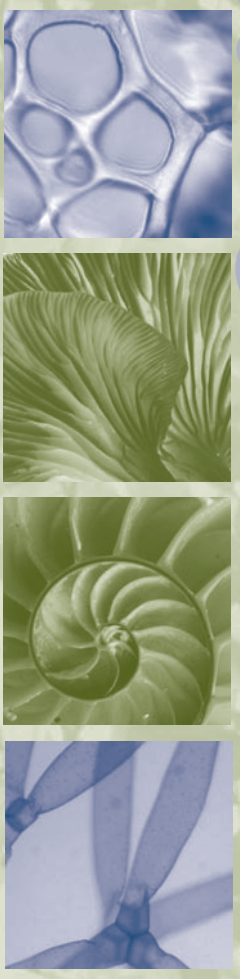
Part I



Introduction to Evolutionary Thinking

On Teaching Evolution and the Nature of Science

Robert T. Pennock

The best science teaching reveals not just the science of nature but also the nature of science. It is all very well and good for a student to learn the facts that science has discovered, but to do no more than that is to miss what is most important and distinctive about science, namely, its methods of investigation.

The most inspiring science teachers already know this. Physicist and Nobel laureate Richard Feynman, who was himself an inspiring teacher, recounted several stories about how his father taught him science. In one story, he described how his father would take him for walks in the woods in the Catskill Mountains and tell him interesting things going on in the forest. Other children would later tease him when he could not give the name of some bird they saw, saying that his father did not teach him anything. But Feynman said that the opposite was true and explained that his father would point to a bird and say, "It's a brown throated thrush—but in Portuguese it's a – –, in Italian a – – and so on. "Now," his father would continue, "you know all the languages, you want to know what the name of that bird is and when you've finished with all that you'll know absolutely nothing whatever about the bird. You only know about humans in different places and what they call the bird. Now, let's look at the bird and what it's doing" (Feynman, 1983).

In a simple and memorable lesson, Feynman's father was introducing the fundamental idea that science begins not in words but in observations. Science is not so much a list of facts we have discovered as a set of methods that let us know when we are justified in adding to or revising that list. Science advances by observation and inductive reasoning, and the student who does no more than memorize what previous scientists have found will be unlikely to make new discoveries about the world or even truly understand why he or she should believe what has already been discovered.

Evolution, as one such fundamental scientific discovery, should be included as a pervasive explanatory framework in all biology courses. But teaching it as a list of facts to be learned is not enough. It ought to be held up as a model of how good science is done. Teachers need to make clear that evolution is science done right, and it is one of the best examples to illustrate the nature of science.

Students may not initially understand this. Indeed, with all the misinformation spread about evolution by creationists, students may come to class with gross misunderstandings about its content and status. The problem is exacerbated by some politicians with a fundamentalist religious agenda who use their positions of power on school boards or state boards of education to attack science. In one recent case, a school board in Cobb County, Georgia, voted to include a disclaimer sticker on biology textbooks that read, in part, "This textbook contains material on evolution. Evolution is a theory, not a fact, regarding the origin of living things," (Cobb County School Board). In another district in Dover, Pennsylvania, a school board required that students be told about intelligent design as an alternative to evolution. The students were to be cautioned about what they would hear about evolution: "Because Darwin's theory is a theory, it continues to be tested as new evidence is discovered. The theory is not a fact," (Dover School Board). Similar disclaimers have been proposed before and eventually overturned, and we may hope that these suffer a similar fate. Such statements profoundly misrepresent both the status of evolution and the nature of scientific theories.

Notwithstanding creationists' claims to the contrary, evolution is fundamental to and well established in science. Rather than what is found on these ideologically biased warning labels, a more accurate statement of the status of evolution in science is the following, which comes from an article in the professional journal *Science* that refers to a statement from the renowned biologist Theodosius Dobzhansky:

> Dobzhansky's famous dictum that "nothing in biology makes sense except in the light of evolution"

> is even more true today than it was half a century ago. The concepts and principles of evolution are so ingrained and fundamental in many fields, not just in the life sciences, that their acceptance seems almost subliminal in many cases. (Hanson, Chin, Sugden, & Culotta, 1999)

However, while it may be acceptable for a researcher to accept evolution subliminally as the ground upon which to base further research, a teacher needs to make such things explicit. Having set forth the ideal of teaching both the science of nature and the nature of science, what I want to do in the rest this chapter is give a few suggestions about how a science teacher can follow in the footsteps of Feynman's father and reveal something about the nature of science while teaching evolution.

* * *

The basic commitment of science is to the empirical testability of hypotheses. Competing hypotheses are tested by checking their observable consequences and assessing whether and how well they fare. Claims that are not susceptible to empirical confirmation or disconfirmation are not a part of science. A necessary step for any scientist, therefore, is to put forward clear statements that are amenable to testing. Charles Darwin and evolutionary biologists who followed him did exactly this.

The central hypothesis of evolutionary theory is what Darwin called *descent with modification,* namely, that new biological species branch off over time as modifications of their ancestors, resulting in a great tree of life. Today we often put this idea in terms that connect it to population genetics and speak of descent with modification in terms of changes of gene frequencies in populations over generations. This allows biologists to form and test precise hypotheses about gene flow over time. The general notion, however, is that the varieties and species that we see today are descended from common ancestors, which is why biologists also speak of this as the *common descent thesis.*

A second group of hypotheses deals with the structure of the tree of life. Here one considers, for instance, which organisms we find today are more closely related to each other and when their lines branched off from their most recent common ancestor.

A third group of hypotheses involves the mechanisms of evolution. These hypotheses deal with things such as the sources of biological variations and the causes that produce useful adaptations and turn one kind of organism into another. Here too there are many specific hypotheses that are part of evolutionary theory, including discoveries about the genetic mechanisms of mutation and recombination, but a major general finding is what has been called *Darwin's law of natural selection,* which is that descent with modification and adaptation result from the natural selection of heritable random variations.

One could easily expand this list. The basic point here is that evolutionary theory is not just a vague statement about change over time, but an interrelated set of specific and well-confirmed hypotheses. That is typical of scientific theories in any field. The next step is to give students a sense of how these and similar hypotheses in other sciences are tested and confirmed.

Students generally have a naïve view of the role of observation in science. To say that science begins in observation is not to say that nothing but a direct observation is acceptable. For instance, it would be wrong to leave students with the impression that scientific testing comes to no more than what is known as *induction by enumeration.* On this method, often attributed to Francis Bacon, one makes direct observations and enumerates what one finds, drawing generalizations from these lists. With that kind of misimpression, students would have a hard time understanding how hypotheses about the past, such as the common descent thesis, could ever be confirmed.

However, scientists do not usually just collect observations as one might collect rocks. A more important kind of reasoning is what is called the *method of hypothesis* or sometimes the *inference to the best explanation.* (We may here skip over some differences between these, but I describe some of the nuances in Pennock [1995]). I have previously explained this in the following manner:

> In this method one assumes a hypothesis for the sake of investigation, asks what would follow empirically if it were true, and checks its probable consequences against the phenomena. One way to do this is to make a prediction based upon the hypothesis and then to see whether the prediction is borne out. Because it is no mean feat to correctly predict the unknown, if the prediction from the hypothesis is successful then this is good reason to infer that the hypothesis is likely to be true. On the other hand, if the prediction turns out to be incorrect then this is good

> reason to infer that the hypothesis is false. Actually, one does not really require a prediction of a future observation; what are called "retrodictions" or "postdictions" of past phenomena also work. The key feature of this form of inference is not whether the data occurs in the future or the past or the present, but whether it stands in the proper relation to the hypothesis. What we are looking for is that the hypothesis is able to adequately *explain* the observed pattern of data. Hypotheses that are inadequate must either be modified or else be rejected in favor of a better alternative. (Pennock, 1999, p. 53)

In other words, the process goes something like this: Rival hypothesized models are put forward and then compared for how well they explain observed patterns of data. The one that provides the best explanation of the phenomena is most likely to be true. Those that fail to account for the data are rejected. Scientific testing is a ruthless process in which only those hypotheses that can adequately account for the data will survive—rather like evolution itself. I have previously described this method of testing using the metaphor of a searchlight:

> Scientists are not passive observers but active researchers who seek out and bring new knowledge to light by following out the consequences of their hypotheses. We should thus think of scientists not as simply using a collection bucket, but as using a flashlight. One tests a hypothesis as one tests a flashlight—by turning it on and seeing whether and how well it can illuminate one's surroundings. If the light is dim one might have to twiddle the bulb or clean the contacts. If it provides no light at all one might have to put in some batteries or just get a whole new flashlight. Particularly powerful theories are like searchlights that shed a broad, bright, and sharply focused beam upon the world, allowing us to clearly see and distinguish its features. (Pennock, 1999, p. 54)

The searchlight metaphor captures the idea that the best hypothesized models truly are illuminating and that there are specific ways that rival hypotheses can be tested, such as by how accurately and to what extent they can explain the observed data and how wide a variety of phenomena they can illuminate. Indeed, it is by virtue of that explanatory relationship that data count as evidence for a hypothesis. The most powerful hypotheses can explain a wide variety of data.

This is what Dobzhansky meant by his statement that nothing makes sense in biology except in the light of evolution: evolution is the fundamental set of principles for explaining the biological world. Not all parts of evolutionary theory are equally well confirmed, and an important lesson about the nature of science is that scientific conclusions are more or less supported depending upon the amount of evidence. There are still many specific evolutionary hypotheses for which we do not have conclusive evidence. To mention just one instance, there are many unanswered questions about which species are more closely related in the tree of life. However, the major elements of evolutionary theory are as well tested and confirmed as anything we know in science. Evolution is the linking explanatory framework between internal (genetic) and external (environmental) factors and between efficient (historical) and functional (teleological) analyses of phenomena. One could, and should, spend an entire course revealing the explanatory power of evolution, but here I will just mention a few examples.

