverse communities, such relationships were found, though there were some surprises (Evans, 1991, 1994/1995, 2000a, 2000b, 2001).

In the following summary of these studies, the term *Christian fundamentalist* refers to families from communities who attend churches *and* schools that endorse Biblical literalism. *Non-fundamentalist* refers to families from communities in the same locale, but who went to churches that did not endorse a literal reading of the Bible and who attended public schools. Importantly, parents from the two communities had similar educational levels and similar expectations of their children's educational attainment. Further, families from the two communities did not differ in the extent to which they endorsed musical activities and typical childhood hobbies, from stamp collecting onwards. Consistent with their respective ideologies, fundamentalist families were more likely to endorse religious activities, whereas non-fundamentalist families were more likely to include fossils and nature in their preferred activities (Evans, 2001).

Overview

Children and adults from both fundamentalist and non-fundamentalist communities were asked a series of open- and closed-ended questions about the origins of the *very first* of different kinds of animals. Given the ages of the child participants, the term *evolution* was never used. In the coding systems, the term *evolutionist* was applied to responses that endorsed the basic macroevolutionary concept rejected by the Biblical literalists described earlier: that one kind of animal could be the predecessor or successor of a very different kind of animal. This is a transformationist idea. Children's responses were termed *spontaneous generationist* (see Mayr, 1982) if they expressed a naturalistic non-transformationist idea, implying that the very first of a kind just appeared or emerged from the ground ("it came out of the ground"). Such ideas were expressed by the early Greeks (Mayr, 1982). Moreover, they are consistent with the observation that living things apparently emerge out of the ground after the snow thaws or a rainstorm (Evans, 2000a). *Creationist* ideas were those in which a supernatural power was invoked (God made it). In the results shown in Figure 10.1 (Evans, 2001), any of these ideas could be endorsed from zero to three times over three open-ended questions about the origins of humans, sun bears, and tuataras. As can be seen in Figure 10.1, children and adults from the two communities clearly differed in the extent to which they endorsed creationist and evolutionist ideas, with creationism overwhelmingly endorsed in the fundamentalist community, by all age-groups.

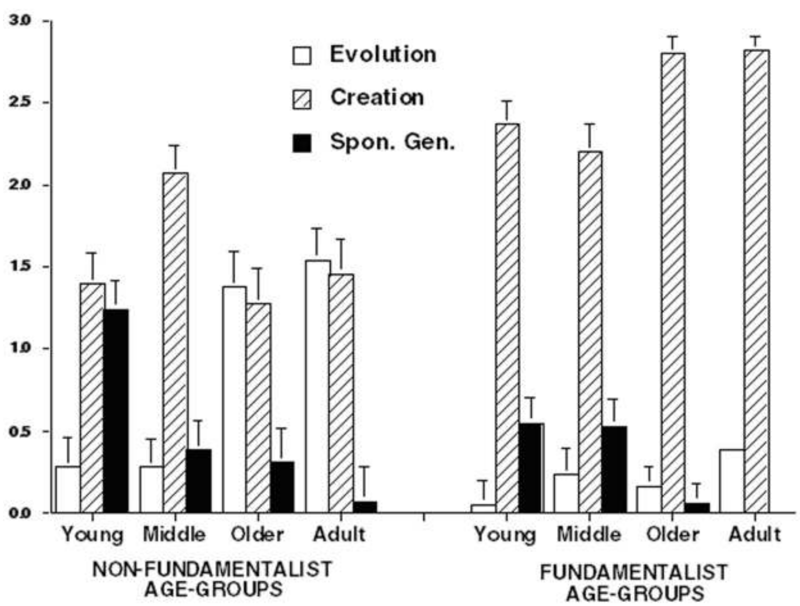

FIGURE 10.1 Beliefs about the origin of species in children and adults from fundamentalist and non-fundamentalist school communities, by age group (Frequency Range 0-3 + SEM).

Overall, the results imply that 5- to 7-year-olds (Young Age-Group) endorse a mixture of spontaneous generationist and creationist ideas, depending on the community of origin. In contrast, 8- to 10-year-olds (Middle Age-Group) endorse creationist ideas, *regardless* of community of origin; in fact, there was no significant difference between the communities for this age-group. By early adolescence (Older Age-Group), however, children's ideas were not significantly different from those of the adult members of their respective communities: evolutionist, creationist, or some mixture of the two (Evans, 2000a, 2001). The pattern of endorsement in the non-fundamentalist community was very similar to that found in national samples (e.g., Gallup, 2007).

Furthermore, consistent with their robust essentialism (Gelman, 2003), 5- to 7-year-olds responded "No" when asked the closed-ended question: Could one species have been the descendent of a completely different kind of animal (see also Samarapungavan & Weirs, 1997). These young children did, however, endorse creationism at higher rates when they were explicitly presented with such ideas: Did God make them? Such results suggest that young children are susceptible to notions of intelligent design, even while they resist notions of species change (Evans, 2001). These findings were interpreted as supporting a constructive interactionist position (e.g., Wozniak & Fischer, 1993). Consistent with their cognitive biases, children spontaneously generate intuitive beliefs about origins, both natural and intentional. Community input reinforces and refines the culturally sanctioned intuitions while purging others, resulting in the distinctive and complex *reflective* belief systems (Sperber, 1996) of the communities at large (Evans, 2000a, 2000b, 2001).

What was most striking about these results were the two age-related shifts: from the mixture of spontaneous generationist and creationist ideas found in the 5- to 7-year-olds to the consistent creationism of the 8- to 9-year olds; and the second shift to the endorsement of evolutionary ideas among early adolescents, at least in the non-fundamentalist communities. A series of follow-up studies examined these shifts in more detail.

Consistent Creationism in 8- to 9-year-olds

Further investigation of the pattern of reasoning of the 8- to 9-year olds in non-fundamentalist communities, revealed an interesting relationship. It appeared that children in this age-group were beginning to confront existential questions, of eternity and of death, and it was this capacity that helped to motivate the shift to a consistent creationism (Evans, Mull, & Poling, 2001).

One of the reasons the youngest children appeared to endorse spontaneous generationist ideas was that they had failed to grasp the basic premise of the origins question, that, at one time, a particular kind of animal did not exist (Evans, 2000a, 2000b, 2001). In effect, some 5- to -7-year-olds seemed to believe that the animals were always on earth, but someplace else where they could not be seen, such as underground. The origins questions about the *very first* of a particular kind would make little sense to a child who thought they were eternal. To test this hypothesis, in a different study 99 preschool and early school age children, who attended public schools, were asked "Have there always been 'Xs' here on this world" (*impermanence*), where X was one of three randomly presented pictures of North American mammals and three simple artifacts (Evans, Poling, & Mull, 2001). Children responded with simple yes-no answers. As can be seen in Figure 10.2, not until children were 8- to 9-years of age did they consistently accept the idea of the impermanence of animals and of artifacts.

