Why Evolution Works (and Creationism Fails)

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Contents

Foreword

Some time ago after a public lecture I gave, I had the pleasure of a long and fascinating conversation with several young men who were obviously very intelligent, educated, conservative Christians. They had good questions and they listened to what responses I could offer them, and in return, they were able to ponder some of my own questions for them and provide good answers.

They asked me why, if evolution was governed by random processes, it was not completely incompatible with the idea that there was a purpose and meaning to life, one that could be directed by a divine Creator. This is a good question, but it also begs the question that evolution is in fact governed by random processes. It isn't. Natural selection, the great insight of Darwin and Wallace, is anything but random, which is also true of sexual selection, Darwin's other great evolutionary process. In fact, I don't know of any really important processes in evolution that are random (random drift is one, but we don't know how important it is; neutral evolution isn't important to evolution until something happens to it, which is usually selective). When we talk about "random mutations," we're not talking about causes or effects of mutations (anything can't happen), but about the distribution of predictable effects of mutations in populations (we can know risk factors, causes, and statistical incidences, but we can't predict in advance which individuals will be affected). For scientists, "random" is just a term that describes the statistical distribution of some known effect in a sample.

So, if evolution is not random, does it still deny a purpose or meaning to life? These really aren't questions for science, at least in the sense of ethics, aesthetics, or morals. The purpose of life is to make more life: to survive and reproduce. This is not a conscious purpose of any organisms except humans, as far as we know, but without surviving and reproducing, a species becomes extinct. Then, does life have a direction? The only direction in science is time, and we know from our studies of the evolution of life that species have evolved through time by changing and adapting to whatever the physical environment and other organisms throw at them. This history—or macrohistory, if you will—is certainly a direction, a chronicle of events and changes through time from which we derive ideas about patterns and processes. And beyond this, science does not go.

But, one of my companions asked, if you don't have the fear of losing salvation to provide the basis for your morality, what's to stop you from killing this guy next to you and taking his stuff? I really didn't know, but I replied by asking him why he would want to do that. Wouldn't he regret it? Wouldn't there be reprisals, pursuit, conviction in a court of law? Wouldn't he feel terrible for the victim's friends and family? My companions replied that they could not understand how a system of morality could be built without being based on the fear of divine retribution. So, apparently, for them the problem of good and evil is purely theological, not rational. Upon further questioning it turned out that my companions had not read Plato, and so could not conceive of the idea of the Good in a purely philosophical sense that could be put into social practice. There is also a long tradition of deriving morality from biological principles, and these are discussed in this book.

In America today, and in some other parts of the world, we face a dichotomy of approaches to the world. One is authoritarian, based on the primacy of revealed knowledge that is subject to discussion and examination (and sometimes to revision, though this is not always admitted), but not to test and refutation. This approach is religious, and is based on sacred texts whose wisdom is not questioned; if secular experience is contrary to sacred revelation, the former must be wrong, not the latter. The second approach to the world comes from the Enlightenment, and regards reason, rationality, and empirical experience as the best guides to navigating the real world—by which is meant the understanding of the natural world as well as the development of moral, social, and political precepts. It admits useful ideas from theology and religion, but not for their own sake—rather for their worth, as measured in practical terms. Knowledge is in this approach derived from experience, experiment, testing, and pragmatics. But it also assumes that the empirical world is real, is knowable, and is regulated by patterns and processes that have natural and predictable mechanisms in some sense.

We all know where these two worldviews clash; it is the subject of this book. I hope that readers will find what they need here to begin to evaluate for themselves how and to what extent each traditional approach governs and influences the decisions they make in their lives and the views that they hold. In the twenty-first century, the stakes are too high for us not to be aware of the basis of the decisions that govern our lives and the lives of others.

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Preface

> The greater the ignorance, the greater the dogmatism.
> —Sir William Osler (father of modern medicine)

This book is being published on the one hundred fiftieth anniversary of the publication of Charles Darwin's *On the Origin of Species* and the two hundredth anniversary of his birth. It is an impassioned argument in favor of science—primarily the theory of evolution—and against creationism. Why impassioned? Should not scientists be dispassionate in their work? Perhaps, but it is impossible to remain neutral when, after one hundred fifty years of stunning success, one of our most successful scientific theories is under attack, for religious and other reasons, by laypeople and even some scientists who willfully distort scientific findings and use them for their own purposes.

Most educational books on evolution are written for parents or teachers and are, at best, only tangentially aimed at students. This short book, by contrast, is written primarily for college students, but it will also be useful to their parents and teachers. Nothing will make the eyes glaze over more quickly than technical jargon, and we carefully avoid such jargon wherever possible. In the same way, we stick to broad principles, hoping to make evolution clear without bogging the reader down in too much detail.

Additionally, this book addresses what other books leave out: how science works and how pseudoscience works. We demonstrate the futility of "scientific" creationism and other arguments designed to show that evolution could not have produced life in its present form. The direct descendant of scientific creationism is intelligent-design creationism, and we devote more than one chapter to debunking that misconception.

We next turn to how evolution actually works. Before the theory of evolution, natural scientists thought that they saw design in nature. We show why evolution predicts the appearance of design in nature, though not the reality of design, or at least not purposeful design. In the same vein, we discuss the problem, for creationists, of poor design and why we find it, too, in nature. Then we take up cosmological arguments offered by creationists to explain our existence and find them wanting as well. We conclude with a frank discussion of science and religion, specifically arguing that science by no means excludes religion,

though it ought to cast doubt on certain religious claims that are contrary to known scientific fact.

Finally, we address this book, in part, to those who, for whatever reasons, deny what we consider well-founded scientific facts such as the antiquity of the earth and the descent of species. At the very least, they have an obligation to understand precisely what they are rejecting. We also hope to provide parents, teachers, and others with sound arguments they can easily understand and give them ammunition with which to defend modern science.

Chapter 1

Introduction

> Evolution is so clearly a fact that you need to be committed to something like a belief in the supernatural if you are at all in disagreement with evolution. It is a fact and we don't need to prove it anymore. Nonetheless we must explain why it happened and how it happens.
>
> —Ernst Mayr, Harvard University

The theory of evolution is one of the most successful in all of science. Its predictions have been verified countless times since the publication of Charles Darwin's *On the Origin of Species* in 1859. As we will see, the evidence is so stunning and complete that we are confident in saying that *descent with modification* is an observed fact. Further, the modern theory of evolution, also called the *modern synthesis*, combines Darwin's concept of descent with modification with the theory of genetics. The modern synthesis accounts for the observed facts better than any other theory.