The common descent thesis, for instance, helps explain a huge range of phenomena involving the spatial and temporal distribution of species. Few textbooks have the space to devote to it, but biogeography was one of the most important lines of evidence for Darwin. He was struck, for example, by the ways in which species on islands appeared to be related to but still were notably distinctive from those on the nearby mainland and how even those found on different islands have identifiably different varieties. This pattern suggests that island species and their varieties arose from organisms that had come from the mainland population but then were modified from their original form over generations. Common descent also explains why organisms were different in the past, why the earliest organisms were simpler than later ones, and other such patterns in the fossil record. It also helps explain the patterns of similarity and difference that are observed across taxa, from the general nested arrangements of varieties within species, species within genera, and so on to the specific patterns of genetic commonality and difference that are found between more- or less-closely related species.

The same kind of broad and deep explanatory power may be observed in other hypotheses that compose the general theory of evolution, especially Darwin's law of natural selection. Indeed, the causal

mechanism that Darwin discovered of evolution by natural selection is as powerful and general as laws in physics. Some claim that it may be more so. It is time that biologists return to speaking explicitly in terms of evolution as a natural law. Many already do this, such as this writer, who explains:

> The laws governing tiny entities such as quarks are useless at predicting what the universe's largest objects will do, and vice versa. Biologists may have Darwin's law of natural selection to explain the behaviours of tuskers and bugs, but physicists have no unified code to help them understand both big and small events. (McKie, 2004)

We will see in a moment how this law is essential for understanding phenomena ranging from the evolution of antibiotic resistance in bacteria to the evolution of complex functional adaptations. Here we may just make the simple pedagogical point that biologists cause unnecessary problems when they speak only of *evolutionary theory* and assume that students (and the general public) will understand what this means in a scientific context. Teachers need to speak explicitly of *Darwin's law* to emphasize its universality and generality.

Although Darwin discovered the evolutionary mechanism through his investigations of the biological world, the law is not restricted to biological organisms. The key elements of random variation, replication, and natural selection can be realized in a variety of physical systems, including in computing environments. This means that experiments to test hypotheses about the operation of evolutionary mechanisms can be conducted not only with real organisms like bacteria but also with digital organisms. Such experiments are already being performed by researchers, and I am currently developing an artificial life platform, Avida-ED, that teachers will be able to use in their biology lab classes to allow students to observe Darwin's law in action and test evolutionary hypotheses for themselves.

* * *

There is much more that could be said about the ways that evolution can be used to exemplify and illuminate how scientific methods test and confirm hypotheses. Ideally, one would like to see a textbook that does this systematically. However, I have space here to mention just one more example, and so will conclude with what is perhaps the most significant and persuasive feature of scientific conclusions, namely, their practical utility.

The ultimate test in science is pragmatic. That a claim is put in scientific-sounding language does not make it scientific; for something to be recognized as a scientific fact, it cannot just talk the talk; it must walk the walk. That is to say, it has to make an empirical difference. Put another way, *there is good reason to conclude that we have got our hands on a real fact when using it works.*

On this criterion, evolution scores a knockout. The evolutionary methods of phylogenetics, for instance, that are used to reconstruct the tree of life can also be used to track diseases. Such methods were critical in identifying how HIV was introduced into human beings. They have even been used in a criminal trial to convict a man who had attempted to kill his ex-mistress by injecting her with blood that contained HIV. Understanding the process of evolutionary adaptation is important in medicine, for example, by helping doctors better prescribe the correct dose and regimen for antibiotic treatments so that bacteria are less likely to evolve resistance (Bull & Wichman, 2001). More generally, the specialty of Darwinian medicine is using evolutionary insights to reassess our understanding of the body's natural defenses against pathogens (Nesse & Williams, 1994; Trevathan, McKenna, & Smith, 1999). And evolutionary theory is being applied to help understand the evolution and transmission of infectious diseases, which may help scientists find better ways to fight and prevent their devastating effects.

But rather than go into the utility of these parts of evolutionary theory, I want here to focus on the utility of Darwin's law itself, since that is what some students will have the hardest time accepting as a fact. How can a natural process that is based upon blind random variation and selection, they think, produce anything but chaos, let alone anything functional like a complex adaptation? Again, the best approach will be to highlight experimental tests of the efficacy of the law. We are confident that Darwin's law is a fact—that it can produce complex functional adaptations—because, for example, engineers can apply the law and observe that it does just that.

Darwinian engineering is a relatively recent new application of evolution, but it is already beginning to bear fruit in business and in industry for everything from designing more-efficient supply networks to creating improved pharmaceuticals. Understanding evolution gives one a marketable skill, even in the competitive high-tech sector. Consider a recent job

ad posted by the Internet search company Google:

> You'll find links to more information about our efforts below, but before you get immersed in machine learning and genetic algorithms, please send your resume to us. We're tackling a lot of engineering challenges that may not actually be solvable. If they are, they'll change a lot of things. If they're not, well, it will be fun to try anyway. We could use your big, magnificent brain to help us find out. (Google, 2004)

Google obviously expects its engineers to be able to use cutting-edge techniques. So what are these genetic algorithms that the big-brained applicants were supposed to know about? They are essentially Darwin's law implemented in a computer.

The programmer creates a virtual model that can represent the set of factors and variables that need to be arranged and adjusted in order to create something functional. The genetic algorithm randomly varies possible combinations of values for these variables, creating a population of variants that are then automatically selected according to whether they do better or worse at performing the desired function. At each generation, the losers are eliminated and the winners are reproduced, again with new variations introduced by random mutations or recombination. The computer repeats this process for tens or thousands or more generations, and Darwin's law rearranges the components and tunes the values until they form a set that adequately performs the desired function.

Genetic algorithms and other related evolutionary methods are already being used in other industries to help solve complex engineering problems in areas ranging from computer chip design to antennae design. Some complex automatic traffic controllers were evolved using evolutionary algorithms. Anyone who has flown on the state-of-the-art Boeing 777 plane has benefited from evolution—the turbine geometry of its jet engine was designed with the help of evolutionary programming.

Any of these applications of evolutionary design could be interesting to discuss, but I want to highlight one that will likely be of special interest to students, namely, the use of Darwin's law by Hollywood to produce special effects in some recent blockbuster movies. Students who have enjoyed the amazing battle scenes in movies like the recent historical epic *Troy* have, probably without realizing it, witnessed the results of such evolutionary methods. While some of the soldiers in the battle scenes are played by real actors, many are computer-generated virtual characters. These animated characters are not two-dimensional hand-drawn figures, but have virtual bodies that respond to features in a simulated environment. Their bodies move and react to the simulated forces in the environment in the same way that human bodies move in response to real forces in the world. The software platform—endorphin—that is used for these computer-generated effects, was originally developed by zoologists at Oxford University who were researching the neurobiology of human motion. Endorphin models not only the virtual characters' bodies, but also their brains. These complex neural networks sense the surrounding environment and dynamically control the motion of the arms, legs, and bodies, allowing the characters to walk, run, fight, and so on. But it was not a programmer who wrote the program that controlled these motions; rather, the neural network controllers were evolved using the same kind of implementation of the Darwinian mechanism described above. One may download a sample video from NaturalMotion, the special effects company that did the work for Troy that shows the evolution of a controller for walking. In early generations, the arms and legs of a character flail about randomly, but under the repeated operation of natural selection, subsequent generations evolve to first lurch and stumble about and eventually to stride forward with balance and apparent purpose.

The upshot of these and many other such examples is to demonstrate that evolution by natural selection passes the most basic scientific test—it works.

* * *

Before concluding with a summary of take-home lessons, I would like to make just a few pedagogical suggestions for how teachers may appeal to the above considerations to help students avoid a few common misconceptions about the nature of science in general and evolution in particular.

A common misconception is the one that appeared in the creationist disclaimers quoted above, namely, that evolution is just a theory and that theory is opposite of fact (Pennock, 1999, pp. 174–179). This confuses the colloquial with the scientific notion of theory. In ordinary settings, even scientists may sometimes use the term in the informal sense of being just a proposal or one's best guess. But in science, it would be more precise to use the term *hypothesis*

for such pretested propositions. Explaining how evidence can continue to build up for a hypothesis helps students understand what is wrong with the notion that a theory is the opposite of a fact. As more and more evidence accrues in favor of a hypothesis, there comes a point when we simply accept it as factual and move on to other issues. The term evolutionary theory should be understood in that manner, in the same specialized sense as the term atomic theory in physics. It is a mistake to think that physicists are waiting to switch this to the term atomic fact. The evidence that material objects are composed of atoms is already conclusive, and atomic theory is already accepted as factual. The same is true of evolutionary theory.

A second common misconception is related to this first one, which is to think that evolution is not observable, and so that it is just a matter of faith. There are a variety of reasons for this confusion (Pennock, 1999, pp. 147–151, 179–181), but the most likely source is the erroneous conception discussed above that science is no more than a list of direct observations. Once a student comes to understand other inductive methods such as the method of hypothesis, then it will be easier to recognize that evolution is confirmed by observational evidence in just the same way other scientific hypotheses are. Evolution is not a belief that is taken on faith, but the very opposite; it is a fundamental scientific discovery that has been empirically confirmed by the most rigorous of observational tests.

A third misconception to try to eliminate is the outdated view that science cannot provide explanations but can only give descriptions. This is a leftover error from an outdated philosophy of science known as positivism. Philosophers of science now recognize that explanation is a basic element of scientific reasoning. As we saw above, much of what one does in science is to propose and test hypotheses, and those hypotheses are essentially possible explanations of patterns of data. In science, one explains a pattern by identifying the natural laws that make it so, typically by showing how a phenomenon of interest arises as an effect of causal processes. This is just what we saw in our discussion of evolutionary theory. The thesis of common descent, the law of natural selection, and the various other elements of evolution are fundamental explanatory principles in science and need to be taught as such.