Children in the same study were also asked artificialist (Did a person make it?) and creationist (Did God make it?) questions about each of the same animals and artifacts. Replicating a pattern found among *non-fundamentalist* children in an earlier study (Evans, 2001), but using different measures, it was not until 8- to 9- years of age that children consistently distinguished

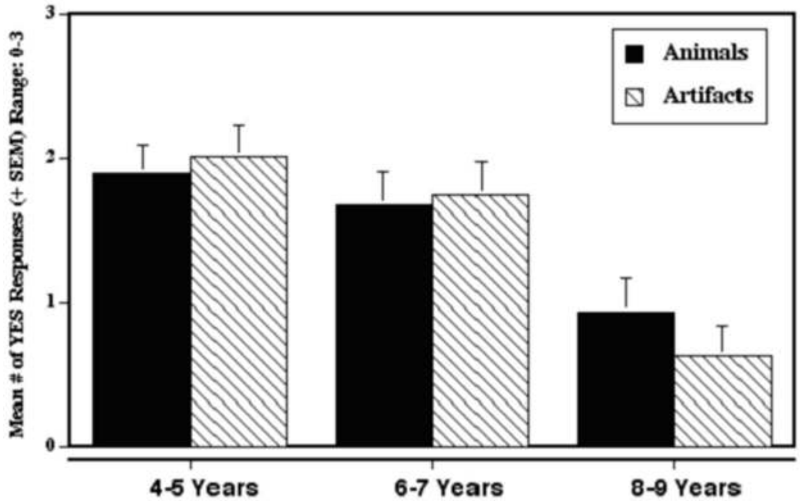

FIGURE 10.2 Were they always here? Children's acceptance of the permanence of animals and artifacts, by age group.

between the creative capabilities of humans and of God (see Figure 10.3). In particular, younger non-fundamentalist children were as likely to state that God made artifacts as humans made artifacts (Evans, Poling, & Mull, 2001). In contrast, *fundamentalist* children from the same age-group seem precocious in that they were significantly more likely to make these distinctions (Evans, 2001). As it seems unlikely that fundamentalist adults explicitly focus on the distinctions between God and human capacities, the conclusion is that children make this inference unaided, perhaps based on repeated exposure to a creationist model.

Children's emerging grasp of core existential concepts should also include death: Entities once created will not continue to exist. Although there is much variation in the age of acquisition,

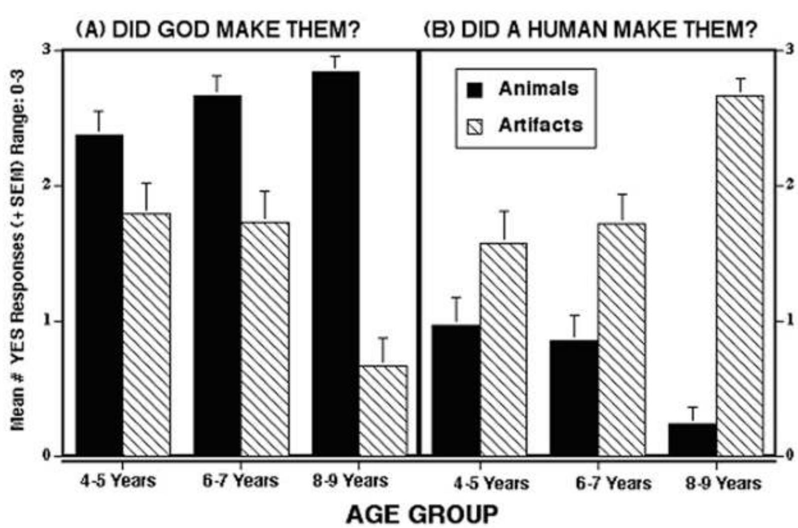

FIGURE 10.3 Children's responses to creationist (A) and artificialist (B) explanations for the origins of animals and artifacts, by age group.

which depends on the measures used, a full understanding of death is often not achieved until children are 7- to 9- years of age (Poling & Evans, 2004b; Slaughter & Lyons, 2003; Speece & Brent, 1984, 1996). Three measures of the death concept, irreversibility, nonfunctionality, and universality (inevitability) were also included in this study, and combined into a composite measure of children's understanding of death (Evans, Poling, & Mull, 2001).

To assess whether the creationism of the children in the study was related to their understanding of existential issues and their capacity to reason about human artificialism, a multiple regression analysis were performed on a composite measure of *coherent* creationism, in which two measures were combined (God made animals, God did not make artifacts): 54% of the variance was explained. Predictor variables included a coherent artificialism (humans make artifacts, not animals), children's understanding of death, children's understanding of the impermanence of objects, and children's age (as a continuous variable). Standardized regression coefficients indicated that age did not add any additional variance beyond the effects of the other variables, all of which contributed variance independently of each other (Evans, Poling, & Mull, 2001).

This study suggests that children's capacity to reason about an intelligent designer is strongly related to their understanding of artifact origins as well as their grasp of existential concepts, rather than other age-related factors. This capability increases children's susceptibility to cultural input, which is why older children are more likely than younger children to evoke God as the designer. What else is needed?

Fina and Ultimate Causal Reasoning in 8- to 9-year-olds

The *final* or teleological cause reasoning of the creationist world view is eschewed by modern science, because the typical scientist should be concerned with proximate cause mechanisms, the immediate cause of the event in question (Root-Bernstein, 1984; Shapin, 1996). Ernst Mayr, the preeminent evolutionary biologist, disagrees with this viewpoint, however. Mayr argued that evolutionary biology differs from the physical sciences because it consider the *ultimate* causes, more specifically the evolutionary reasons, for the existence of a particular biological structure or behavior, as well as the proximate causes (1985, 1988). Thus the evolutionary biologist asks both how and why questions: How does a particular organ work? Why does that organ have that particular structure and function? (Evans 2000a, 2001; Southerland, Abrams, Cummins, & Anzelmo, 2001).

This integration of causal levels is one of the reasons that evolutionary biology appears to challenge the creationist world view. The causal status of proximate *causes* and that of the more distal *reasons* (or purpose) for a behavior or event has been the subject of much philosophical and psychological debate (e.g., Malle, 2004; Sehon 2005). A *reason* explanation is also called teleological reasoning, but if it is conceptualized as a more distal causal level, the evolutionary cause, some of the angst surrounding the creation/evolution debate should melt away. In effect, many of those scientists and theologians described earlier have managed to accommodate those causal levels by considering God as the first cause (Baker, 2006), the reason why life exists, and evolutionary causes as critical links in a naturalistic causal chain set into motion by God. The problems really arise when God is thought of as the more immediate or proximate cause of the origin of species, a central planner, as in the Biblical literalist account.