Biological, or organic, evolution refers to descent with modification, or changes among organisms over generations. The unit of evolutionary change is the population, not the individual. But change begins with the molecules and molecular interactions of genetic material in an individual and ultimately develops in individuals physical or behavioral traits that differ from their ancestors'. Because the change is in the genetic material of the individual, that change is heritable. In other words, if the individual reproduces successfully, that change is passed on to its offspring. Ultimately, the change may become common within the population of which the original individual was a member. At this point, we conclude that the population has evolved, because it has experienced a widespread biological change. Indeed, the definition of evolution is the widespread change of a genetic trait within a population. Finally, if the population evolves so far that it cannot normally interbreed with the ancestral population, we say that a new species has evolved.

WHY IS EVOLUTION IMPORTANT?

Evolution is critically important today, yet many people—especially in the United States—reject it, often on religious grounds. Why is it so important, and why do so many people reject it? We will answer those questions in order.

The world that the next generation inherits will be shaped in large part by our understanding of evolution or, perhaps, by our lack of understanding. For example, when antibiotics were discovered, many physicians wrongly assumed that bacterial diseases would become a thing of the past. Only a few prescient thinkers recognized that bacteria would evolve resistance to antibiotics and warned against overusing them. Such warnings went unheeded even though a penicillin-resistant strain of the bacterium *Staphylococcus aureus*, which can cause skin infections, meningitis (a brain disease), pneumonia, and septicemia (blood poisoning), was discovered within four years of the first mass production of the very first antibiotic. Indeed, today, a number of harmful bacterial species, including those that cause tuberculosis and childhood ear infections, are resistant to at least one widely prescribed antibiotic. These organisms have evolved into their new, antibiotic-resistant forms by random genetic mutation, the process that provides the raw material for natural selection. *Plasmodium*, the parasite that causes malaria, has likewise grown resistant to the early treatment, quinine, and its later derivatives.

Because there are only a limited number of ways to kill bacteria (without also killing the host), we may have few remaining opportunities to develop new, effective antibiotics. If public health policy reflected a keen understanding of evolution, we would stop prescribing antibiotics for diseases against which they are ineffectual, and we would not administer them routinely to livestock and fowl, as we do now.

Similarly, many insects and noxious weeds have become resistant to insecticides and herbicides, and farmers have to use more and stronger chemicals to control them. In addition, the mosquitoes that carry malaria have become resistant to insecticides. Besides mosquitoes, many species of lice, ticks, bedbugs, and fleas, not to mention cockroaches, have become resistant to one or more insecticides. Many of these insects transmit diseases to humans. Any evolutionary biologist could have predicted insecticide resistance.

Erosion of Genetic Diversity

An evolutionary biologist would also be greatly concerned about the loss of diversity among our food crops and the lack of diversity in our agricultural fields. Today, for example, farmers in developed countries plant only a relatively few varieties of wheat. They used to plant hundreds of varieties of apple; now we commonly see less than a dozen. A potent fungus attacking one of our more common food crops could wipe out a significant fraction of our food supply.

Indeed, 30 percent of all farm animal breeds worldwide may be at risk of extinction. Ironically, these animals have evolved special traits that have been naturally selected to make them well adapted to local environmental challenges like disease and drought. Nevertheless, these local breeds are being replaced by farm animals that originated in developed countries with temperate climates and have been bred for high milk production and fast growth. Livestock from the developed countries may be genetically unfit to survive and reproduce in areas like sub-Saharan Africa, where they may not be well adapted to the local climates or grasses. As the new breeds with their low diversity and higher yields become more prevalent, the local populations decrease and are put at risk of extinction, along with the special traits and the genes that control them. This is an example of an evolutionary phenomenon called the *erosion of genetic diversity*. When genetic diversity is limited, plants and animals may not be able to respond to a new epidemic because the genes that might have helped them respond are gone.

We also see erosion of genetic diversity in wild populations of plants and animals, but for different reasons. Human activity has caused the degradation and in a few cases the complete disappearance of many (perhaps most) of the Earth's ecosystems. As natural habitats are altered and removed for human benefit, populations of species that depend on these habitats shrink, and some populations become so small that they can no longer survive. Conservation biology, an entirely new branch of biological science, was developed as a reaction to this biodiversity crisis. One of the ethical and philosophical foundations of the Society for Conservation Biology is that evolution is essential to the continued existence of life on Earth; interference with evolutionary patterns disrupts interactions among species and therefore reduces general ecosystem health. Human interference could result in such severe losses of biodiversity that the very nature of our existence will be put at risk. Only through a deep understanding of the mechanisms that drive evolution can we expect to be effective stewards of the organisms upon which we depend.

A theme that connects the examples in the preceding paragraphs is economics. Indeed, the thirst for economic growth influences the decisions we make about our effects on the natural world, often regardless of our knowledge and understanding of evolutionary processes.

Evolution in Medicine

If a virus or a bacterium can be transmitted easily from one human to another, it is, so to speak, in the interest of that virus to not harm its hosts. The common cold, for example, is transmitted when people are in close if not direct contact. The virus does not live long in the air, so person-to-person contact is necessary for the health of the virus itself. The virus thus thrives only if an infected person can get up and go to school or work. A mutant virus that forces

a person to stay at home is at a disadvantage with respect to a virus that does not, so the common cold has evolved to *not* make people very sick.

Similarly, a great many people, including almost all adults over thirty years old, are infected with the Epstein-Barr virus (EBV). This virus quietly takes over the machinery that controls cell division, yet produces almost no symptoms. Such viruses can lie dormant for years without being detected. Only when college or high-school students who have already been infected with EBV, for example, get run down does their immune system lose control, and they get mononucleosis. Worse, when something goes terribly wrong, the presence of the *pathogen* (an organism that causes disease) becomes a serious problem for its host. For example, malaria patients have a compromised immune system, and their bodies lose their ability to control cell division in the cells infected with EBV. Cells divide rapidly, and soon a tumor forms. The patient then can develop a form of cancer called Burkitt's lymphoma. Burkitt's lymphoma is common in equatorial Africa, where malaria is also common.

If a pathogen does not have to be transmitted by direct contact, then it can kill its host quickly and still survive by infecting another host. Malaria, for example, is spread from person to person by mosquitoes. That is, a mosquito bites an infected person and swallows some parasites. That mosquito bites another person and inoculates that person with the parasites. The disease is spread without direct contact between people. It is therefore in the interest of the parasite to strike its victims hard and fast: People infected with malaria are less able to defend themselves against mosquitoes. They may be bitten many times, so the parasite spreads effectively. Evolutionary biology tells us that, if we can keep critically ill people from being bitten by mosquitoes, as with mosquito netting, then mosquitoes will be able to bite only relatively healthy people. Hence, as with the common cold, the virulence of malaria will decrease.

A waterborne disease such as cholera is also spread without direct contact. Cholera causes diarrhea. If sanitation is poor, then sick and dying people will transmit cholera by contaminating the water supply. We can attack the disease by cleaning up the water supply and by ensuring that water for washing clothing and bedding is not mixed with the drinking water. When we do so, we find that the bacterium that causes cholera becomes less virulent, because now it must keep its host alive if it is to survive. People still get cholera, but the disease is not as serious as it was in the eighteenth and nineteenth centuries. Pathogens adapt to new conditions, and the study of evolution gives us clues on how to fight certain diseases.