Science teachers, I suggested, have a special responsibility to reveal not just the science of nature but also the nature of science. And biology teachers, I argued, have a special opportunity to do just that when they are teaching evolution. Evolution is science done right and is one of the best examples to illustrate the nature of science. As we have seen, science is not so much a list of facts, but a set of methods that let us know when we are justified in revising that list. Scientific testing of hypotheses is a ruthless process in which only those that can adequately account for the data will survive—rather like evolution itself. Most objections to evolution are the result of common misunderstandings about the nature of science. When properly understood, one recognizes that the core elements of evolutionary theory are as well confirmed as any hypotheses in science; together they are the fundamental explanatory framework in biology. This is true not just of the central thesis of descent with modification, but also of the mechanism that Darwin discovered. Evolution by natural selection is not just a good idea, it's a law of nature. Darwin's law passes the most basic scientific test—it works. Indeed, it works so well that its application for practical design problems can give those who use it a competitive advantage. Americans may finally accept that evolution is a fact when they realize that you can make money with it.

If science teachers can get these ideas across to our students, we will have begun to do for budding biologists what Richard Feynman's father did for him. Paraphrasing his key idea, we may say: let's look at the world and see how it is evolving!

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Chapter 2

Looking for God in All the Wrong Places:
Answering the Religious Challenge to Evolution

Kenneth R. Miller

"*You've got to be kidding.*" As often as not, that's the response I receive from scientific audiences when I talk about the battles now raging across the United States over the teaching of evolution. To most of my academic friends, evolution is an issue that was legally settled in the 20th century, and scientifically settled in the 19th. They take it for granted that objections to Darwin's great idea were disposed of in the Huxley-Wilberforce debate, or the Scopes trial, or in the 1987 *Edwards v. Aguillard* (U.S. Supreme Court) that found "creation science" to be a religious doctrine. And they'd be wrong, for evolution is once again at the center of debates across the country.

These are interesting times, to put things in their most positive light, times when ordinary Americans are asking questions about the nature of science and its importance in their lives. Some of these questions, of course, are throwbacks to the days when the Bible was uncritically regarded as a book of natural history. Nonetheless, to carelessly assume that today's opposition to evolution is simply the result of biblical literalism is to miss the point—and to seriously underestimate the challenge it poses to science. Despite this qualification, religion is indeed at the heart of today's anti-evolutionism. The challenge to science is to understand and appreciate the powerful and sincere motivations of those who have risen against the "Darwinian orthodoxy" that, in their view, controls science and education in the United States.

The stakes of this conflict, in my view, could not be greater. American science will face a peril of the first order if it fails to understand and to respond effectively to this challenge. The first step in an effective scientific response, as I will argue in the pages that follow, is to develop a deeper understanding of the relationship between science and religion.

A Landscape in Conflict

Roughly half the American people, depending on how the question is asked, reject the theory of evolution. Such widespread opposition has provided fertile ground for anti-evolution movements in a variety of states for many years. The most striking success of such movements in the past decade came in the summer of 1999, when the elected Board of Education of the state of Kansas acted to remove all mention of evolution from its science education standards (Holden, 1999). The sweeping nature of the board's actions, which also targeted the system of geologic ages as well as the big bang theory of cosmology, caught many scientists by surprise. The reaction was swift and effective. Trusting in democracy to set things right, a coalition of educators, scientists, and technical professionals implored Kansas voters to elect proscience candidates in the 2000 elections. And so they did (Dalton, 2000). A new majority on the board reinstated a set of pro-evolution standards, and the temporary extinction of evolution in Kansas was history—at least for the moment.

With the benefit of hindsight, we can now see that the battles over curriculum in Kansas were nothing more than the opening skirmish in a war that has spread to every corner of the United States. In 2002, Ohio came close to authorizing the teaching of "intelligent design," and two years later agreed to a lesson plan inspired by "design" criticisms of evolution. Schools around the country followed the lead of Alabama in pasting stickers inside biology textbooks urging students to be skeptical of their evolutionary content. And a number of school districts, including ones in Wisconsin and Pennsylvania, moved to implement instruction in intelligent design in their classrooms. At this writing, it is fair to say that virtually every American state has seen its share of anti-evolution activity, running the gamut from protests against textbooks to legislative efforts mandating "balanced treatment" and direct efforts to implement frankly anti-evolution curricula.

The Order of Battle

When faced with challenges to a well-supported scientific idea, the first instinct of most scientists is to

respond scientifically by providing direct answers to the criticisms of evolution. This is an important activity, and it must not be neglected. Controversy is an essential part of science, and addressing scientific conflict is something that researchers are used to doing as a normal part of science. However, the conflict over evolution is unlike the controversies that scientists have come to expect within their disciplines. The evolution controversy is far more than a conflict over scientific ideas. It is a struggle for the soul itself.

The PBS television series Nova recognized this point squarely in 2001 when it concluded its landmark eight-hour mini series, *Evolution*, with a program on the religious conflicts inherent in the battle over evolution. The narration of a promotional piece describing that final program told viewers:

> Today, even as science continues to provide evidence supporting the theory of evolution, for millions of Americans, the most important question remains "What about God?" (Jersey & Page, 1999)

Exactly. For most Americans, "What about God?" is indeed the most important question. The religious character of the debate gives conflicts over evolution a cultural and political weight unlike that in any other scientific controversy. One way to understand this is to look at the material produced by the anti-evolution movement to show their own adherents the importance of the struggle. An example is shown in figure 1, redrawn from the Web site of a prominent anti-evolution organization.

Figure 1. Opponents of evolution see it as the foundation of social and political trends that they decry for moral and religious reasons. (Source: Answers in Genesis Web site, URL:http://www.answersingenesis.org/Home/Area/overheads/images/oh20010316_6.jpg.)

If Darwin's great idea is seen as the foundation of everything wrong in society, including lawlessness, abortion, pornography, and the dissolution of marriage, then it must be opposed at all costs. Furthermore, any factual evidence that science might gather in favor of evolution must be disregarded in favor of the greater truth upon which all of society is founded. Such powerful motivations drive sincere and dedicated opposition to science and must not be underestimated.

Making the Case for Science

In many cases, the attacks upon evolution require a direct response that deals with the nature of science and the weight of scientific evidence. This is particularly important when the tactics employed by the anti-evolution movement do not directly reveal the religious and cultural motivations of their proponents. Over the past several years, one of the most effective techniques has been to call for "critical thinking" of scientific evidence related to evolution. Since science itself is based upon critical thinking, at first glance it is difficult to see why anyone would object to Darwin's theory being subjected to critical analysis in which students are asked to examine evidence for and against evolution.

In many parts of the country, this tactic has taken the form of disclaimer stickers attached to biology textbooks. Although the state of Alabama has done this for years, when the school board of Cobb County, Georgia, attached such stickers to textbooks in 2002, it sparked a lawsuit that reached trial in 2004. The exact wording of the Cobb sticker avoided all mention of religion:

> This textbook contains material on evolution. Evolution is a theory, not a fact, regarding the origin of living things. This material should be approached with an open mind, studied carefully and critically considered.

Nonetheless, six parents in the Cobb public schools saw the wording of this sticker as a clear attempt to promote a particular religious point of view and filed a lawsuit in federal court to have the stickers removed. The scientific community in Georgia and elsewhere rallied around the parents and helped answer the claim of the government (the Cobb board of education) that the purpose of the sticker was merely to promote critical thinking. A number of witnesses at the trial, myself included, made the point that the stickers called for critical thinking regarding just one scientific theory. In effect, the stickers told students that they needed to keep an open mind *only* when studying evolution. Apparently, as I told a reporter after my testimony, the board felt that *everything* in science was absolutely certain—except for evolution.

In reality, of course, *everything* in science should

be studied with an open mind and subjected to critical analysis. To single out evolution, as the Cobb board had done, was clearly designed to affect learning by weakening the standing of evolution in the minds of Cobb students. In January 2005, the court found for the plaintiffs and ordered the stickers removed (Ebert, 2005).

Developing a proper understanding of the nature of scientific theory, which was at the heart of the Cobb case, is one of the ways in which science must be defended against its critics. Another lies in providing factual answers to the specific objections raised against evolution. Any number of books and publications has provided answers for those willing to do battle in the name of science, and I strongly recommend the superb archive of material found at the Talk Origins Web site (http://www.talkorigins.org) to those who find themselves facing specific arguments against evolution.

The most direct way to respond, of course, is by providing the evidence upon which evolution is based. For example, one of the oft-repeated criticisms of evolution is that the fossil record contains no "intermediate forms." Since such "transitional" species are said to be critical for Darwin's theory, their supposed absence is presented as powerful evidence against the idea of evolution. In truth, such accusations are easily answered by a quick exposure to the reality of the fossil record. As the National Academy of Sciences noted in 1999:

> So many intermediate forms have been discovered between fish and amphibians, between amphibians and reptiles, between reptiles and mammals, and along the primate lines of descent that it often is difficult to identify categorically when the transition occurs from one to another particular species.

When speaking in public, I find it particularly instructive to do what opponents of evolution cannot do; namely, to thumb through the last few issues of journals such as *Science or Nature* and show a slide or two of the latest fossil discoveries that have filled in a previously "missing link" or demonstrated the details of an evolutionary transition. A particularly effective example is the growing record (Thewissen & Bajpai, 2001) documenting the evolution of cetaceans from land mammals, a fossil record that anti-evolutionists once proclaimed would never be found. Not only does this record fly in the face of their previous pronouncements, but it continues to expand in a dramatic and instructive way.

If the evolutionary picture of whale evolution is correct, for example, a series of intermediate stages should have existed in which the auditory apparatus of these animals was remodeled from one useful for hearing in air to one well suited for hearing under water. In 2004, those intermediate stages were found, and their detailed descriptions provide a detailed demonstration of the robust nature of the evidence documenting this remarkable evolutionary transition (Nummela, Thewissen, Bajpai, Hussain, & Kumar, 2004).

For much of the public, the willingness of the scientific community to address such questions and to provide detailed, factual answers to the challenges laid down by the opponents of evolution is critical. In a democracy, science is a public activity dependent upon public support and understanding, and those can best be earned by freely sharing the evidence supporting evolution. When this is done, for many people, the issue is settled and the controversy is over. For others, however, it is not. And the reason is that for many Americans the debate over evolution is not a scientific one—it is a cultural, political, and religious one.