The focus here is on children and when they begin to make sense of these crucial distinctions. The short answer is that, as yet, not very much is known about this issue. To understand origins questions children have to integrate proximate and more distal causes into a complex causal structure. Only then can they consider *how* and *why* something came into existence (see also Abrams, Southerland, & Cummins, 2001; Southerland et al., 2001). There is plenty of evidence that young children use proximate cause reasoning (e.g., Wellman & Gelman, 1998). In the spontaneous generationist reasoning of the 5- to 7-year-olds, for example, they easily explain how the animal became visible (it came out of the ground), but they do not explain how it got there in the first place. Yet, the ease with which 5- to 7-year-olds agreed that "God did it," when offered the opportunity to do so in closed-ended questions (Evans, 2001), not only suggests a role for "testimony" (Harris & Koenig, 2006) in children's endorsement, but also suggests that they can incorporate distal cause reasoning.

The evidence presented earlier, however, demonstrated that for younger children, at least, this information is not yet integrated into a knowledge structure, in that "God did it" is just a loosely associated piece of information, no different from "a person did it" (Evans 2000a, 2001). Furthermore, younger children appeared to consider God as the proximate cause of the event in the sense that he directly makes objects/species in the way that people make artifacts, rather than considering the final cause, the reason why he made the object. Further evidence to support this argument is found in a recent study in which children were asked open-ended questions about the origins of the very first artifacts: Younger children gave single cause answers, whereas older children were more likely to integrate different causal levels (Evans, Mull, Poling, & Szymanowski, 2005). The following responses to the question: How do you think the very first chair got here on earth illustrate this age-related shift:

> From the store (6 years); God made it (6.8 years) Humans build it (6.8 years)
>
> God makes trees, so we can cut the trees down, and make chairs out of wood (8.3 years)
>
> God gave people the idea to make a chair (11. 8 years).

Moreover, in some recent work investigating the development of a folk theory of intentionality (Malle & Knobe, 1997), it was not until 8- to 9-years of age that children appeared to be converging on the adult theory (Mull & Evans, 2007). The *intentionality* inherent in an action such as that of a child knocking over a glass, for example, is interpreted differently by different age-groups. One-year-olds both recognize and respond appropriately to goal-directed actions such as the hand movements or visual gaze that are the immediate precursors to an action (Tomasello et al., 2005). Preschoolers often report that an action occurred because of the protagonist's desires: "he wanted to knock over the glass" (Mull & Evans, 2007). Five- to seven-year olds report the immediate or behavioral concomitants of the action, such as looking and pushing. Older children are more likely to report the more distal causes underlying the action, such as the knowledge, skills, and beliefs of the perpetrator: "he knew what he was doing when he looked and pushed the glass" (Mull & Evans, 2007).

This research indicates that it is not until they about 8- to 9-years of age that children fully describe the reasons, in particular the prior intentions, that make up a folk theory of intentionality (Mull & Evans, 2007). At this point they integrate an understanding of proximate cause goal-directed actions, apparent at all ages, with more distal mental state explanations. Researchers investigating school-age children's understanding of the mental processes that underlie more complex actions report a similar age-related trajectory (Amsterlaw, 1999; Flavell et al., 1995, 2000). These findings could well explain why it is often not until 8- to 9-years of age that children begin to fully conceptualize God as intelligent designer; younger children are less likely to integrate the immediate causes of an action (he made it) with the final causes (the reasons why he made it). If the same capacity underlies the ability to reason about ultimate or evolutionary causes, then it is not too surprising that it is not until the end of the grade school years that children typically begin to reason in evolutionary terms.

Evolutionary Ideas (macro- and micro-) in Older Schoolchildren

In sum, the work described so far indicates that to reason about the origins of novel entities, artifacts or animals, children should have confronted core existential questions and be able to integrate proximate and ultimate causes into a complex causal chain. This emerging cognitive capacity is necessary, but not sufficient. It is related to final cause creationist reasoning as well as ultimate cause evolutionary reasoning. What else might predict acceptance of evolutionary ideas? In this section both micro- and macro-evolutionary concepts are considered.

Clearly, exposure to a particular cultural environment is critical, but which aspects of that environment have predictive value? As described earlier, by early adolescence, children raised in more religious contexts, such as Christian fundamentalist homes and schools, were more likely to maintain and extend their creationist ideas, whereas their non-fundamentalist counterparts were more likely to endorse evolutionist views (Evans, 2001). Importantly, that research also revealed that the latter endorsement was related to several factors other than community of origin.

Independent of the consistency of parent evolutionist beliefs, an understanding of the fossil evidence and a willingness to accept the (incorrect) idea that animals change in response to environmental factors (e.g., giraffes' long necks result from their habit of stretching their necks to reach into tall trees to obtain food) predicted preadolescents' macroevolutionary ideas. Even though the mechanism they endorse is incorrect, they acknowledged the critical role of environmental pressure in species changes (Evans 2000a, 2000b). Children from fundamentalist families believed that animals would not change, because "God made it that way so it can't change" (11 year-old; Evans, 2001). Altogether, on open-ended questions, these factors explained 76% of the variance in the frequency of preadolescents' evolutionary ideas. Predictors of the frequency of preadolescents' creationist ideas, included the consistency of parent creationist ideas, attendance at a Christian fundamentalist school, and a lack of knowledge of the fossil evidence, altogether accounting for 67% of the variance (Evans, 2001).

One of the surprising findings in Evans' (2001) study was that many of the participants had mixed beliefs, endorsing both evolutionist and creationist ideas. Moreover, many in the non-fundamentalist community, while accepting that non-human species evolved, believed that humans were created by God. A more recent in-depth investigation of this finding revealed a much more nuanced acceptance or rejection of evolution than national or international surveys would allow. In this study, we hypothesized that an acceptance of radical within-species change, such as the metamorphosis of caterpillars into butterflies (Rosengren, Gelman, Kalish, & McCormick, 1991), would predict acceptance of evolutionary origins, because in both cases such an acceptance requires a modification of core essentialist constraints on species concepts (Evans, Rosengren, Szymanowksi, Smith, & Johnson, 2005). The relation between an acceptance of macroevolutionary change and the nature of the living kind was examined in 115, 6- to 12-year-olds and their parents from both Biblical literalist and theistic evolutionist families (defined by parental belief system). Participants of all ages were more likely to accept evolutionary ideas for animals that undergo metamorphosis and were taxonomically distant from the human, in the following order: Butterflies > frogs > non-human mammals > humans (Figure 10.4).