Genetic diseases may also be understood by applying evolutionary theory. Sickle-cell anemia, for example, is a genetic disease that is most prominent among people of sub-Saharan African descent. Sickle-cell anemia evolved as an accidental replacement of one molecule for another in the DNA within

the gene family that makes hemoglobin proteins. As a result, one of the main proteins in hemoglobin becomes horribly misshapen, compromising the oxygen-carrying capacity of hemoglobin. The misshapen protein can also easily form crystals within red blood cells, causing them to become elongated, or sickle-shaped. These elongated cells not only have a reduced oxygen-carrying capacity; they also block blood vessels and cause pain or organ failure. Before the development of modern medicine, patients with sickle-cell anemia had considerably shortened lives.

Individuals who carry only one copy of the sickle-cell gene do not express the symptoms of the disease. Rather, those who express the symptoms of the disease carry two copies of the gene. In part because of their shortened lives, they are less likely to produce offspring than those who do not express the symptoms. We might therefore think that a disease-causing mutation as debilitating as sickle-cell anemia would quickly disappear from the human population. Why then has this disease persisted? Precisely because an individual needs two copies of the sickle-cell gene to have full-blown sickle-cell anemia. What is truly fascinating from an evolutionary perspective is that *carriers*, or individuals who carry one normal copy of the hemoglobin gene and one sickle-cell copy, are almost completely protected from the symptoms of malaria. In the presence of malaria-carrying mosquitoes, carriers are more fit than individuals who carry only normal hemoglobin genes; to the population as a whole, the advantage of being resistant to malaria outweighs the disadvantage of sickle-cell anemia, so the sickle-cell gene persists. Without an understanding of evolution by natural selection, we would have no way of explaining why sickle-cell anemia does not disappear in a few generations.

Genealogy

Finally, we note the popularity of genealogy; many people study genealogy as a hobby and take it seriously because it puts their lives into a larger historical context. People want to draw a genealogical chart and work it back through as many generations as they can. On the other hand, some geneticists and evolutionary biologists approach genealogy not as a hobby, but as a scientific pursuit. They ask interesting questions and often come up with fascinating answers. For example, in 2003, Tatiana Zerjal of the Department of Biochemistry at the University of Oxford, along with a group of other scientists, published in the *American Journal of Human Genetics* a paper that explains genetically the genealogy of Genghis Khan and his descendants. They show that the Y-chromosomes of 8 percent of the males throughout a large part of Asia most likely originated with Genghis Khan himself. Indeed, this finding means that 0.5 percent of males (around 16 million) in the world may be descended from Genghis Khan. Historians confirm this possibility with their accounts of the conquest and slaughtering of many populations as

Genghis Khan and his male descendants established the largest land empire in history. At the same time, Genghis Khan and his descendants fathered hundreds of children.

Evolutionary biology allows us to extend our genealogy much farther back. For example, analysis of the DNA of females leads back to a single female, nicknamed "mitochondrial Eve." Importantly, mitochondrial Eve is not the first woman who ever lived, but rather the individual woman whose lineage has survived to the present. The descendants of most, if not all, other females alive at the time of Eve appear to have died out. If that is so, then we are all descended from Eve. Similar analysis of the DNA of males leads to a single male, nicknamed "Y-chromosomal Adam," who is probably the ancestor of all males alive today. Oddly, Adam and Eve did not live at the same time. (Eve most likely lived 140,000 years ago and Adam, 60,000 years ago; it is safe to say that they never met.) Moreover, we can project back approximately 4 billion years to the Last Universal Common Ancestor, or LUCA, from which descended the three major domains of life, Archaea, Bacteria, and Eukarya.

WHY DO PEOPLE DENY EVOLUTION?

We sometimes hear people say that scientists "believe in" evolution, as if evolution were a religious *dogma*, that is, a doctrine declared to be authoritative by a church or other religious organization. Scientists do not believe in evolution in the way that some theologians believe in dogmas. To the contrary, no matter what their religion, scientists *accept* evolution on the weight of the evidence. Specifically, most scientists (and the vast majority of biologists) find the physical evidence in favor of descent with modification to be conclusive and the modern theory of evolution to best explain that fact. Acceptance of evolution does not depend on any particular religion or nationality; biologists the world over are virtually unanimous in accepting and working with evolution.

If biologists are certain of the validity of evolutionary theory, why do so many lay persons, especially in the United States, reject it? Probably for several reasons: They confuse evolution with atheism or think it may lead to atheism; they think it contradicts the Bible; or they think it implies a purposelessness to their existence. Others think that evolution cannot explain morality and indeed leads to immorality. Additionally, many people simply do not understand the theory and incorrectly think that chance is its sole explanation for the evolution of complex organisms.

Evolution and Unbelief

The charge that evolution may lead to atheism is exaggerated but not wholly unfounded. Several surveys taken between 1914 and 1998 have shown, for example, that biologists and anthropologists are more likely to disbelieve in

God than are physical scientists or engineers. No one is certain why, but possibly it is because biologists and anthropologists see a great deal of evil (or the animal kingdom's equivalent of evil) in their studies of animal behavior, and they think that evil militates against the existence of God. For example, many species of insects employ a strategy called *parasitoidism*. One such group includes species in the wasp family Ichneumonidae. Ichneumon wasps lay their eggs in the bodies of caterpillars so that their larvae can eat the caterpillars alive. Darwin himself was so disturbed by the ichneumon wasp that he wrote in a letter, "I cannot persuade myself that a beneficent and omnipotent God would have designedly created the Ichneumonidae with the express intention of their feeding within the living bodies of Caterpillars, or that a cat should play with mice." Importantly, Darwin did not say "God," but "a beneficent and omnipotent God."

Such considerations, we argue, do not necessarily rule out a deity, though they may push the concept of a personal, intervening deity to arm's length.

But suppose that evolution did in fact imply atheism? Would that necessarily bear on the truth or falsity of evolution? No. To understand that statement, we discuss a logical fallacy that philosophers call the *appeal to the consequence*: rejecting a claim of fact because its consequences are perceived to be undesirable. Thus, it is a fallacy to reject evolution because you do not like its consequences (or what you think are its consequences). Evolution may or may not lead some people to disbelieve in God; that has nothing to do with its validity. In the same way, a false doctrine that leads people to believe in God is no more true for that consequence. In short, a claim of fact must be judged solely on its merits, not on our preference for its consequences. More to the point, evolution must be judged on its merits, even though it may lead some people to disbelieve in God.