The Challenge from Design

Today's anti-evolutionism often marches under the banner of intelligent design (ID), the proposition that, in the words of its proponents, some features of living things are too complex to have been produced by evolution. As William Debmski (1999) of the Discovery Institute has explained, it is the view of ID supporters that

> intelligent causes are necessary to explain the complex, information-rich structures of biology and that these causes are empirically detectable.

Detailed critiques of ID have been published elsewhere (see, for example, Forrest & Gross, 2004; Scott, 2004; Pennock, 2001) and addressed in other papers in this volume. Indeed, the ease with which ID critiques of evolution are answered was demonstrated in the April 2002 issue of *Natural History* magazine where three leading ID proponents were each given a page to argue their viewpoints. Each was then rebutted by a scientist who had little trouble demonstrating the lack of scientific evidence for design.

For many people, however, scientific critiques of ID matter little if design serves as the only possible

alternative to the Darwinian vision of a meaningless, purposeless, pointless existence. This realization is at the very core of the so-called Wedge strategy articulated by the pro-ID Discovery Institute. The Wedge depends upon establishing a link in the minds of the public between evolution and philosophical atheism. Indeed, Phillip Johnson, a retired professor of law at the University of California, considered by many to be the intellectual founder of the ID movement, has been remarkably open on this point:

> The objective [of the Wedge strategy] is to convince people that Darwinism is inherently atheistic, thus shifting the debate from creationism vs. evolution to the existence of God vs. the non-existence of God. From there people are introduced to "the truth" of the Bible and then "the question of sin" and finally "introduced to Jesus." (Boston, 1999)

Sadly, this is a point on which all too many scientists, ill at ease with theology and philosophy, concede ground and retreat into the empirical world they know and understand. Those unfamiliar with Christian theology may assume that the design movement is a genuine reflection of mainstream theology on the point of biological origins, and thereby playing directly into the anti-God strategy articulated by Johnson. They couldn't be more wrong.

Surely, you might suggest, if you've made a case for design you've made a case for God. That is indeed the cover story, the packaging with which the ID movement has sought support from the mainstream religious community. In reality, however, the ID movement poses theological problems far more serious for Christian thinking that those presented by evolution, and these problems must be pointed out.

Theology Matters

The classic argument from design, upon which the modern ID movement is based, necessarily involves the existence of a designer. In the minds of many people, therefore, theism of any sort is inextricably wedded to the concept of design and to the existence of a designer. For those who seek meaning and purpose to their lives and to the universe as a whole, this idea has an immediate attraction. Indeed, I would argue that theists, by definition, believe in a transcendent intelligence, sometimes expressed as a view that there is an intelligent design to the universe. For what it is worth, that is a view that I hold myself. But that is *not* what is meant by intelligent design in the context of today's ID movement.

Today's ID movement proposes that design, in the form of outside intelligent intervention, is required to account for the origins of living things. This makes ID quite different from more general philosophical considerations of meaning and purpose in the universe and makes it a specific doctrine of special creation. ID proposes that design, which can only be understood as a series of specific creative acts, explains the origins of major taxonomic groups, specific biochemical systems within living cells, and the information content of living organisms. Design advocates often protest that they are not creationists, and yet each of these events would in fact have required a specific *creative* act to put a design into concrete form. This is why today's ID is in fact a form of *special creation*.

Making a distinction between the broader and more general view of design in the universe and the doctrines of special creation advanced by the ID movement is critical to the struggle faced by science today. If that distinction is not made, then any argument against design, in the minds of many listeners, automatically becomes an argument against God. Whatever one's own beliefs on matters of faith, that is not a mistake that science can afford to make. Theology really does matter.

Devil in the Details

To many believers, the ID argument has an automatic attractiveness for the very simple reason that it appeals to an outside agency (the designer, whom they readily identify as God) to account for existence. The simplicity of this appeal has led many Christians, deeply concerned about evolution's apparent contradiction of Genesis, to embrace design as a worthy alternative. Once one looks closer, however, the superficial appeal of ID begins to collapse. A careful examination reveals at least six fundamental problems, most of them insoluble, that ID theory poses for Christians.

ID's acceptance of the geologic timescale

In their effort to shed the label of creationist, ID advocates have been adamant that they accept what astronomy and geology say about the age and origin of the universe and the history of planet Earth (an example is found in West, 2002). While this may seem to make ID less of

a target for scientific attack, especially from the physical sciences, it also directly contradicts the view of Earth history held by many who regard the Bible as a book of both history and science. ID advocates are happy, of course, to accept the support of fundamentalist Christians who regard evolution's contradiction of their young Earth views as anti-Christian—but they are remarkably careful not to point out that ID does exactly the same thing.

The problem of persistent intervention

Since ID accepts the system of geologic ages, the special creation events that it attributes to acts of design must have taken place at specific and distinct points in Earth history. For example, the bacterial flagellum must have been first created at a specific time and place, probably more than a billion years ago. The eukaryotic cilium, however, had to be created several hundred million years later, when the first eukaryotic cells appeared. Design's multiple roles in the Cambrian explosion, often dated between 565 and 530 million years ago, occurred much later, and the design (special creation) of the vertebrate blood-clotting system occurred still later, since no true vertebrates appeared in the Cambrian. In fact, if one takes every structure, organ, and evolutionary novelty attributed to design, one finds that the designer has been active through Earth history. In other words, his intervention has been constant and persistent.

Christians who regard God's work as having been literally finished, complete, and perfect at the conclusion of a six-day creation week will find ID's view of natural history to be a direct contradiction to their beliefs. More generally, one must ask how an all-powerful creator could possibly have been part of a scheme of design that seems to have required him to intervene repeatedly, each time in violation of the laws of the very universe he designed. Since all of the Abrahamic religions teach that God's intention was to create a world in which we might know, love, and serve him, ID fails each of them by implying that the designer's work was haphazard and required repeated tinkering in order to get it right.

The problem of extinction

ID routinely ignores the problem of extinction, because even the very word calls into question the notion that living things could have been intelligently designed. Yet extinction, the permanent loss of species, is one of the key aspects of the fossil record, and repeated episodes of mass extinction characterize the history of life on Earth. Evolution, which attributes novelty and adaptation to natural selection, anticipates and explains extinction as a normal part of the struggle for existence at the heart of the Darwinian mechanism. ID can explain extinction only as an imperfection or failing on the part of the designer to anticipate the demands of nature. That might not be a problem so long as the identity of the designer is a mystery, but once that designer is identified as the God of Abraham, the ID argument is left appealing to God's failings as an explanation—something that the Christian view of God's nature simply does not allow.

The intentionality of design

If a designer exists whose wisdom extends, as ID claims it must, to the information content of the human genome, that designer must have been directly responsible for the design of other forms of life as well. This doesn't sound like much of a problem until one begins to apply design theory to the pests, parasites, and plagues that have afflicted us throughout the ages. If we choose to give a designer direct credit for the complexity of the genome that makes us human, then we must attribute the fiendishly clever design of the HIV genome to the same genius. If the Cambrian explosion is evidence of direct and intentional design, then the direct intent of the designer must also include the pustules of bubonic plague, the shivers of malaria, the cruel disfigurement of smallpox, and the ravages of parasitic worms. Darwin himself described "the clumsy, wasteful, blundering low and horridly cruel works of nature" (Darwin, 1856/1991), and since his time, the number of such examples has only increased.

The imperfection of design

The advocates of design often appeal to the exquisite perfection of the human body. The careful coordination of parts and processes, they

argue, can only be the result of careful, intelligent action on the part of the designer. My own experience is that the persuasiveness of this argument is inversely proportional to the average age of an audience of listeners. As one reaches a certain age, and poorly designed systems and organs such as the spine, the eyes, and the prostate begin to malfunction, the notion that biological systems are the result of careful, intelligent engineering begins to break down. Theologically, how do we explain such problems? Do we attribute them to failings on the part of the designer? Surely not. But then the only option is that these problems are the intentional plan of that designer to hobble and cripple us as we advance in years. Either way, we have a problem. We must attribute either malice (see number 4, above) or incompetence (see numbers 2 and 3, above) to our designer.

Theological inconsistency

ID advocates have drawn much aid and comfort from a view of the universe known as the anthropic principle. The term was first used in a 1973 paper by astrophysicist Brandon Carter, who pointed out that many of the fundamental constants of nature seem almost to have been fine-tuned to make life as we know it possible. In fact, if any one of a number of such constants were even slightly different, life would never have evolved. Barrow and Tipler (1986) explored this view in *The Anthropic Cosmological Principle,* and ID proponents have embraced it ever since. The appeal of the anthropic principle is that it provides a cosmological rationale for intentionality in the universe. There simply must be a designer in order to get all these constants right, a designer who intended for us to arrive in his universe. That, they say, validates intelligent design.

Maybe so. But there is a curious inconsistency in ID's embrace of the anthropic principle. The principle is built around the realization that nature seems to be fine-tuned so as to make life possible. But ID actually argues exactly the opposite —namely, that nature is *not* hospitable to the evolution of life. In fact, the ID movement spends a great deal of intellectual effort claiming that the emergence of life would be a direct violation of the laws of nature. In effect, they are saying that their evidence for the designer is that he made the universe *not quite* hospitable enough for life to appear, and then he had to violate those fine-tuned rules to directly design (create) the first living thing and had to violate them again to produce each of its major advances. How fine-tuned could the universe be if it requires so much tinkering?

Their view of the designer seems to state that he was clever enough to produce a universe in which life could exist, but not clever enough to create a universe in which it could *evolve.* This curious and arbitrary limitation on the creator's power makes neither scientific nor theological sense.