Moreover, among theistic evolutionist families, metamorphosis understanding was related to evolutionary concepts, independently of the child's age. This was not the case in Biblical literalist families however, where older children understood metamorphosis but still retained their explicit belief that each "kind" has a unique and God-given essence that cannot change. Although, one clear implication of these studies is that teaching children about metamorphosis may provide them with the basis for modifying an early cognitive constraint, namely an essentialist bias, there is an important caveat. Metamorphosis as a model for species change introduces an inaccurate if

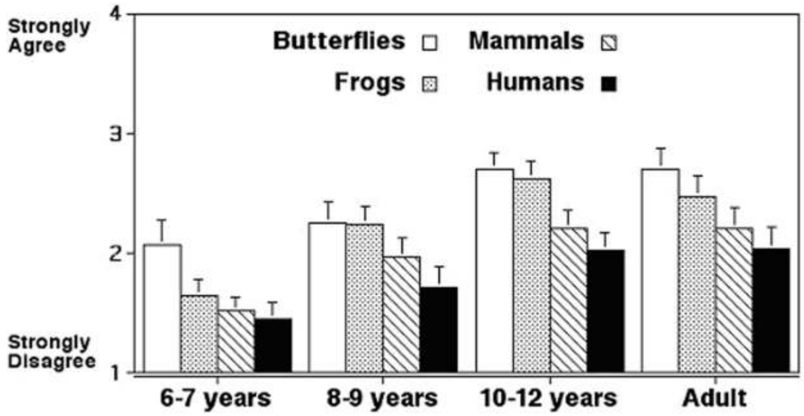

FIGURE 10.4 Did it evolve? Mean agreement (+SEM) for butterflies, frogs, mammals and humans, by age group.

prevalent analogy: Evolutionary change is like developmental change.

One further, critical factor related to evolutionist and creationist ideas in a population is the acceptance of the human as an animal (Carey, 1985). In the same study, children were also asked whether humans, other mammals, butterflies, frogs, and artifacts were animals (Evans et al., 2005). Apart from the human, children of all ages were quite clear which were animals and which were not. For the human there was both a developmental and a community influence, with older children from theistic evolutionist families most likely to agree that the human was an animal (see Figure 10.5). Moreover, independently of other relevant factors, such as parental promotion of religious interest in the child, and the child's age, acceptance of the human as an animal was positively related to children's macroevolutionary ideas ($\beta = .29$; $p < .01$).

Early adolescents have the capacity to reason about original cause. They may also accept that populations of animals undergo macroevolutionary change. The latter acceptance is most likely to occur if the essentialist bias that species are unchanging has been modified by exposure to evidence of species change, from fossils, to metamorphosis, to adaptive variation. Moreover, many of the children who endorsed macroevolutionary ideas also spontaneously invoked some

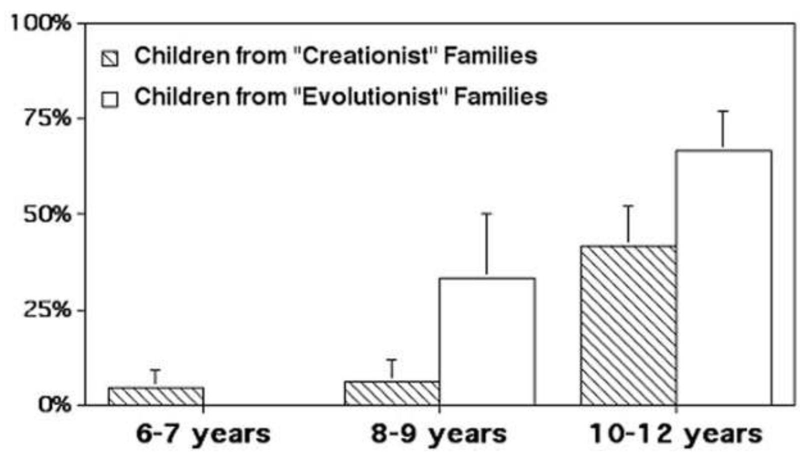

FIGURE 10.5 Is the human an animal? Percentage agreement among children from mostly "creationist" and mostly "evolutionist" families, by age group.

kind of evolutionary cause that would explain these changes. In most cases this was a teleological cause, such as a need-based or developmental change in response to environmental factors, seen also in other studies with these age-groups (e.g., Abrams et al., 2001; Brumby 1979; Deadman & Kelly, 1978; Southerland et al., 2001); presumably no-one taught them this, it is one that they inferred with minimal input. But there were occasional instances of something approaching a Darwinian mechanism.

Here is the response of a 10-year-old girl with no formal exposure to evolutionary theory, who had been asked about the adaptation of a novel animal called a spiggle (it looked like a mixture of a pig and a squirrel) to its newly aquatic environment — a previously dry island that had been flooded. Note the sequence of causal chains in her response (Evans 2000a):

> If there are spiggles that weren't streamlined, they wouldn't be well equipped for the life they lived so the streamlined webbed spiggles would live and –slowly the stronger webbed ones would survive and eventually all would be like this. (p. 248)

A typical response from a younger child was:

> [they] watched the fishes, copied them, one spiggle got to swim and taught the others. (p. 230)

Both of these responses were original. The younger child was using his understanding of human activities as goal-directed and intentional to model how spiggles could change. The 10-year-old, in contrast, thought that the spiggle population can vary (some are streamlined, some are not), and that the aquatic environment acts as a selection force, with the streamlined, webbed spiggles surviving. There is no reference to intentional or goal-directed actions. She has almost described the mechanism of natural selection.

High-school and College Students' Understanding of Evolution

The focus of this chapter, thus far, has been on concepts of species origins rather on mechanisms of change within a population. What has been demonstrated is that by early adolescence those children who accept the idea of common ancestry, that one kind of animal could have been the descendent of a completely different kind, are also likely to endorse pre-Darwinian teleological ideas of evolutionary change. The main focus of the extensive research on high-school and college students' misunderstanding of evolution has been on mechanisms of microevolutionary change, in particular students' understanding of natural selection (Catley, 2006; Poling & Evans, 2004b). This research has also addressed the issue of what kinds of teaching methods are required for students to shift from a pre-Darwinian mechanism of individual change to the Darwinian mechanisms of natural selection in a population. This work has been detailed elsewhere (e.g., Anderson, Fisher, & Norman, 2002; Catley, 2006; Poling & Evans, 2004b; Shtulman, 2006). In this section, some of the most relevant conclusions will be summarized and related to the developmental studies and more recent research on museum visitors' understanding.

What is striking about this research is the extensive documentation of the overlap between students' intuitive notions of evolutionary change and pre-Darwinian evolutionary concepts (e.g., Chambers, 1994; Mayr, 1982; Shtulman, 2006), though they are certainly not identical (Evans, 2001; Kampourakis & Zogza, 2007). Students' ideas focus on individual change rather than population change and utilize commonsense concepts, similar to those found in younger children: (1) that evolutionary change is need-based and adaptive, in a teleological sense, (2) that it is developmental and progressive: an emergence from an underdeveloped form, and (3) that it is not so much a dynamic process as a series of discrete events (e.g., Banet & Ayuso 2003, Bizzo 1994, Clough & Wood-Robinson, 1985a, 1985b; Dagher & BouJaoude 1997, Deadman & Kelly, 1978, Ferrari & Chi, 1998).