A related objection to evolution is its apparent discord with the Bible, especially the first chapter of Genesis. Although some people have tried to reconcile the account in Genesis with the modern theory of evolution, those arguments are inconsistent and unconvincing: The theory of evolution disagrees with much that is written in the Bible—but only if we interpret the Bible literally. A great many religious people take the Bible figuratively or as spiritual metaphor (or distinguish between those parts of the Bible that relate history and those that do not) and find no contradiction between their religion and the theory of evolution. We do not presume to offer religious advice, but we urge *biblical literalists* to read further and be open to a thoughtful consideration of evolution.

Evolution and Purpose

Some people deny evolution because they think that the universe must have some overall purpose, or else life is futile. Does evolution imply

purposelessness? Not to the many religious believers who accept it. Such adherents range from *deists*, who think that God set the universe in motion and then wholly or largely withdrew, to *theistic evolutionists*, who think that God is active in the world today but does not intervene to contradict *natural law*. To most theistic evolutionists, evolution is God's way of fulfilling God's purposes, whatever those may be. This book has no quarrel with religious believers such as theistic evolutionists; rather, its quarrel is with creationists who flatly deny the findings of modern science.

But, as we noted in connection with atheism, even if evolution implied a lack of purpose, it would be a logical fallacy to reject it on that grounds. Evolution is a fact, whether or not we like the consequences. If that fact implies a lack of purpose—and not everyone concedes that it does so—then people will simply have to find their own purpose or their own meaning in life.

Evolution and Morality

Yet another objection to evolution is that it is amoral or leads to immorality. Besides being another appeal to the consequence, the claim is not true. To the contrary, as we show in chapter 17, there is good evidence that morality is an evolved behavioral characteristic and that it derived from the propensity of organisms—from slime molds to ants to pack animals such as wolves—to cooperate among their own species. Religious leaders have often exemplified good morality or even been enforcers of public morality, but we do not need religion to be moral; it is arguably in our nature.

Similarly, evolution has been blamed for *social Darwinism*, the theory that those who have wealth and power do so because they are biologically superior, and its odious cousin, *eugenics*, which proposes that only certain supposedly superior groups of people are fit to produce offspring. Social Darwinism circularly argues that if some people are successful, then they must be superior. It has been used to justify, for example, the laissez-faire social and economic policies of the robber barons of the nineteenth century. Social Darwinism confuses what is with what should be. Exploitation, slavery, and the divine right of kings have existed for thousands of years and did not need to rely on evolution for theoretical support. Blaming evolution for social Darwinism is yet another appeal to the consequence.

Chance in Evolution

Many find the theory of evolution distasteful because they think it relies entirely on chance. They liken the development of a multicellular organism to tossing a million coins and getting just the right outcomes or tossing all the parts of an airplane into the air and having them fall to earth as a completed Boeing 747. No one seriously thinks that evolution works that way, and, indeed, the Boeing 747 evolved to its present form beginning with the Wright

brothers' plane at Kitty Hawk through a great many intermediate forms. We will show later in the book that, although chance plays a role in evolution, natural selection is by no means wholly random.

Consider the example of the shark and the dolphin. Both live in similar environments and are adapted for swimming underwater. Both swim by waving or oscillating their tails, the shark horizontally and the dolphin vertically. Even though the shark gets its oxygen from water and the dolphin gets it from air, they have remarkably similar shapes; we would say they are both well *adapted* to the liquid environment. Yet the shark evolved from a fishlike ancestor, and the dolphin evolved from a land mammal. Chance played a role, for example, in how fast and by what route each evolved into its present form, but the needs imposed by the watery environment dictated the streamlined shape of each animal. Evolution thus displays a sort of lawlike behavior and does not depend wholly on chance. The history of each lineage, for example, determined how each animal solved certain problems, such as locomotion.

Natural selection often starts with different raw materials and converges to the same solution. The constraints imposed by the environment forced the shark and the dolphin to develop similarly streamlined shapes, even though they are not closely related. These are not isolated examples but exemplify a common theme, *convergent evolution*, the evolution of similar traits in response to similar environmental constraints. Still, their different histories forced the dolphin to swim with an up-and-down undulatory motion, whereas fish swim with a side-to-side motion. Evolution does what it can with the raw materials available to it; because the terrestrial ancestors of the dolphin could not bend their backs in a side-to-side motion, the dolphin does not swim like a fish.

The Tasmanian wolf, or thylacine, is a marsupial native to Australia and New Guinea. It has recently become extinct and is preserved only in paintings and photographs. It is more closely related to a kangaroo and a possum than to a wolf, but it looks remarkably like a wolf and fills the same ecological niche as the wolf. And other extinct marsupial, *Thylacosmilus*, closely resembled the saber-toothed tiger but is only very distantly related. The echidna, or spiny anteater, is closely related to the platypus, but it has developed a long snout and a long, sticky tongue like those of the true anteaters (which are related to sloths) and aardvarks. In addition, the echidna has evolved spines or quills similar to those of hedgehogs and porcupines, none of which are closely related to each other. Such convergent evolution is not the result of chance.

Camouflage and *mimicry* differ from convergent evolution in that the organism evolves to look like the background in which it lives (camouflage) or to physically resemble some other organism (mimicry). Like convergent evolution, camouflage and mimicry do not evolve by chance but gradually, owing to the needs of the organism in its environment. Thus, to avoid predators, the snowshoe hare develops a white coat in the winter, the praying

mantis looks like a leaf, and the walking stick (an insect) looks like a twig. Similarly, predators such as the polar bear and the Arctic fox have evolved white coats to avoid detection by their prey. More interestingly, a moth may evolve to resemble a wasp, so that predators that have been stung by a wasp will avoid the moth as well as wasps, or an edible butterfly may mimic an inedible but unrelated species. These last two examples are of a special kind of mimicry called *Batesian mimicry*, after the English naturalist Henry Walter Bates, in which an innocuous species (the mimic) resembles something poisonous or dangerous (the model) in order to protect itself.

Convergent evolution, mimicry, and camouflage do not evolve by chance; they evolve gradually and for specific reasons over many generations as organisms become more streamlined, better camouflaged, or better mimics as the result of natural selection.

The well-known case of the peppered moth in England provides iconic evidence of the evolution of camouflage as environmental conditions changed. After the beginning of the Industrial Revolution, trees in and around many English cities became covered with soot. Against the black background of the soot, the light-colored moths were easily snapped up and eaten by birds. A darker variety of the same moth almost completely replaced the light-colored, peppered variety. When clean air acts were introduced and the soot gradually disappeared from the trees, the lighter variety of moth reasserted itself. Chance played a role in the selection of the darker moths, but their selection was virtually inevitable as the trees darkened and provided less and less camouflage to lighter moths. Recently, in response to creationist criticisms of the pioneering field work on the peppered moth by the naturalist Bernard Kettlewell in the 1950s, Michael Majerus of the University of Cambridge performed a multiyear experiment designed to answer the creationists' criticisms and found that the original experiments hold up very well.