Endless Forms

There is no question that many opponents of religion have enlisted Darwin's great idea to help formulate their own apologetics of disbelief. This is the strategy that has been taken by any number of prominent writers such as Richard Dawkins, E. O. Wilson, and William Provine. Dawkins once famously wrote that the world we know about through evolution has "precisely the properties we should expect if there is, at bottom, no design, no purpose, no evil and no good, nothing but blind, pitiless indifference," (Dawkins, 1995). Dawkins is, of course, welcome to this view of the universe. But it is important to note that his conclusions on the purpose of existence, although they may be informed by evolution, are philosophical ones. They are not testable by the methods of science, and they have no more scientific standing than the claims of another evolutionist that there is "grandeur in this view of life," and that "from so simple a beginning…endless forms most wonderful and most beautiful have been and are being evolved." That other author, of course, was Charles Darwin (1859).

The key question all of us must face is whether science carries us as deeply into the mystery of life as we truly wish to go. For many people, I am sure that it does. But people of faith, myself included, would argue that it does not. It is important to understand that this is not a rejection of science so much as a recognition of its limitations, limitations that are generally recognized by people regardless of their religious views. I would argue that accepting the validity of this choice, even if one does not agree with it, is the first step in making peace between science and religion—a peace devoutly to be wished for.

Understood in this way, evolutionary science becomes not a contradiction of God but part of God's handiwork, making science a partner with faith in exploring the majesty of creation. Along these lines, it is worth reminding Christians who are skeptical of this view of evolution of the words of the Lord to Isaiah:

> For my thoughts are not your thoughts, neither are your ways my ways, saith the LORD.
>
> For as the heavens are higher than the earth, so are my ways higher than your ways and my thoughts higher than your thoughts.
>
> Isaiah 55:8–9 (King James version)

God, Isaiah tells us, doesn't work, or think, or act as we do. He operates on another level entirely. And a God who makes all things new is certainly not one who would have imprinted a static, inflexible order into his living world. Rather, he is one who would have foreseen a world of dynamism and change and built the capabilities for that change into the very fabric of his creation, a fabric that makes evolution possible.

What emerges from this view is not a middle ground of pointless compromise, but a genuine understanding of the ways in which faith and reason may complement each other. As Ian Barbour (1997), the distinguished scholar of religion and science put it:

> Both the scientific materialist and the scientific creationist have failed to respect the proper boundaries of science. The former makes statements about religion as if they were part of science. The latter makes statements about science that are dictated by religious beliefs.

And, I would add, both are wrong.

Having made this point, I would nonetheless agree that for many Christians, evolution presents serious challenges to their understanding of faith. I have tried to answer many of these in my book *Finding Darwin's God* (Miller, 1999), and other authors, more expert in matters of theology and philosophy than I, have made similar efforts. I would particularly recommend books by theologian John Haught (1999, 2001) and also works by Michael Ruse (2001) and Keith B. Miller (2003).

Many Christians worry, for example, that if evolution explains the origins of species by purely material means, there will be nothing left to attribute to God. This is a curious concern for people who feel, as Christians should, that God is active and involved in their lives on a daily basis. The issue of God's involvement in the world of today certainly does not depend on whether or not he directly violated the natural laws of his own making millions or billions of years ago to create life, but rather on the spiritual reality of the Savior in the world today. Furthermore, the means by which God might accomplish his purposes are, as Isaiah reminds us, well beyond our capacity to understand.

Others are concerned that the elements of chance and unpredictability that are part of evolution mean that evolution could not possibly be part of a divine plan. But chance is real, and the unpredictability of historically contingent processes, like evolution, was understood and explained by theologians well before Darwin. As John Haught has pointed out, even St. Thomas Aquinas understood that unpredictability was one of the ways that God might have built the capacity for free will and moral choice into his universe:

> Even St. Thomas Aquinas argued that a world devoid of chance or contingency could not really be distinct from its God. "It would be contrary to the nature of providence and to the perfection of the world if nothing happened by chance." Thus, the randomness and undirected features of evolution are not just "apparent" as some of the "separatists" would argue. They are, in fact, essential features of any world created by a gracious God. (Haught, 1999)

I have also been confronted by believers who fear that evolution's view of nature "red in tooth and claw" is at odds with their view of a gracious and loving God. In particular, they worry that the Darwinian struggle for existence is not the way that the God of scripture would have provided for his creatures. In reality, of course, death and struggle are facts of life, not the inventions of Charles Darwin. And Darwin was hardly alone in the recognition that death could be a creative force. The psalmist makes this point eloquently in a way that any ecologist would understand and endorse:

> These all look to you to give them their food at the proper time.
>
> When you give it to them, they gather it up; when you open your hand, they are satisfied with good things.

> When you hide your face, they are terrified; when you take away their breath, they die and return to the dust. When you send your Spirit, they are created, and you renew the face of the earth. Psalms 104, 27–30

Finally, many Christians frankly worry that in contradicting the Genesis account of creation, evolution (and for that matter the sciences of geology, astronomy, and cosmology) has forever set itself at odds against the authority of scripture. It's worth noting, as I have pointed out elsewhere, that St. Augustine, writing in AD 414, warned the faithful against using the scriptures of Genesis as a scientific text. St. Augustine was concerned that nonbelievers might hear Christians, in his words, "talking nonsense on these [scientific] topics" (Augustine, 414/1982, 19:39) and bring the Bible into disrepute. St. Augustine was not concerned, needless to say, about evolution, but about making the authentic spiritual authority of scripture stand above the lower level of empirical knowledge obtained by science. That is still a concern today.

In reality, evolution allows us, as John Haught (2001) has pointed out, to see the deeper meaning of Genesis:

> After Darwin we are actually in a position to see deeper into the Bible's accounts of origins (which incidentally are not limited to Genesis) and their religious meaning than ever before. We no longer have to look to the Bible to satisfy our curiosity about "how things began." Science can do that better anyway. Instead, we can now focus on levels of meaning in the creation accounts that hide themselves from us as long as we try to make them compete with the ideas of science.
>
> In this age of science, in other words, we can actually see more clearly than before that the point of the Biblical creation accounts is essentially religious. Genesis, for example, seeks to awaken us in a sense of gratitude for the sheer glory and extravagance of creation. It tells us, through two distinct accounts, that the universe is grounded in love and promise. It provides us with a reason to hope. It assures us, moreover, that our world is essentially good and that nature is not to be confused with God. (p. 75)

Science and Spirit

There is great danger in the current battle over evolution. Some of these dangers are obvious. If science education in the United States is forced to accommodate religiously driven, nonscientific ideas such as intelligent design, the notion of science as objective search for the truth will be forever dashed in American classrooms. Science may become just another form of relativistic knowledge, in which one view, one school of thought, is just as good as any other, because the ultimate test of theory and hypothesis against nature has been discarded. In its place we may find a "science" transfigured to conform to the ideas that make people comfortable, rather than to the ideas that stand the test of observation and experiment. This would be a scientific and educational tragedy of the first order.

In seeking to avoid this outcome, we should think far more carefully than we have in the past of the relative roles of science and religion. The presumed war between science and religion is really a misperception of the proper role of faith in society. There are genuine moral questions associated with the practical applications of science and the morality associated with the gathering of scientific data. This is a point upon which moral people agree—whether they consider themselves people of faith or not. And there is no reason to disqualify the moral choices of religious people from having their proper influence upon science. The scientific community must realize that in its search for the truth it has a great ally in the religious community, and it must cultivate, rather than reject, ties to people of faith who understand and respect the role of science.

Properly understood, faith seeks knowledge to expand our view of the world. It gives us a new and more complete way to understand scripture and our religious traditions, and it rejects the pedestrian view of the designer given by the ID movement. The God of Abraham is not a deity of cheap tricks who needs to personally design and fashion the mundane details of every living organism. Rather, a true respect for the Abrahamic tradition favors an expansive view of creation, a faith at harmony with reason, a synergy centered on the value of science in exploring the world in which we live, and a world that can be loved and appreciated by believers and nonbelievers alike.

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Evolution Is a Fact

Walter M. Fitch

Creationists often say that evolution is not a fact but a poor theory. I present an easy proof that it is a fact. It requires only a clear definition of evolution, some simple data, and proper logic.

"Evolution" is a word nearly every one knows and routinely uses in its colloquial sense, namely: *Evolution is noncyclical change over time*. The word "noncyclical" is important because winter, spring, summer, fall, winter, spring… is change, but it is not evolution. The reason it is not is because of the seasonal cyclical nature of the process bringing the changes back to the beginning over and over again.

So let us examine a case where there is no cyclic process (figure 1). We have a picture of many automobiles starting early in the 20th century and coming up to the end of the 20th century, a period spanning 100 years. These autos have obviously changed over time and so meet the definition of evolution, and so, for this example, evolution is a fact. It is not something for which there is room for debate. However, as there are many examples of evolution, it would be wise, for clarity, to call this automotive evolution.

Thus automotive evolution is a fact.

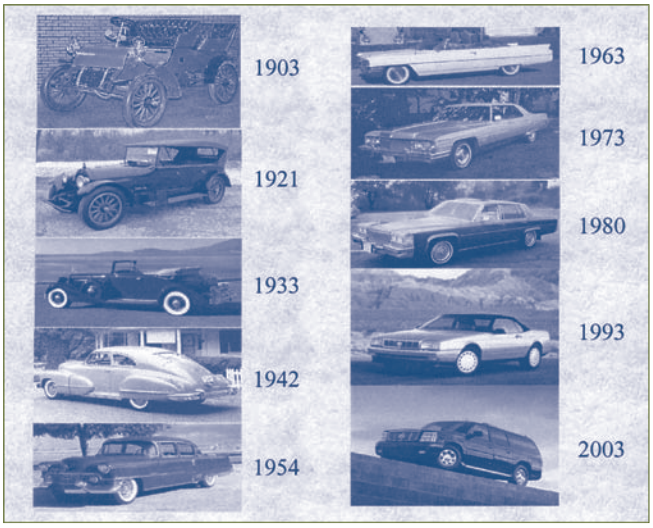

Figure 1. Evolution of cars: Photos of 10 cars and the year created.

Figure 2 shows a photograph of the opening words from Geoffrey Chaucer's *Canterbury Tales,* written about 1390. If you've read any of Shakespeare's works, you know they are not easy to read, but they are a lot easier than reading Chaucer. The English language has obviously changed over time and thus meets the definition of evolution, and so, for this example, linguistic evolution is a fact.