Such ideas are found at all grade levels, including science undergraduates and medical students, and are remarkably resistant to instruction (Bishop & Anderson, 1990; Brumby, 1982, 1984; Lawson & Worsnop, 1992). More recent studies of the effects of classroom instruction that include students' understanding of the nature of science and the nature of knowledge has yielded more promising results (Bell, Lederman, & Abd-El-Khalick 2000; Passmore & Stewart, 2002; Sandoval & Morrison, 2003; Sandoval & Reiser, 2004; Scharmann, 2005; Sinatra et al., 2003). Even so, the effects are not large. One possible explanation for such results is that these studies include students who are uninterested in the topic and who are merely learning enough material to pass the course, not to acquire the deep understanding necessary for understanding evolutionary concepts.

Natural History Museum Visitors' Understanding of Evolution

What about a population that would be expected to have a good grasp of evolutionary theory and who have a demonstrated interest in natural history, such as natural history museum visitors? On average, such visitors are more highly educated than the general population; 60% or more have a college education (Korn, 1995). Additionally, of course, they are interested enough in natural history to voluntarily visit such a museum, where they are likely to encounter exhibits on evolution (Diamond & Scotchmoor, 2006). As such, they would be expected to be more knowledgeable about natural history, and more accepting of evolution than the general population.

It is indeed the case that museum visitors are less likely to be creationist and more likely to accept evolutionary origins than the general population (Spiegel et al., 2006). But, just like the rest of the population, it depends on the target species. When asked about *human* origins, 28% of a sample attending three Midwest museums were creationist (Evans et al., 2006), compared with 46% in the general population (Gallup, 2007). However, only 6% of the same sample held consistently creationist views, regardless of the species, which included HIV, diatom, fruit-fly, ant, finch, and whale, as well as the human. What is more surprising is that only 34% of the same sample could be described as knowledgeable about evolution, and, even then, none of the visitors consistently invoked Darwinian reasoning across all seven species. Just like participants in earlier studies, most visitors used mixed reasoning, for some species they were informed Darwinian reasoners, for others they invoked novice naturalistic reasoning, and, occasionally, but most often for the human, they were creationist (Diamond & Evans, 2007; Evans, Spiegel, Gram, Frazier, Cover, Tare, & Diamond, 2006).

These kinds of findings are not only replicated in other museum settings across the United States (Spiegel et al., 2006), but are also found among visitors from international communities, where the acceptance rate of evolutionary origins, common descent, is much higher. Silver and Kisiel (2006) compared U.S., Canadian, English, and Australian natural history museum visitors and found that only about 30% had a reasonable grasp of natural selection. In the United States and in other English-speaking countries, museum visitors exhibit the same kinds of misunderstandings of evolution found in young children and in school-age and college students, with a preponderance of teleological, intentional, and essentialist explanations. The universality of these ideas is quite striking.

Two examples will suffice. When asked to explain why there were now 800 species of fruit flies on the Hawaiian Islands, when several million years ago there were only a few such flies, 50% of a natural history museum sample used the kind of essentialist, proximate cause explanations, described earlier in young children:

> Obviously people have brought the fruit flies in. And Dole probably, Dole pineapple people probably brought them in. (Diamond & Evans, 2007, p. 1503)

In response to a question about changes in beak size in the Galapagos finches over seasons, this museum visitor invoked the classic teleological story of the giraffe's neck, to describe biological change:

> Evolution for survival. …Well, in order to survive, their body parts had to adjust to certain things, similar to the way giraffes' necks probably grew long as they reached for the plants at the top of the trees, so the beak grew longer in order to deal with the tougher seeds. (Diamond & Evans, 2007, 1504)

MISUNDERSTANDING EVOLUTIONARY BIOLOGY: IMPLICATIONS FOR THEORIES OF CONCEPTUAL CHANGE

In the final section, a summary of the developmental research is followed by a discussion of the strengths and weaknesses of the intuitive theory approach and a consideration of a potential research agenda based on this theoretical framework.

Summary

Cognitive biases that are intrinsic components of an intuitive psychology and biology (e.g., Astuti, Solomon, & Carey 2004; Carey, 1985, 1995; Hatano & Inagaki 1999; Inagaki & Hatano 2002; Keil, 1994, 1995; Medin & Atran, 2004; Wellman & Gelman, 1998), intention, essentialism, and teleology, make it difficult for children and adults to accept and explain the core tenets of evolutionary theory: That naturalistic, non-teleological, and non-intentional processes result in population change, speciation, common descent, and the interrelationship of all living things. These final steps, especially common descent, are explicitly rejected by Biblical literalists, even when they endorse changes in gene frequency in a population. Speciation and phylogenetic change challenge the Biblically-based tenet that each living kind has an unchanging God-given essence (Evans, 2001. 2005; Morris & Parker, 1982).

The developmental evidence demonstrates that in comparison with older children, 5- to 7-year-olds are more likely to believe that animals and artifacts are eternal and unchanging and use simple proximate cause reasoning to explain the origins of animals and artifacts ("it was in the store," "it came from someplace else"). Thus, for the younger children in these studies, the whole question of "origins" is often moot. From their perspective, the animals were always here on earth, perhaps hidden somewhere, and unlikely to change. Therefore, it makes little sense to ask how "the very first" of a species got here on earth. This kind of intuitive reasoning is hypothesized to give rise to a view of species as unvarying and stable. For example, 5- to 7-year-olds are unlikely to accept that animals undergo radical changes over their lifetime. If asked to pick the adult of a tadpole, younger children typically pick a bigger tadpole, not a frog (Rosengren et al., 1991).

Children aged 8- to 9-years are in an interesting transitional phase (Evans, 2005). They are more likely than their younger siblings to endorse life-cycle and within-species variation and change, but less likely than 10- to 12-year-olds to accept common descent. The majority endorse some form of creationist or intelligent design ideas, regardless of home background. One of the reasons for these age-related differences is that children of this age group are beginning to confront existential questions. Unlike 5- to 7-year-olds, they know more about death and they realize that animals are not eternal, in that they were not always here on earth. So the question now arises:

How did they get there in the first place? These children appeal to their intuitions about human intentions and design and apply it to species: If tools can be designed, so can animals. Simultaneously, they are integrating levels of cause, proximate and more distal, into the kind of complex causal structure that is necessary for the ultimate cause reasoning of the evolutionary biologist

Depending on their family belief system, creationist or not, and their exposure to fossil and natural history knowledge regarding animal change, 10- to 12 year-olds are more willing than younger children to accept that one kind of animal could have descended from a completely different kind. Regardless of age, children who accepted that the human was an animal and who understood metamorphosis were more likely to accept common descent (Evans, Rosengren, Szymanowski, Smith, & Johnson 2005). The latter finding implies that these children endorse a common misconception, that species change is analogous to developmental change in individuals. There was an important caveat, however. Children from Biblical literalist families (God created each kind) accepted metamorphosis but did not accept common descent for humans or other mammals. Yet, irrespective of background, all age groups were more likely to accept common descent for butterflies and frogs than for mammals or humans.