Age of the Earth

Darwin developed his theory at a time when the age of the earth was in dispute, and William Thomson, later Lord Kelvin, had incorrectly calculated the earth to be on the order of 100 million years old at most. Darwin's theory of evolution predicted a much older earth, as did certain geological observations. As it turned out, Darwin was correct and Kelvin wrong: Kelvin had assumed that the earth was formed as a ball of molten rock and estimated its age by calculating its cooling rate. Kelvin's method was legitimate, but the calculation is almost impossible. His incorrect assumption that core of the earth was solid, however, invalidated his conclusion.

Darwin and the geologists were thus vindicated in their belief that the earth was much older than 100 million years. Radioactive dating and other techniques have since established the age of the earth as 4.5 billion years.

Many but not all of those who attack evolution believe in a young earth and a young universe, typically 10,000 to 20,000 years old but sometimes as little as 6,000 years old. Evidence from geology, astrophysics, physics, and cosmology, as well as biology, confirm conclusively that the earth and the universe are billions of years old. Thus, *young-earth creationism* becomes an attack on all of science; the attack on evolution is only the thin edge of the wedge.

Old-earth creationists and *intelligent-design creationists* accept the antiquity of the earth and the universe but argue, for different reasons, that biological evolution could not have taken place without at least some guidance. We will examine their arguments in detail later, but we note here that, if we accept the claims of creationists, we will ultimately stop doing science, because "at least some guidance" assumes in advance that we cannot answer many scientific questions about evolution, human origins, or indeed the origin of life. That is not to say that science and religion cannot coexist. Creationism, however, by assuming the answers, rules out investigations of certain open problems. Creationists' claims are therefore subtle attacks on biological evolution in particular and science in general. All creationists, in varying degrees, deny both the conclusions of science and the methodologies of science.

Thought Questions

1. As we systematically erode the genetic diversity of our food crops by selecting specific, desirable traits, we also select undesirable traits in our weeds. From an evolutionary perspective, why do you think that weeds, in particular, can grow back after being pulled out by the roots or sprayed with herbicide? Why can weeds grow in dry, barren soil where food crops cannot? Why are our food crops susceptible to insect damage, whereas weeds and flowers are less so? Hint: Why do you think many plants are poisonous? Explain your answers.
2. Think of something you believe strongly. List the reasons you believe it. Are they legitimate reasons? What makes them legitimate reasons?
3. Think of something you *dis*believe strongly. List the reasons you disbelieve it. Are they legitimate reasons? What makes them legitimate reasons?
4. Citing an authority to support a contention is called an *appeal to authority*. When is it appropriate to accept the word of an authority and when not? Who can fairly be called an authority? Can you give examples of people who may be authorities in one subject but not in another?

Chapter 2

The Structure of This Book

> One cannot help but be in awe when contemplating the mysteries of eternity, of life, of the marvelous structure of reality. It is enough if one tries merely to comprehend a little of the mystery every day.
>
> —Albert Einstein

A modest fraction of this book is devoted to refuting all varieties of creationism. Hence, we discuss, in chapter 3, a "History of Creationism and Evolutionary Science in the United States." Before the development of modern science, nearly everyone was a creationist, in a sense. But even those who believed in the Bible literally saw the necessity to interpret it so that their understanding of the Bible was consistent with scientific facts as they were understood at the time. Thus, when the antiquity of the earth became apparent, theologians proposed, for example, that the days of the creation might have been eons and not literal twenty-four-hour days. When the theory of evolution posed a new threat, it became one factor that brought about a more literal interpretation of the Bible. In the mid-twentieth century, the little-known pseudoscience of flood geology evolved into creation science, and its proponents engaged in political activity designed to force creation science into the public schools alongside evolutionary biology. When courts deemed creation science to be religion, not science, it evolved again, this time into intelligent-design creationism.

In chapter 4, we show "How Science Works." In a nutshell, scientists make hypotheses and then compute or deduce specific, detailed consequences of those hypotheses. They then carry out experiments or make observations to test whether the consequences of their hypotheses are correct. If so, then the hypotheses are tentatively accepted. More experiments or observations and more hypotheses follow in order to verify or refine the original hypotheses. Sometimes an observation or experiment precedes a hypothesis. Some hypotheses are rejected, others accepted. When enough hypotheses have been accepted and we have a large body of knowledge, then we say that we have a successful *theory*. Additionally, by performing experiments, making observations, and

testing hypotheses, science constantly uncovers new facts and is fruitful in a way that pseudoscience and creationism are not.

In science, a theory is a comprehensive body of knowledge, hypotheses, and deductions that explain a broad range of facts. It is often mistaken to be a mere notion, an untested idea, as when someone says, "I have a theory about why they lost the game." In general, a mature theory is so complex and has so many interwoven strands of evidence that we cannot ask whether a theory is correct or incorrect. Rather, we may ask whether a given hypothesis can be tested. Sometimes, a hypothesis is rejected, but that does not mean that the overall theory is wrong, only that some aspect needs further investigation. Most important, we do not reject a well-supported theory just because we have found some flaws. And—creationists must understand this point—we do not accept a rival theory by default but rather subject it to scrutiny by proposing specific hypotheses, deducing consequences, and testing those hypotheses. To date, no competitor to the theory of evolution has been subjected to such scrutiny.

It is very hard to define what is science and what is not; the boundary between science and nonscience is often fuzzy. It is perhaps easier to distinguish between science and pseudoscience, as we do in chapter 5, "How Pseudoscience Works." We note specific properties that make an endeavor pseudoscience: untestable or far-fetched hypotheses; denial of known fact; intention to show that something is true, rather than find out whether it is true; and sometimes the belief that the establishment is conspiring against the pseudoscientist. In chapter 5, we expand on these themes with reference to two specific pseudosciences: homeopathic medicine and astrology. As we will see, pseudoscientists "know" in advance the answer they are trying to get and will not be swayed by facts or logic.

In chapter 6, "Why Creationism Fails," we look at classical scientific creationism, that is, the predecessor to intelligent-design creationism. Young-earth creationists believe that the universe is approximately 10,000–20,000 years old (though some still stick to the biblical age of 6,000 years) and that Noah's flood was real and worldwide. They account for the stratification we find in the fossil record by citing unspecified hydrodynamic forces and also by appealing to an unsupported theory that more-advanced animals survived the flood longer than less-advanced animals and so were deposited on top. They provide no evidence, however, that their theory makes better predictions than standard geology. Old-earth creationists accept the antiquity of the earth and the universe but try to force the chronology of the Book of Genesis to match the geological and paleontological records. They claim, for example, that human beings predated Adam and Eve, but Adam and Eve were the first humans to have a soul. Their claim is untestable because the fossil record does not distinguish between people with souls and people without.