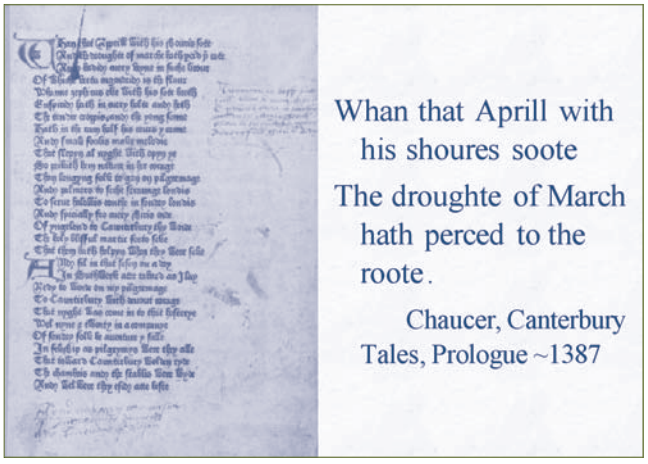

Figure 2. Excerpt from Chaucer's Canterbury Tales and text. (Caxton's Chaucer, British Library)

Figure 3 shows a photograph from Mount Everest in the Himalaya and a mountain from the Appalachians. This does not demonstrate evolution because Everest and the Appalachian mountain are not the same mountain, and I cannot wait around until Everest is eroded down to the size of an Appalachian mountain. It does, however, illustrate the process of mountain building and its erosion. If one looks at many geologic sites and notes how the rivers, such as the Mississippi and the Amazon, are daily carrying many megatons of sand from the hinterland and dumping it out on the deltas, it is rational to believe that mountains evolve. It obviously meets the definition of evolution, and so, for this example as well, geologic evolution is a fact.

Figure 3. (a) View from top of Mount Everest. (http://www.nationalgeographic.com/everest/) (b) View from top of Appalachian mountain ridge from Ellis Ridge, Beverly, West Virginia. (Debra Mauzy-Melitz).

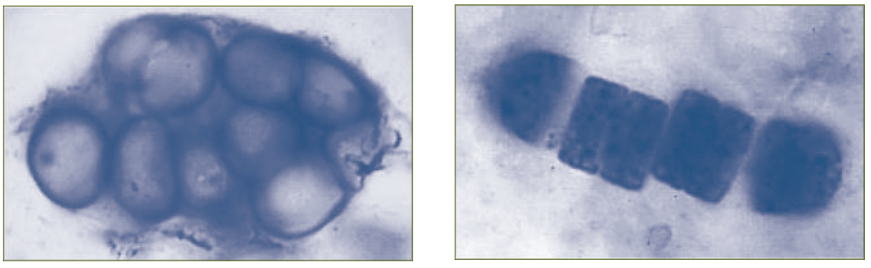

Figure 4. (a) Colonial chroococcalean form of cyanobacteria dating to Late Proterozoic from Bitter Springs chert in central Australia. (http://www.ucmp. berkeley.edu/bacteria/cyanofr.html) (b) Filamentous *Palaeolyngbya cyanobacteria* dating to Late Proterozoic from Bitter Springs chert in central Australia. (http://www.ucmp.berkeley.edu/bacteria/cyanofr.html)

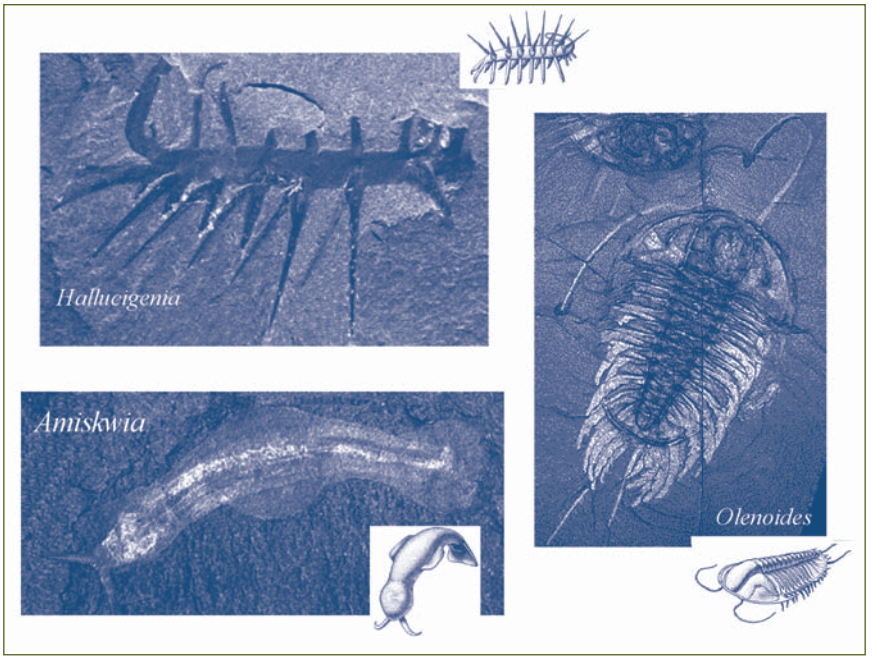

Figure 5. (a1) Fossil of *Hallucigenia.* (Smithsonian Institution, http://www.nmnh.si.edu/paleo/shale/pfoslidx.htm) (a2) Drawing of *Hallucigenia.* (Smithsonian Institution, http://www.nmnh.si.edu/paleo/shale/pfoslidx.htm) (b1) Fossil of *Amiskwia.* (Smithsonian Institution, http://www.nmnh.si/edu/paleo/shale/pfoslidx.htm) (b2) Drawing of *Amiskwia.* (Smithsonian Institution, http://www.nmnh.si.edu/paleo/shale/pfoslidx.htm) (c1) Fossil of *Olenoides.* (Smithsonian Institution, http://www.nmnh.si.edu/paleo/shale/pfoslidx.htm) (c2) Drawing of *Olenoides.* (Smithsonian Institution, http://www.nmnh.si.edu/paleo/shale/pfoslidx.htm)

Now examine figures 4, 5, 6, and 7. Figure 4 shows two blue-green algae that existed 850 million years ago. Figure 5 shows some trilobites that existed 550 million years ago. Figure 6 shows some sharks that existed 400 million years ago. Figure 7 shows some armored dinosaurs that existed 200 million years ago. Each figure shows only a small portion of the known creatures that existed at any one time, but all the figures are representative of the differences among the organisms that existed at different times. They depict very clearly that these organisms changed greatly over vast stretches of time. They obviously meet the definition of evolution, and so, for this fourth example as well, evolution is a fact. And what is it that is evolving? Here it represents the kinds of organisms on the tree of life, and thus this is biological evolution and is comparable in that sense to many other examples of evolution. It cannot be legitimately denied because the assertion of evolution is just a logical result; the organisms, in fact, meet the definition of evolution, noncyclic change over time.

There are many other cases of evolution. There is evolution of housing; there is evolution of medical practice; there is evolution of the universe; there is evolution of guns; and there is evolution of creationist arguments.

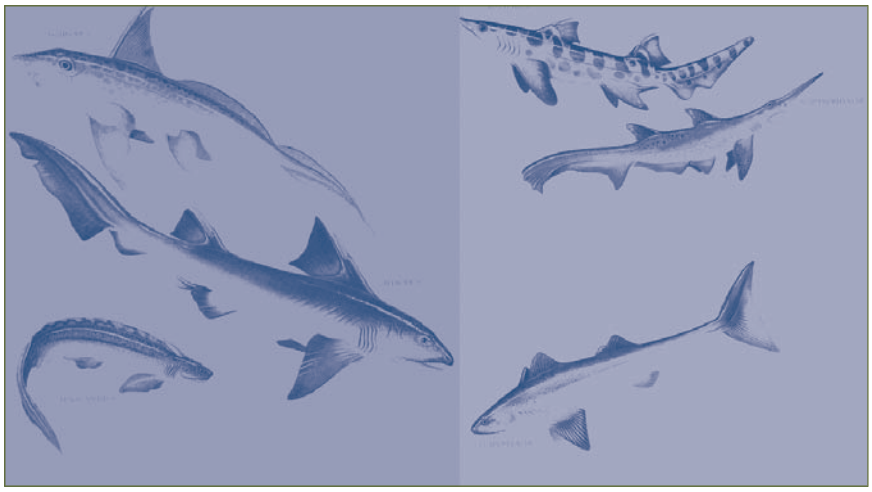

Figure 6. Illustration of 6 types of cartilaginous fishes.

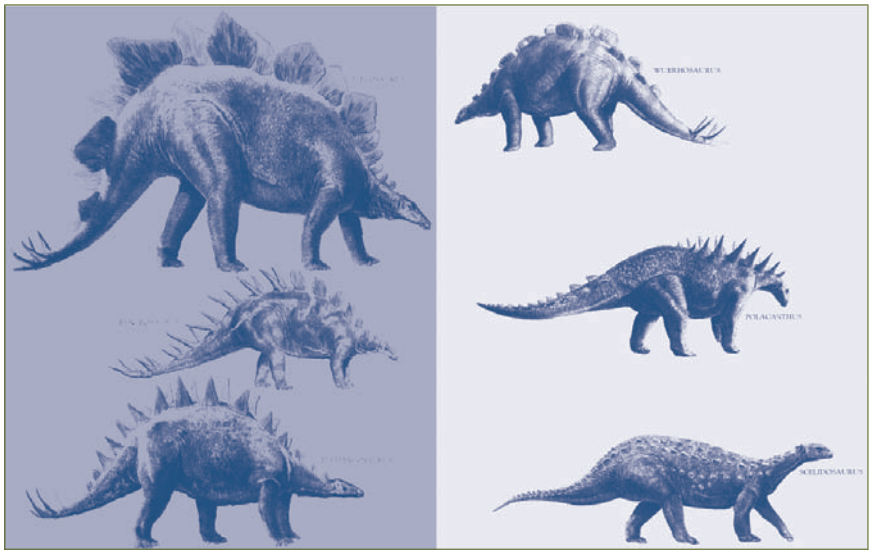

Figure 7. Illustration of 6 types of armored dinosaurs.