Such results are in keeping with earlier findings that about 30% of older children and adults entertain mixed beliefs, accepting evolutionary origins for non-human species and creationism for humans, for example (Evans, 2001; Sinatra et al., 2003). Further, a recent study of museum visitors' explanations of biological change in diverse organisms revealed a similar inconsistency: their endorsement of evolutionary or creationist origins depended (1) on organism under discussion, as well as (2) whether the question was about microevolutionary or macroevolutionary change (Evans et al., 2006).

In sum, intentional, teleological, and essentialist views of species origins are found historically, in children, and in students and adults from different cultural backgrounds. Microevolutionary questions elicit naïve biological explanations, in museum visitors and students of all ages from the United States (e.g., Bishop & Anderson 1990, Brumby 1982, 1984; Clough & Wood-Robinson 1985a, 1985b; Spiegel et al., 2006), Japan (Inagaki & Hatano, 2006), Netherlands (Samarapungavan & Wiers, 1997), and other cultural settings where they have been tested (e.g., Dagher & BouJaoude, 1997; Silver & Kisiel, 2006). Typically, they take the form of the erroneous pre-Darwinian microevolutionary concept, that individuals in a population change over the life-span in response to the demands of a novel environment and that subsequent generations inherit these changes (Chambers, 1994; Mayr, 1982). This goal-directed or teleological concept of species change, in response to an individual organism's needs, can persist in the face of focused instruction (e.g., Anderson et al., 2002; Bishop & Anderson, 1990). On the other hand, macroevolutionary or *origins* questions are more likely to elicit *intentional* creationist or intelligent design explanations, especially in the United States.

The Explanatory Potential of Intuitive Theories

The intuitive theory or developmental constraint approach described in this chapter offers a robust theoretical framework for integrating a large body of data on the misunderstanding of evolution. It provides a developmental framework for understanding the persistence of essentialist, teleological, and intentional concepts of evolution in the lay public and in students, before and after instruction (Evans, 1994/1995, 2000a, 2000b, 2001). It links these misunderstandings to broader cultural and developmental factors, such as the rejection by Biblical literalists of macroevolutionary change and young children's resistance to between-species transformations, both of which, it is argued, are tied to essentialist reasoning patterns. It can be related to discussions of emergent knowledge in other conceptual domains, such as diSessa's phenomenological primitives in a naïve physics (diSessa, 1993; diSessa et al., 2004; Southerland et al., 2001). Moreover, the focus on evolutionary biology, in this chapter, provides data to amply support a more recent consensus in the science education community that "Children's rich but naïve understandings of the natural world can be built on to develop their understanding of scientific concepts" (Duschl, Schweingruber, & Shouse, 2006, pp. 11–14).

It can also predict contextual effects: To the extent that a naïve psychological framework is elicited then evolution will be rejected. Naturalistic, non-teleological, evolutionary concepts of species change run counter to the folk concepts of intentionality (Malle, 2004; Malle & Knobe, 1997) that are the foundation of a naïve psychology (e.g., Wellman, 2002). The human, of course, is the quintessential intentional entity. In support of the prediction, the human, and species closely related to the human, are more likely to elicit intentional explanations such as intelligent design and creationism (Evans, 2001; Evans et al., 2005; Sinatra et al., 2003). As well, species that are taxonomically distant from the human are more likely to elicit naïve biological explanations, including naturalistic proximate cause explanations and non-intentional, teleological evolutionary explanations. Further, unlike evolutionists, creationists do not consider the human to be an animal (Evans et al., 2005). In cultures that do not share Western monotheistic beliefs in the privileged human, the relationship between the human and other primates is much more likely to be acknowledged (Inagaki & Hatano, 2006).

Creationists are particularly resistant to the idea of evolutionary origins, macroevolution, but, for the most part, they will accept microevolutionary processes governing within-species change (Evans, Hazel, Nesse, Weder, Murdock, Gervasi, & Witt, 2007). Why might that be? The obvious explanation is that evolutionary origins directly contradict the received word of God that each kind was specially created with an unique immutable essence: one kind cannot become another — a reified essentialist notion (Evans, 2001). Change over the lifespan of an organism is endorsed, however (Morris & Parker, 1982). More subtly, though, if the mutability of kinds is accepted, then this might well arouse existential angst, particularly concerning the extinction of the human. In contrast to a sample of evolutionary biologists, for example, midwestern parents and children were more likely to reject the possibility of human extinction than the extinction of non-human species (Poling & Evans, 2004a).

In addition to intentions and goals, a naïve psychological framework also encompasses emotions, beliefs, and desires (Wellman, 2002). This licenses another prediction that the extent to which a naïve psychology is elicited, then evolution will be associated with negative feelings and emotions. As described earlier, the apparent purposeless of evolutionary explanations elicits deep-seated concerns, even when evolution is accepted (Brem et al., 2003; Jackson, Doster, Meadows, & Wood, 1995). Parents respond to these concerns by worrying whether they can raise moral children: "if children are nothing more than apes evolved then we cannot expect them to act more than that to one another…" (Evans, 1994/1995, p. 124; 2000b). Even teachers respond to these concerns with heightened levels of stress (Griffith & Brem, 2004; Hahn et al., 2005).

Causal Flexibility and Explanatory Coherence

Although the exact nature of the cognitive biases associated with the intuitive theory approach has been the source of a lively and often contentious debate (e.g., Astuti, Solomon, & Carey 2004; Carey, 1985, 1995; Hatano & Inagaki 1999; Keil, 1994, 1995; Medin & Atran, 2004), this has only strengthened the subsequent research. Teleological explanation is considered of key importance (Evans, 1994/1995, Inagaki & Hatano, 2002; Keil, 1994; Kelemen 1999; Opfer, 2002). One contentious issue is whether this explanatory mode is necessarily linked to the mental state explanations of a naïve psychology, especially in young children (Kelemen, 2004).