Chapter 7, "The Argument from Design," surveys a venerable but now discredited philosophical argument that goes back at least to the Roman philosopher Cicero. The modern form of the argument from design may be traced to William Paley, the naturalist and theologian who developed the famous watchmaker analogy. Paley's argument was, in essence, that we can recognize design in an artificial mechanism such as a watch; how then can we not recognize design in the intricate workings of nature? Paley's argument was accepted as sound until Darwin and Alfred Russel Wallace developed the theory of descent with modification, which showed how the appearance of design could accumulate over eons of trial and error. Indeed, Darwin himself accepted Paley's argument until he and Wallace discovered a better explanation.

Creationism is now packaged as *intelligent design*, but it is the same old creationism dressed up in a cleaned and pressed nineteenth-century lab coat. Chapter 8, "Why Intelligent-Design Creationism Fails," outlines the modern arguments. The mathematician William Dembski considers that a very complex entity such as a chlorophyll molecule could not have arisen by chance but must have been designed. To distinguish between design and chance, he proposes an *explanatory filter*, but does not give enough detail to make the filter useful. In addition, the filter suffers from *false positives*; that is, it can sometimes detect design incorrectly. We discuss the explanatory filter in detail in chapter 8.

Like Paley, modern creationists rely on analogies between human artifacts and, for example, biological systems. The molecular biologist Michael Behe likens the bacterial flagellum to an outboard motor. He argues that since it has three interacting parts, every one of which is crucial to its operation, and since no two of the parts could function without the third, the flagellum could not be the product of evolution but rather must have been designed. It is simply too unlikely, says Behe, that all three would have assembled at one time. Biologists recognize, however, that evolution sometimes gradually adapts for one function parts that were originally used for another; we have a fair idea how the bacterial flagellum could have evolved from a flagellum that was originally used for parasitism or secretion rather than swimming. Indeed, an earlier biologist, the Nobelist Hermann Muller, in 1918 explicitly predicted the evolution of complex, interlocking systems in which parts that were once merely important evolved to become crucial. That is, Muller used evolutionary theory to predict a phenomenon that Behe eighty years later claimed could not evolve by natural selection.

Chapter 9, "The Father of Evolution," begins Part II, "The Science of Evolution," with a brief romp through the personal evolution of Charles Darwin from a promising clergyman to a paradigm-shifting force in the natural sciences. We continue in chapter 10, "How Evolution Works," with an explanation of some of the ways evolution works. First, we note that some organisms are more *fit* than others; that is, they are better able to survive and

reproduce. The fitness of an animal can depend on many factors, such as weight and size, and there may be an optimum weight and size for any given species. If, however, the environment changes, the optimum weight and size may change too. The animals immediately become less fit than they were before, but their weight, size, and other characteristics may change gradually, over many generations. If the species changes enough, it may come to be regarded as a new species. Indeed, in chapter 10, we outline field observations suggesting that a certain kind of fly has evolved into a new species owing to the introduction of the apple into North America.

Chapter 11, "Recapitulation," explains how eighteenth-century embryologist Ernst Haeckel's enthusiasm for Darwin's theory resulted in some misleading drawings and decades of textbooks with the faulty idea that "ontogeny recapitulates phylogeny." Haeckel's idea of recapitulation does, however, explain some benchmarks that are essential for proper continued development of vertebrate embryos.

Next we turn to a new field of biology called evolutionary developmental biology (*Evo Devo* to its practitioners). In this exciting field, scientists investigate how genes control development and how tweaking the genes and their protein products has resulted in impressive and surprising changes in the final form and function of organisms. In chapter 12, "Evo Devo: How Evolution Constantly Remodels," we introduce the fruit fly, one of the model organisms scientists have relied on for understanding everything from the evolution of embryonic development to the human disease of cancer. We also explain how evolutionary pathways are predictable when different populations experience the same environmental pressures. We present a twist to the idea of the "survival of the fittest," and instead offer the new idea, the "arrival of the fittest." We end the chapter with a detailed explanation of how complex systems evolve, and provide evidence against the failed idea of irreducible complexity.

Chapter 13, "Phylogenetics," takes the reader through the history of the ever-changing branching models of life. Here we explain why these tree-like models are best guesses, or hypotheses, that incorporate the latest available data. Through several illustrations and explanations we show how, with new data and new ways of looking at the relationships among species, we get closer and closer to how groups of past and present animals are related. We then examine the process of building a phylogenetic tree from scratch using data from a population of lizards on the Canary Islands.

Chapter 14, the last chapter in the "Science of Evolution" unit, is titled, "Design by Committee: The Twists, Turns, and Flips of Human Anatomy." Here we investigate several aspects of being human that present our species with unique challenges. We explain that the evolutionary pathways humans have taken have resulted in some innovations that are far from perfect: evolutionary engineering is costly and also cumbersome.

Following our discussion of evolutionary biology, we begin Part IV, "The Universe." The ancient Greeks realized that fossils were the remains of plants and animals that had lived long ago; the European idea of a young earth is simply a result of a too-literal interpretation of the Bible. By the time Darwin wrote *On the Origin of Species*, geologists had begun to amass considerable evidence favoring an ancient earth. Some physicists, however, thought that the earth was much younger. As we show in chapter 15, "How We Know the Age of the Earth," the discovery of radioactivity in 1896 invalidated the physicists' arguments and also provided a stable clock with which to measure the time since the earth formed. Early attempts at *radiometric dating* were imprecise, in part because no one knew the concentration of radioactive material in a mineral when it formed. By the second half of the twentieth century, however, geophysicists had developed methods to account for that unknown and have measured the age of the earth very precisely. We can say almost without doubt that the earth's crust solidified at least 4.4 billion years ago. Similarly, cosmologists have observed the expansion of the universe and discovered the *cosmic background radiation*, which we may think of as the afterglow of the *big bang*. Using detailed theories to explain the observed properties of the background radiation, cosmologists have deduced that the universe as a whole is approximately 13.7 billion years old, with an uncertainty of approximately 1.5 percent.

As far as we can tell, the universe is not especially hospitable to life, or at least not to life as we know it. Even the solar system as a whole does not seem hospitable; the earth is most probably the only astronomical body in the solar system where complex, multicellular life has developed. We know next to nothing about the rest of the universe, except for the relatively recent discovery that a significant fraction of stars may have planetary systems. It thus seems likely that the conditions necessary for the development of intelligent life have arisen on earth purely by chance: if it had not been earth, then it might have been somewhere else.

Nevertheless, some physicists and astronomers persist in arguing that the universe was designed for life, and they point to the supposed *fine-tuning* of the fundamental physical constants as evidence. Specifically, as we discuss in chapter 16, "Is the Universe Fine-tuned for Life?," they claim that if any one of a dozen or two *fundamental constants*, such as the charge on the electron and the mass of the proton, were changed, then the universe would not be able to support complex life. The fine-tuning argument presumes life like ours, but there is no justification for such a presumption. In addition, it has been tested by a mathematical simulation, which suggests that the fundamental constants are not as finely tuned as is claimed.