It is perhaps worth noting a slightly different logical problem regarding evolution. Creationists argue: evolution is a theory; a theory is but another word for "guess"; therefore, evolution is but a guess. In logic, this is called the fallacy of equivocation and it occurs when the meaning of a word changes between the first and second premise.

A simple example is: nobody's perfect; I am a nobody; therefore I am perfect. The fallacy arises because in the first premise "nobody" means "not one person," while in the second premise "nobody" means "a person who is not highly thought of."

In the first premise—evolution is a theory—the word "theory" is intended by evolutionists to mean something comparable to the theory of gravity or the theory of relativity. Thus, evolution has been so thoroughly tested and has passed those material tests so well that evolution merits being called a theory. In the second premise, "theory" means something quite different, an idea that has little more merit than a coin toss.

In the search for truth, logical fallacies, including those of equivocation, are inappropriate.

Learning the Lay of the Religious and Political Land

Barbara Forrest

Introduction

No academic subject in American education generates as much resistance as evolutionary biology. America is the only industrialized country in the world whose citizens argue not only about whether evolution should be taught but about whether it even happened. The cultural debate over evolution—in the world's most scientifically advanced country—is an incredible phenomenon. Unfortunately, it is one science teachers must confront, and they must do so straightforwardly, without apology and without retreat. Fortunately, law and science are on the side of the teachers, who are charged with educating students about evolution as the debate swirls. The fact that the law is on their side gives them the right to teach evolution. The fact that the science is on their side gives them the obligation to teach it. And while few teachers are optimally equipped with the scientific knowledge and pedagogical skills needed for this task, it is also probably true that even fewer understand fully the cultural and religious agenda of the creationists who are using politics to advance their goals. In addition to knowing science, teachers must know the lay of the religious and political land in order to navigate the cultural minefield that the teaching of evolution has become.

Although creationists have long been a fixture in American society, never—until now—have they infiltrated the country's educational, cultural, and political mainstream. They are doing so under the guise of intelligent design theory (ID). Headquartered at the Discovery Institute's Center for Science and Culture, a conservative Seattle think tank, the leaders of the ID movement, calling themselves the "Wedge," lay out their goals and lines of attack in a document titled "The Wedge Strategy." It outlines an ambitious plan for challenging the scientific status of evolutionary biology and the naturalistic methodology upon which science necessarily relies. However, rather than challenging evolution with new science, ID proponents—who have produced no science to support their claims—have constructed a well-financed public relations program and an influential network of political supporters who include United States senators and congressmen.

This new breed of creationists has shattered the time-honored truism that higher education is an antidote to pseudoscience. Their supporters include well-credentialed faculty in public and private—including Ivy League—universities, who have subordinated their academic integrity to their religious loyalties in the mistaken belief that evolution and personal piety are antithetical. Although few compared to the tens of thousands of scientists and other academics who accept evolution, these faithful academic followers have placed their credentials and reputations at the service of Wedge politics. They testify before school boards and state boards of education, sign public statements questioning the findings of evolutionary biology, and slip ID into freshman seminars, honors classes, and other courses outside required curricula. Yet, however valuable these pro-ID professors are to the public relations campaign, the Wedge's ultimate target is secondary education. This means that science teachers must understand the threat ID poses to the students for whose education they are responsible.

Two of the broadest pillars of support for American democracy are public education and separation of church and state. The Wedge strategy threatens both. The first line of attack against science education aims to defeat naturalism. ID proponents reject the naturalistic methodology of science, proposing supernatural (their euphemism is "nonnatural") explanations for natural phenomena. They argue that

"methodological naturalism"—a fancy term for "scientific method"—is equivalent to "philosophical naturalism," a view of reality that excludes supernaturalism. The second line of attack is the plan to enter science classes indirectly, through the seemingly innocuous proposal that teachers address evolution's "strengths and weaknesses." Inserting this thin end of the wedge will create and opening for the broad end: teaching ID as a solution to the shortcomings of "naturalistic" evolution.

These tactics distort the nature of science and violate constitutional safeguards protecting science education. Methodological naturalism, the search for natural explanations of natural phenomena, means using empirical observation and reason to explain whatever lies within reach of human sensory and cognitive faculties. Since those faculties are insufficient to explain anything beyond the natural world, scientific conclusions necessarily stop short of the supernatural. Since matters of religious faith usually presuppose the supernatural, they lie beyond the scientist's reach. Naturalistic methodology thus leaves unaddressed the supernatural's existence or nonexistence. So contrary to ID creationists, methodological naturalism is not equivalent to philosophical naturalism; it leaves everyone, even scientists, free to make personal religious commitments.

ID's success would initiate a radical realignment of educational and constitutional priorities. If ID creationists succeed in wedging ID—in any of its euphemistic guises—into public school science classrooms, their true agenda will surface quickly. Sympathetic teachers and administrators will be granted a license to teach views consistent with ID creationist orthodoxies. The Wedge leaders' religious rectitude has channeled them into an offensive, exclusionary posture that will emerge aggressively once constitutional barriers are broken. Two of them, William Dembski and Jay Richards (2001), articulate their vision with jarring simplicity: Christians have a mandate to declare the truth of Christ…[which] consists of bringing every aspect of life under the influence of this truth."1 The jurisdiction of this mandate includes public schools, where religious diversity is the norm. Wedge founder Phillip Johnson extends the jurisdiction further:

> "Secular society, and particularly the educational institutions, have assumed…that the Christian religion is simply a hangover from superstitious days," Johnson said. "With the success of intelligent design… we're going to understand that… the Christians have been right all along—at least on the major elements of the story, like divine creation. And that…is going to change society's understanding of what constitutes knowledge…"
>
> As a result, Johnson says, it will no longer be plausible to argue that "Christian ideas have no legitimate place in public education, in public lawmaking, in public discussion generally…" (Hartwig, 2001)[2]

For Johnson, "Christian ideas" translate to intelligent design creationism, which he hopes to integrate into the policy governing American public education.

Brief Description of the Resources

These resources will help raise the awareness of science teachers about (1) the religious identity and political strategies of intelligent design, the most recent form of American creationism; (2) the correct understanding of methodological naturalism and philosophical naturalism and the ID movement's attempt to conflate these concepts; (3) the unconstitutionality of ID creationism; and (4) the viewpoints of scientists who undertake the task of preserving the integrity of their science while maintaining personal religious commitments.

Details of the Resources

Title	Author	Medium	Grade Level	Publisher	Copyright	Cost/Ordering Information
Creationism's Trojan Horse: The Wedge of Intelligent Design	Barbara Forrest and Paul R. Gross	Book	Postsecondary background resource for teachers	Oxford University Press	2004	$40.00 Oxford University Press: http://www.oup.com/us/?view=usa; Amazon.com ($30.40); and author's Web site: http://www.creationismstrojanhorse.com
"The Wedge of Intelligent Design: Retrograde Science, Schooling, and Society." In Noretta Koertge (Ed.), Scientific Values and Civic Virtues. In press.	Barbara Forrest and Paul R. Gross	Book article	Postsecondary background resource for teachers	Oxford University Press	2005	$25.00 Oxford University Press: http://www.oup.com/us/catalog/general/subject/Philosophy/Science/?view=usa$ci=0195172248
"A Defense of Naturalism as a Defense of Secularism." In Matthew J. Cotter (Ed.), Sidney Hook Reconsidered	Barbara Forrest	Book article	Postsecondary background resource for teachers	Prometheus Books	2004	$32.00 Prometheus Books: http://prometheusbooks.com/catolog/book_1544.html; and Amazon.com ($20.16)
"Is It Science Yet? Intelligent Design Creationism and the Constitution" (Public Law and Legal Theory Working Paper No. 124)	Barbara Forrest, Steven Gey, and Matthew Brauer	Law review article	Postsecondary background resource for teachers	State University College of Law	September 2004	Free Social Science Research Network: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=590882; and forthcoming in *Washington University Law Quarterly*, *83*, 2005.
U.S. Supreme Court, Edwards v. Aguillard 482 U.S. 578		Supreme Court decision	Postsecondary background resource for teachers		1987	Free FindLaw: http://caselaw.lp.findlaw.com/cgi-bin/getcase.pl?court=us&vol=482&involve=578
Eight Major Court Decisions against Teaching Creationism as Science	Molleen Matsumura	Pamphlet	Postsecondary background resource for teachers	National Center for Science Education		Free National Center for Science Education: http://www.ncseweb.org/resources/articles/3747_8_major_court_decisions_against_2_15_2001.asp
Perspectives on an Evolving Creation	Keith Miller	Book	Postsecondary background resource for teachers	Williams B. Eerdmans Publishing Co.	2003	$36.00 Eerdmans Publishing: http://www.eerdmans.com/shop/product.asp?p_key=0802805124; Amazon.com ($23.76); and author's Web site: http://www-personal.ksu.edu/~kbmill/Book_Ann.html

Extended Description of the Resources

These resources are not recommended as teaching resources but as background information for teachers who must teach evolution and related subjects (geology, anthropology, etc.) in the face of the advance of intelligent design creationism. The central points that they will help in various ways to reinforce are that (1) American public schools reflect the nation's religious and cultural diversity; (2) public schools must remain secular neutral zones out of respect for both this diversity and the United States Constitution, which governs public policy concerning education; (3) teachers have both the law and science to call upon for support in fulfilling their pedagogical responsibilities; and (4) the scare tactics employed by ID creationists—such as the idea that teaching evolution precludes religious faith—are demonstrably false.