The research described in this chapter suggests that this is not the case. More specifically, it would appear that when linked to intentional mental state explanations, teleology motivates a naïve psychology, but when linked to functional explanations that serve the organism itself, it motivates a naïve biology (Poling & Evans, 2002, 2004b; Keil, 1994). Children discriminate between these explanatory modes (Schult & Wellman, 1997) and use them flexibly (Gutheil, Vera, & Keil, 1998). Even though 6- to 7-year-olds often favor psychological explanations for biological phenomena (Carey, 1985), they agree that animals breathe because they *need* to (a functional explanation that serves the organism) and not because they *want* to (a mental state explanation) (Poling & Evans, 2002). This kind of evidence suggests that although mental state explanations may be a default, they are not the only ones available to young children (Gutheil, Vera, & Keil, 1998). This capacity to shift explanations depending on the context is called *causal flexibility* (Poling & Evans, 2002) and it is demonstrated in children and adults when they shift explanatory modes depending on the species. It should be a fundamental component in any explanation of conceptual change.

The evidence presented in this chapter suggests that as children learn more about change and diversity in the biological world (and provided they are not reared in a fundamentalist environment) they shift from a naïve psychological framework to a naïve biological one, to explain species change. Initially, the latter yields a non-Darwinian teleo-functional explanation (see Inagaki & Hatano, 2006) for evolutionary change. With more experience of the natural world, essentialist and teleological biases guide the burgeoning biologist as he/she investigates the patterns of similarity and differences in species, and links them to adaptive functions.

It should be noted that the claim is *not* that the evolutionary biologist is freed of a teleo-essentialist bias, but that it is reconfigured in the process of re-representing the realities of the biological world. For the evolutionary biologist, genes reflect essences and adaptation reflects ancestral environments, encoded genetically. These changes indicate the emergence of a richer and more coherent knowledge structure; an age-related but not an age-dependent shift.

While their beliefs appear to be locally coherent, this set of findings suggests that explanatory coherence writ large (Thagard, 1989), is not necessarily found in a lay population (Evans, 2001). In many cases, participants in these studies shifted between explanations, such as creationist and evolutionist, depending on the target organism and on their interpretation of the question (see also Gutheil, Vera, & Keil, 1998; Poling & Evans, 2002; and in the physical domain, diSessa, 1993; diSessa et al., 2004). Further, these findings suggest that conceptual change is not necessarily achieved by radically reconfiguring a preexisting conceptual structure, but by sidelining one particular conceptual framework in favor of another, as circumstances change (Keil 1994; Keil & Newman, chapter 4, this volume). Meanwhile, with development, both biological and intentional frameworks are undergoing conceptual enrichment and change fueled by the acquisition of culturally and experientially provided information.

As in the history of science (Thagard, chapter 14, this volume), these studies demonstrate shifts from intentional to mechanistic-biological explanations of origins. Yet, at least ontogenetically, this is not a progressive tendency. It is not that young children are unable to conceive of a naturalistic explanation for species origins, but that the explanations they do utilize, such as spontaneous generation, are, as yet, inadequate to the task. For children, this is a proximate cause mechanism that explains how species became visible, but not how they originated *ex nihilo*. Plausibly, such naturalistic explanations could eventually yield a pre-Darwinian evolutionary explanation in children who are not exposed to the attractive creationist alternative (Evans, 1994/1995, 200, 2001; Samarapungavan & Weirs, 1997). Mayr (1982) makes a similar argument historically: Were it not for the impact of Christianity, the spontaneous generationist ideas of early Greek philosophers could have yielded evolutionary explanations, in that both were non-teleological and naturalistic.

In children who are exposed to creationism, to a greater or lesser degree, the shift to an intentional mode, in which species are treated as artifacts of God, is accompanied by the capacity to integrate both proximate and final causes into an explanatory framework. Intriguingly, this pattern of complex causal reasoning also underlies the ability to appreciate ultimate cause evolutionary explanations for the origins of species.

Integrating Domain-specific and Domain-general Approaches

The preceding sections have detailed the emergence of domain-specific intuitive reasoning processes utilizing a developmental framework, which yield testable hypotheses regarding an everyday understanding of evolutionary biology. The data provided so far offer support for this framework theory. A weakness of this approach, however, is that it does not directly address "the interplay between domain-specific and domain-general knowledge over the course of development" (Duschl et al., 2006, pp. 11–15).

Clearly, students' personal epistemology (e.g., Hofer & Pintrich, 1997; Muis, Bendixen & Haerle, 2006; Sinatra et al., 2003; Sinatra & Mason, chapter 21, this volume), in particular their understanding of the nature of science (e.g., Abd-El-Khalick & Akerson 2004; Bell et al., 2000) and their ability to distinguish between belief and knowledge (Southerland, Sinatra, & Matthews, 2001; Sinatra, 2005), as well as more general reasoning processes (Kuhn, 1999; Lawson, & Worsnop, 1992) all play a role in their understanding of evolutionary biology. From a domain-general perspective alone, though, it would be difficult to explain why the term evolution arouses such misgivings (Brem et al., 2003) or explain the existence of contextual effects, such as the consistent finding that creationist concepts are more likely to be evoked for human origins and for macroevolutionary processes (Evans 2000b; 2001; Evans et al., 2005, 2007).

On the other hand, the developmental data presented here have domain-general implications, in particular the integration of proximate and more distal causal levels to explain evolutionary concepts. The ability to link causal levels must underlie a range of domains that consider existential issues, from philosophy and religion to evolutionary biology. Researchers, in particular Lawson and his colleagues, have related students' domain-general reasoning processes, using a Piagetian framework, to their misunderstanding of science (e.g., Lawson, Alkhoury, Benford, Clark, & Falconer, 2000), and of evolution (Lawson & Worsnop, 1992). They suggest a hierarchy of descriptive, hypothetical and theoretical concepts that range from more to less observable (Lawson et al., 2000), which could potentially be tied to an intuitive theory framework.

There are several possible ways of integrating these perspectives (Duschl et al., 2006). One possibility, relevant to the current topic, is to consider how domain-specific processes may become available to other domains as intuitive theories are extended and developed. Mathematics, for example, is essential to a theoretical physics, even though it probably plays no role in an intuitive physics. Children's theory of mind or intuitive psychology, likewise, may be extended to inform a personal epistemology, which, in turn, can be utilized in a number of academic domains. As described earlier, although preschoolers and young school-age children may reference unobservable mental states, such as know, think, and believe, the complexities of the thinking process, such as being in two minds or having conflicting ideas, are not grasped until they are 8- to 9-years of age or older (Carpendale & Chandler, 1996; Flavell, Green, & Flavell, 1995; Mull & Evans, 2007). This emerging ability to reflect upon their own knowledge (Wellman & Johnson, in press), allows children to integrate diverse views of knowledge, and to actively consider the distinction between knowledge and belief (Southerland et al., 2001).