The *anthropic principle* builds on the fine-tuning argument and argues that the universe was designed for us, and that we know that because we are here.

We find that argument circular and think that it is also based on a poor understanding of probability. A more recent argument infers design from the claim that life is rare but that the earth is located in a privileged position within both the galaxy and the solar system. We find this argument not only circular but also untestable because its authors will also infer a designer if life is found to be plentiful.

Part V concerns "Evolution, Ethics, and Religion." Francis Collins, the head of the Human Genome Project, is not alone in thinking that morality is uniquely human and requires a supernatural explanation. We show in chapter 17, "Evolution and Ethics," however, that cooperation has evolved at all levels in the animal kingdom and can lead to *reciprocal altruism* of the "you scratch my back, I'll scratch yours" variety. Human morality may have evolved from mere reciprocal altruism to true, selfless altruism as the result of both biological and cultural factors. The fact that ethics or morality is an evolved trait, however, by no means implies that evolutionary biology is incompatible with religion.

In chapter 18, we show "Why Science and Religion Are Compatible." Specifically, we argue that science does not exclude religion, though it surely calls certain specific religious beliefs into question. Religious beliefs that do not deny known scientific fact, by contrast, are not incompatible with science, and many scientists are themselves religious. We analyze the example of two brothers-in-law, one a palaeontologist and one a minister, each of whom began his career as a biblical literalist. Each modified his beliefs—the palaeontologist re-evaluated the evidence for evolution, while the minister carefully re-examined the internal inconsistency of the biblical accounts. We conclude the chapter by refuting the well-known contention of the palaeontologist Stephen Jay Gould that science and religion have authority over separate domains of knowledge, or *magisteria*. We argue that Gould may be right in principle, but wrong in practice, and that there must invariably be some tension between science and religion.

We conclude with the observation that evolutionary biology explains the observed facts better than any competing theory; indeed there is no competing theory. Creationism is not just a trivial pseudoscience but attacks the very foundation of modern science. It has no program but rather postulates that it can overthrow evolutionary biology, cosmology, and geology merely by pointing to anomalies or observations that so far remain unexplained. It is like the knight who attacks the tail of the dragon because he does not have the skill to attack the fire-breathing end.

Thought Questions

1. Who should read this book? Why?
2. Do you find this book threatening? Why? Do you think anyone else will? Why?

Chapter 3

History of Creationism and Evolutionary Science in the United States

> In all modern history, interference with science in the supposed interest of religion, no matter how conscientious such interference may have been, has resulted in the direst evils both to religion and science, and invariably; and, on the other hand, all untrammeled scientific investigation, no matter how dangerous to religion some of its stages may have seemed . . ., has invariably resulted in the highest good both of religion and science.
>
> —Andrew Dickson White, cofounder of Cornell University

In the beginning, nearly everyone was a creationist, in a manner of speaking. Much about the universe and the earth has the appearance of design, and the only designers we know (humans) are purposeful and intelligent. Lacking any other theory, we find it easy to ascribe the design we see in nature to a deity or, in the case of the Greeks, Romans, and others, deities. To Christian Europeans and Jews, the creator was God; Christian Europe accepted the Hebrew Bible as an accurate account of the creation of the earth. When the Scottish archbishop James Ussher in 1654 examined the chronologies of the Bible beginning with the creation, he was doing cutting-edge scholarship that required a knowledge of ancient history, languages, and cultures, as well as a deep understanding of the text itself. Using the Hebrew Bible as his guide, Ussher concluded that God had created the universe in 4004 B.C.E.

By 1800, however, geological evidence had demonstrated that the earth was far older than a few thousand years (see chapter 15), and the fossil record showed that modern floras and faunas had descended from earlier floras and faunas. Evolution was in the air, so to speak. Charles Darwin's grandfather, Erasmus Darwin, speculated that all warm-blooded animal life had descended from a single ancestor, but he suggested no real mechanism for modification

of this ancestral species into the myriad species known in his day. The French naturalist Jean-Baptiste Lamarck in 1802 developed what could be called the first comprehensive theory of evolution.

Lamarck noted that animals are fitted to their environment and thought that a *life force* drove organisms to greater complexity, precisely because of the pressures put on them by the environment. In Lamarck's view, animals developed their characteristics by an act of will and, because of a presumed adaptive force, passed their newly developed characteristics to their descendants. Thus, for example, a blacksmith's descendants will become stronger than he because he acquires powerful muscles from the activity of metalworking and passes them to his descendants. But we cannot breed mice without tails by simply cutting off their tails generation after generation, because, according to Lamarck, there is no adaptive force cutting off the tails. Lamarck's theory, which is now discredited, is often called the *inheritance of acquired characteristics*. It was influential among scientists and natural philosophers of Lamarck's time. Unfortunately, however, the theory could provide no real explanation *why* characteristics might be inherited.

The English naturalist Charles Darwin provided that mechanism after his fateful voyage around the world as the naturalist on the H.M.S. *Beagle* (see chapter 9). Darwin recognized that individual organisms of the same species differ slightly and that the differences were at least partly heritable. He realized that a series of small changes could accumulate over a long time to produce profound changes. Although Darwin did not know how these small changes were transferred from one generation to the next, he saw clearly how beneficial changes could be amplified by competition and selection, rather than by an adaptive force. Another English naturalist and explorer, Alfred Russel Wallace, working primarily in the Amazon and in Indonesia, came to approximately the same conclusion at approximately the same time. Indeed, Wallace's findings inspired Darwin to publish his own theory jointly with Wallace in 1858 and to publish *On the Origin of Species* in 1859.

The Great Awakenings

Even before Darwin and Wallace's theory of evolution, the discovery of exotic lands and exotic species presented problems for literalist belief in the Bible. How, for example, did animals and plants get from Mount Ararat (after the *Noachian* flood described in the Bible) to the Americas, Australia, and New Zealand? Why do Eurasian and African species differ from their apparently close relatives in the Americas? Why are Australian species strikingly different from species in the rest of the world? Adherents sometimes had to go to great lengths to harmonize their belief in the Bible with new discoveries.

Higher criticism is the term generally used for careful, dispassionate efforts to deduce the origin, age, or veracity of various sections of the Bible.