Creationism's Trojan Horse: The Wedge of Intelligent Design is the most exhaustive exposé to date of ID as both a continuation of traditional American creationism and an integral part of the religious right's program to undermine public education and secular society. The political strategies and connections of the Wedge are painstakingly explained and carefully documented. The discussion of ID leaders' regressive understanding of science and the exclusionary character of their personal religious views, which form the theological framework of the Wedge, is further developed in "The Wedge of Intelligent Design: Retrograde Science, Schooling, and Society." The law review article by Forrest, Gey, and Brauer analyzes the constitutional, philosophical, and scientific deficiencies of ID creationism. Gey's arguments draw heavily upon the landmark U.S. Supreme Court ruling

Edwards v. Aguillard (1987). Both the article and the *Edwards* decision are very readable resources that will enable teachers to understand the legal rationale for the Court's outlawing of creationism in public schools.

Edwards is also the ruling in the wake of which ID proponents consciously crafted their Wedge strategy in an effort to skirt constitutional barriers to teaching creationism. The National Center for Science Education's *Eight Major Court Decisions against Teaching Creationism as Science* is a useful summary of federal court rulings prohibiting the teaching of creationism in public schools.

Perspectives on an Evolving Creation speaks directly to the ID movement's use of the Wedge metaphor. The metaphor represents the movement's effort to "wedge" supernaturalism as a scientific principle of explanation in to the public mind, thus splitting off and discarding the concept of science as naturalistic. *Perspectives* is unique among recent books relevant to both the evolution/creationism issue and the science and religion dialogue. Composed of essays written by evangelical scientists and scholars, the book is clear evidence that scientists can function with integrity, using science's naturalistic methodology, while maintaining meaningful religious commitments. Their essays show that, while such a choice is not without challenges, they view modern science as both a profession and a source of religious inspiration, not, as do ID proponents, a bothersome obstacle to be cleared from their pathway into American science classrooms.

Notes

1. Dembski, W. A., & Richards, J. W. (2001). Introduction: Reclaiming theological education. In W. A. Dembski & J. W. Richards (Eds.), *Unapologetic apologetics* (p.18). Downer's Grove, IL: InterVarsity Press.

2. Hartwig, M. (2001, July 18). The meaning of intelligent design. *Boundless*. Retrieved December 14, 2004 from www.boundless.org/2000/features/a0000455.html

Problems with Teaching, Learning, and Creationism

Brian Alters

Introduction

It does not help science instructors to hold inaccurate stereotypes about why their students reject evolution and how students feel about this issue. On the contrary, by holding ideas that more accurately reflect their students' rejection and by understanding the sometimes complex culture that supports such rejection, instructors may better address their students' concerns and thus increase learning.

There are many reasons why people fear evolution, and there are some commonly encountered primary religious and nonreligious rationales underpinning those misgivings. Many professional creationists have elevated the conflict between evolution and creationism to the status of a war. Creationists consider the conflict extremely important—as important as many of their fundamental religious doctrines. With creationist attempts to increase the enlisting of students to carry on battles in science classrooms, the reality is that there are a large number of creationists who consider teachers of evolution as the enemy.

Of course there are a variety of creationist views, with their differing intensities of resolve, that conflict with evolution and nature of science instruction. Being aware of students' creationist culture, that engenders misconceptions about evolution in particular and science in general, can be a major aid to instructional practice.

Most educators would probably agree that it is important to know why students think something they are being taught is inaccurate. Yet when it comes to students rejecting the teaching of evolution, many educators just chalk it up to students being creationists and do not explore their reasons any further. However, the label "creationist," while often useful for categorizing the wide variety of people who reject evolution, is much too broad to give educators an appropriate understanding of the numerous rationales students have for rejecting the underlying theory of biology.

Many science instructors believe that anyone who rejects evolution must be a religious literalist fundamentalist and/or someone with a conservative political agenda. However, polls show that about half of Americans choose options other than evolution to explain how humans arose on Earth. These figures indicate that more persons than just religious fundamentalists (let alone literalist fundamentalists) or political conservatives choose nonevolutionary options.

Many students who reject evolution *do* have rationales for their objections. Some of these rationales are well thought out, while others border on the affective domain—responses that stem from emotion. The cognitive rationales range from what most people would consider to be purely religious rationales to rationales that may strike many as nonreligious. The vast majority of students, however, hold some combination of religious and nonreligious rationales for their rejections.

Instructors should be aware of students' conceptions in order to help them learn the science of evolution better and to understand why the scientific community agrees that evolution is the only scientific theory to explain the diversity of life. Otherwise it will be difficult, if not impossible, to productively address students' misconceptions about evolution. Additionally, to better understand why many students (and nonstudents)

contend that the evolutionary science we teach is inaccurate, it is illustrative to examine some of the religious and nonreligious rationales underpinning their thinking.

There are specific yet greatly varied religious and nonreligious rationales that students typically give for their rejection of evolution. The vast majority of student rationales for rejecting evolution fall outside the context of the public school curricula. Therefore, these conceptions about evolution are most likely engendered through non-formal learning activities.

It comes as no surprise to most instructors that creationist students generally have religious reasons for rejecting evolution. Instructors can benefit by understanding these reasons, how they are engendered, and what happens when creationists perceive that science and their religious beliefs are in conflict. In addition, instructors may benefit from understanding the underlying creationist philosophy as well. Two characteristics seem to be almost universally present among creationist students: (1) they are pleasantly surprised when they learn that their instructor has some knowledge about their most important beliefs and (2) their admiration and respect for that instructor increases considerably due to this knowledge—usually helpful in a teaching milieu.

A great number of students think evolution is inaccurate not solely for religious reasons but for a combination of religious and nonreligious reasons. Quite often their nonreligious reasons for rejecting evolution are related to their religious beliefs. The professional literalist organizations certainly understand this connection and use many related theological and nontheological approaches to convert progressives and theists to a literalist position. Likewise, progressives use similar tactics in an attempt to convert literalists and theists.

Yet many scientists are under the impression that the entire phenomenon of rejecting evolution is solely a religious issue, and they are quite surprised when confronted with what often seem to be nonreligious challenges to what they are teaching about evolution. These nonreligious rationales are primarily misunderstandings concerning science content and/or process and are usually some of the issues discussed in creationist publications, on creationist speaking tours, and during publicly held evolution/creation debates. Many of these misconceptions (not considered misconceptions by the professional creationists) are also propagated as "good" or "true" science by literalist organizations. Such conceptions held by students are important for instructors to understand.

It is strongly recommended that science instructors access their students' prior knowledge concerning these nonreligious misconceptions to better address them pedagogically in the classroom. There appears to be some common misconceptions that are likely candidates for students to bring to their science courses. Whether or not students or others bring typical misconceptions or more in-depth challenges, with which instructors may not be familiar (often courtesy of professional creationists), to the science classroom, consulting the following resources should be helpful.

Taking into consideration all the controversy, many creationists and noncreationists alike ask: Why teach evolution? Clearly, instructors should teach the myriad reasons why evolution education is essential. There are also some other typical questions that students, parents, and others ask of science instructors who teach evolution. These are questions heard directly from students and that instructors report hearing most often; they are illustrative for understanding the mind-set of the questioner. Because it is important for instructors to understand why their students ask the questions they do, instructors should be aware of the potential motivation behind the question and sometimes what the questioner is really asking.

Students often ask instructors explicit creation/evolution–type questions. The most typical questions related to science education, religion, and general education would be helpful for instructors to know. Sometimes science instructors have questions related to how they, as instructors, might proceed in answering such queries. These questions would be best answered before teaching, as well as having appropriate pedagogy and teaching suggestions for evolution.

Instructors are often expected to answer many questions from students, parents, and administrators. Some of these are: What do you mean by evolution? Is it true that evolution is not based on evidence? How can you teach something that no one can see? If organisms evolve, then why do they look so well designed? Why can't intelligent design theory be included in the science curriculum? Because scientists don't know every detail of how evolution occurs, shouldn't they at least consider supernatural causes as scientific explanations and teach such possibilities in the science classroom? Why is evolution considered a scientific fact? Why is evolution by natural selection a law of nature? Why can't you prove evolution to me? What good is a partial eye, wing, or other structure? Isn't evolution a theory in crisis? Didn't Darwin recant on his deathbed? Do you know about scientific creationism? What's wrong with presenting both sides? And there are a host of other questions about the characterization of science, theory, and law, horizontal versus vertical evolution, missing links, punctuated equilibrium, dinosaurs and human tracks, dating fossils and rocks, laws of thermodynamics, plate tectonics, probability, and much more. (adapted from *Defending Evolution in the Classroom,* 2001)

Needless to say, evolution education is a mixture of numerous issues, To help instructors with the forgoing matters, the following recommended teaching resources should prove helpful.

Brief Description of the Resources

Defending Evolution in the Classroom is written exclusively to instructors; it explores the answers to students', parents', and others' questions concerning religion and evolution, as they pertain to evolution education. *Evolution vs. Creationism* is written to both students and instructors in a balanced, comprehensive survey of evolution versus creationism, including its history.

Details of the Resources

Title	Author	Medium	Grade Level	Publisher	Copyright	Cost/Ordering Information
Defending Evolution in the Classroom: A Guide to the Creation/Evolution Controversy	Brian Alters and Sandra Alters	Book	High school through university	Jones & Bartlett Boston, MA	2001	Hardback: $39.95 Paperback: $29.95 www.jbpub.com
Description: Book for instructors						
Evolution vs. Creationism: An Introduction	Eugenie C. Scott	Book	High school through university	Greenwood Press, Westport, CT	2004	Hardback: $49.95 www.natcenscied.org
Description: Book for students and instructors						

Extended Description of the Resources

Defending Evolution in the Classroom covers: (1) why students reject evolution: religious and nonreligious reasons; (2) creationist students' culture and the nature of science; (3) questions and answers about science education, religion, and general education; (4) methods for teaching

evolution; (5) why students should learn evolution; and (6) why creationists have declared war on science educators.

Evolution vs. Creationism covers: (1) science, evolution, religion, and creationism; (2) a history of the creationism/evolution controversy; and (3) selections from the literature concerning cosmology, astronomy, geology, patterns and processes of biological evolution, and legal, educational, religious, and nature of science issues.