Thus, even though very young children can distinguish between domains at an intuitive level, in the sense that they can tell the difference between an apple and a thought about an apple (Wellman, 2002), their ability to reflect upon the nature of their own and others' knowledge requires a different level of analysis (Wellman & Johnson, in press). There is a recursive quality to this ability, the capacity to re-represent representations, which may be tied to other processes such as the emergence of executive function (Wellman, 2002) and the integration of causal levels (Mull & Evans, 2007). It is quite plausible, therefore, that this reflective capacity is a function of an elaborated intuitive psychology, focusing on the nature of knowledge, which then becomes more broadly accessible to other domains, including academic domains (Muis et al., 2006).

A Research Agenda?

This analysis would not be complete without suggesting a research agenda, one that integrates disparate disciplines. No longer can it be said that students' understanding of evolution is under-researched (Cummins et al., 1994), but what is lacking is a coherent theoretical framework, particularly one that integrates the developmental origins of adult resistance to evolution (Bloom & Weisberg, 2007).

Clearly, a multifaceted approach is needed. At the level of basic research, we need to know much more about the development of intuitive cognitive biases, essentialism, teleology, and intention, and their relationship to intuitive and folk theories of biology and psychology (e.g., Coley, Solomon, & Shafto, 2002; Kelemen & DiYanni, 2005). This requires a philosophical as well as a psychological analysis (e.g., Sehon, 2005). A key task, which builds on this research, is to establish how these initial constraints are reconfigured to support Darwinian evolutionary explanations, in formal (e.g., Rudolph & Stewart, 1998; Shtulman, 2006) and informal (Diamond & Scotchmoor, 2006; Weiss, 2006) educational settings. New techniques, particularly modeling techniques, for teaching evolutionary biology and science (e.g., Alters, 2005; Jensen & Finley, 1996; Lehrer & Schauble, 2006; Southerland & Sinatra, 2003; Wilensky & Resnick, 1999) should be informed by a developmental constraints framework. As well, it is important to make evolution more engaging for students, especially those who are not science majors, by focusing on topics that might intrigue them, such as Darwinian medicine (e.g., Nesse & Wilson, 1996) or forensics (Mindell, 2006).

One of the contextual factors emphasized in this analysis is the resistance to macroevolutionary concepts, even when microevolutionary concepts are deemed acceptable. Several investigators are focusing their efforts on students' understanding of common descent and of cladograms that introduce *tree thinking*, a modeling technique used by evolutionary biologists to represent phylogenetic relationships between organisms. Students can also be exposed to these concepts via an understanding of geological or deep time (Dodick & Orion, 2003). As it turns out, though, tree thinking is not that easy, in that students have difficulty both with the spatial relationships as well as the underlying evolutionary concepts (Baum, DeWitt-Smith, & Donovan, 2005; Novick & Catley, in press). Although the introduction of modeling as an abstract concept is often problematic (e.g., Windschitl & Thompson, 2006), simplified tree-diagrams could be made sufficiently concrete so that they convey evolutionary relationships over time in a way that transcends cognitive or perceptual biases.

Besides the tools of evolutionary biology, such as tree-diagrams, which are often opaque, the language of evolution is also a potential barrier to understanding. Darwin struggled with this language (Beer, 2000). Evolutionary biologists use everyday terms such as adaptation and design in a highly specialized manner, but the language provides traps for the unwary. In fact, biologists have long been criticized for their teleological terminology (e.g., Jungwirth, 1975; Sprinkle, 2006). In a recent article on evolution and cancer in *Scientific American*, science writer Carl Zimmer describes cancer cells that "trick the body into supplying them with energy to grow even larger" (2007, p. 69). Even the title is problematic: *Evolved for Cancer*. This evocative but teleological/intentional language powerfully conveys the basic idea, but amazingly no-one has studied what effect this may have on the naïve reader. Does the reader immediately grasp the metaphor? If, as in this case, the language of biology mirrors students' intuitive cognitive biases, does it reinforce these biases or could it scaffold an understanding of Darwinian evolution?

No intervention focusing on evolutionary concepts is likely to work, at least in the United States, without extracting an emotional cost. Entrenched creationist beliefs (Chinn & Brewer, 2000) that are strongly rooted in a literal reading of the Bible are unlikely to change, but most of this research indicates that the about two-thirds of the U.S. public are confused rather than resistant. Even so, unlike the physical sciences, evolutionary biology arouses existential anxieties. Addressing these issues raises many problems (Pennock, 2002). Furthermore, there are important epistemological issues, which have not yet been satisfactorily resolved at the philosophical or the psychological level, but which need to be addressed. How is the relationship between religion and science to be disambiguated? Judge Jones of the Dover trial (Mervis, 2006) focused on the distinction between supernatural and natural causation, rather than differences in standards of evidence. Can such ideas even be raised in the science classroom? If so, how can this be achieved?

To solve these problems requires an approach that integrates the multiple factors and multiple disciplines referenced in this chapter. Evolutionary theory is the foundational theory for a broad range of endeavors from the biological, health, and social sciences to the computational sciences. In addition to its intrinsic importance, evolution should be part of the knowledge base of any informed citizen of the 21st century, who should grasp the evolutionary issues that underlie the impact of human activities on the natural world. Besides these important applied outcomes, investigations of the reasons why evolution is so easily misunderstood should provide insights into the way the human mind processes information about natural and supernatural causation, potentially impacting many disciplines.

CONCLUSION

The evidence presented in this chapter supports the position that the human mind seems almost incapable of conceptual change when confronted with scientific data that contradict a self-serving view of the world. About one-half of the U.S. public embraces creationist ideas about the origins of species. Even among those members of the public who accept evolutionary origins, including common ancestry, most invoke intuitive non-Darwinian teleological concepts to explain species change. Moreover, only about one-third of those with a demonstrated interest in natural history, such as museum visitors, grasp Darwinian evolutionary concepts. The latter patterns are replicated in other industrial societies.

As this chapter demonstrates, though, there are glimmers of hope, exemplified in the following conversation between a 12-year-old boy and his mother, as they sat next to the mythologist, Joseph Campbell, at a lunch counter (1972):

Boy: "Jimmy wrote a paper today on the evolution of man, and Teacher said he was wrong, that Adam and Eve were our first parents."
Mother: "Well, Teacher was right. Our first parents *were* Adam and Eve."
Boy: "Yes, I know, but this was a *scientific* paper."
Mother: "Oh those scientists!" she said angrily. "These are only theories."
Boy "Yes I know," was his cool and calm reply; "but they have been factualized: they found the bones" (pp. 1–2).

Campbell goes on to argue that it would behoove scientists to understand the "life-supporting nature of myths" before they are overthrown by "young truth-seekers of this kind" (p. 2) (Evans, 1994/1995).

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NOTE

1. The reported percentages of the population that endorse evolution or creation vary minimally depending on the type of question (Miller et al., 2006)

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