Augustine of Hippo, a Christian church father and philosopher of the fourth to fifth centuries; Desiderius Erasmus, a Dutch philosopher and Catholic theologian of the fifteenth to sixteenth centuries; and Baruch Spinoza, a Dutch-Jewish philosopher and theologian of the seventeenth century all engaged in something like higher criticism, but it originated primarily in the eighteenth century during the *Enlightenment*, a philosophical movement that stressed reason. Higher criticism means, for example, carefully studying alternate versions of the text and alternate narratives within the text, using contemporaneous languages to deduce meanings of obscure passages, and comparing certain narratives of the Bible with narratives from other documents, whether mythical or historical. One intention of higher criticism is to ascertain which parts of the Bible are likely to be historically accurate and which are not. Higher criticism culminated in the twentieth century with the discoveries that the Gospels of the New Testament were not written contemporaneously with the life of Jesus and that the Hebrew Bible consists of several discrete, interwoven threads that tell inconsistent stories.

The Enlightenment was a philosophical and intellectual movement that began in the late 1600s in England, France, and Germany, and stressed the primacy of reason over traditional religious and social ideas. The American Founding Fathers were heavily influenced by the Enlightenment. Interest in religion declined as a result of the Enlightenment and its emphasis on secular learning, and church services in Europe and North America became more intellectual and sterile. The Great Awakening, a religious revival that came to be known as *evangelical*, was in part a reaction against the intellectualism of the Enlightenment and took place in the 1730s and 1740s. During the Great Awakening, sermons and church services became dramatic or emotional rather than intellectual. Preachers stressed sin, punishment, redemption, and the omnipotence of God. The New England preacher Jonathan Edwards argued that faith alone was sufficient for an encounter with God, that reason was neither necessary nor possible. But Edwards and his contemporaries recognized the need not only to confirm their beliefs with reference to scripture, but also to interpret scripture correctly. Although they were *biblical inerrantists*, who believed the Bible to be free of errors and therefore creationists in a sense, they were not *biblical literalists*, and their beliefs were markedly different from those of modern creationists. Even though the Great Awakening stressed religious experience over secular learning, the intellectual ferment of the time spawned several institutions of higher education, including Princeton, Brown, and Rutgers Universities.

In the United States, the Second Great Awakening took place between the early 1800s and the 1840s, and had a progressive philosophy that favored improving society through temperance (abstinence from drinking alcoholic beverages), women's suffrage, and the abolition of slavery. It was thus

consistent with nascent evolutionary theories, such as Lamarck's, which saw evolution as a series of progressive improvements. Although most Northern states had abolished slavery by the 1820s, the (mostly Northern) abolitionist movement to abolish slavery in the South gained strength during the Second Great Awakening. Indeed, both the Methodist and Baptist Churches split into Northern and Southern branches in 1845 because of disagreement over slavery. Some evangelical preachers deliberately linked evolution and abolition. Some of the Southern churches may have begun their drift into biblical literalism when they invoked the Bible to justify slavery (see especially Genesis 9:24–27, where Noah curses Canaan, son of Ham).

The initial reception of Darwin's theory in the United States was mixed. When *On the Origin of Species* was published in 1859, it became the subject of debate among leading American scientists, including Louis Agassiz of Harvard, who was arguably the most prominent biologist in the United States. Agassiz accepted that species went extinct but did not accept descent with modification; rather, he insisted that God had created from scratch each new species that appeared in the fossil record. The botanist Asa Gray of Harvard University collaborated with Darwin and was immediately convinced of Darwin's core arguments when he read an early draft of *On the Origin of Species*. Unlike Agassiz, Gray accepted descent with modification, but thought that natural selection was not the only mechanism involved in speciation. Rather, he thought that God must guide the process. Agassiz and Gray thus anticipated some of the arguments of old-Earth creationism and theistic evolution.

Following the American Civil War, many evangelical Christians came to terms with the theory of evolution. They did not give up their biblical inerrantism, but rather interpreted scripture in such a way as to make it consistent with modern science. Thus, they developed the *day-age theory*, in which the "day" of the early chapters of Genesis is taken to mean an age of undefined duration, or various *gap theories* to account for apparent discrepancies between the Bible and evidence from geology and palaeontology (see chapter 6). By the 1880s, however, higher criticism had cast doubt on the inerrancy of the Bible. In particular, the German biblical scholar Julius Wellhausen formulated the *documentary hypothesis*, which argued that the Hebrew Bible was not a single document but rather an edited, or *redacted*, compilation of several documents, all interwoven as wires are woven into a cable.

The Third Great Awakening was in part a response to higher criticism. It began, more or less, in 1886, when the prominent evangelical preacher Dwight L. Moody founded the Moody Bible College. Moody favored biblical literalism and linked evolution with atheism. The Third Great Awakening culminated in the publication of a series of pamphlets called "The Fundamentals" between 1910 and 1915. "The Fundamentals" taught, for example, the inerrancy of scripture, the divinity of Jesus, and the reality of miracles. "The

Fundamentals" themselves were not consistently anti-evolutionary, but some of the essayists opposed natural selection because of its relation to a liberal, naturalistic interpretation of Christianity.

In 1923, George McCready Price, a Seventh-Day Adventist and self-taught geologist, published a book on *flood geology*, in which Price purported to show that geologists' dating of fossils (see chapters 6 and 15) is false and based on circular reasoning. Price's book marks the beginning of modern scientific creationism, but, as a Seventh-Day Adventist, Price was outside the evangelical mainstream and therefore had little influence. His work was updated in 1961 by hydrologist Henry M. Morris and theologian John C. Whitcomb Jr. in their book *The Genesis Flood*, which argued that the earth was only several thousand years old and that the entire fossil record was deposited within a short time by the Noachian flood (see chapter 6). Morris later founded the Institute for Creation Research and became a key spokesman for scientific creationism.

The Scopes Trial and Its Aftermath

By the 1920s, evolution was to some extent in retreat, at least in the public eye. Many if not most biologists accepted evolution in the sense of descent with modification, but they doubted that natural selection was the most-important mechanism. Intellectuals and religious leaders opposed to eugenics, social Darwinism, and laissez-faire capitalism, not to mention atheism and immorality, blamed the theory of evolution for spreading these ideas. At the same time, partly because of child labor laws, more and more children spent their days in school instead of in the fields and the mills. Public secondary education was booming, and high school students were exposed to biology and evolution. Under pressure from fundamentalists, twenty-three state legislatures considered legislation restricting the teaching of evolution in the public schools. Three states, including Tennessee, actually enacted such legislation.

The fledgling American Civil Liberties Union (ACLU), concerned about restrictions on civil liberties during World War I, actively sought a biology teacher to contest the Tennessee law, the Butler Act, initially on the grounds that it violated teachers' freedom of speech. Hoping to drum up a little business, a Dayton businessman, George Washington Rappleyea, soon arranged for a biology teacher, John T. Scopes, to be prosecuted for violating the Butler Act. In defense of Scopes, the ACLU brought in a legal team including the well-known defense lawyer and agnostic Clarence Darrow. The prosecution imported the progressive-populist politician William Jennings Bryan.

Although the ACLU was initially concerned with free speech, both Darrow and the prosecution intended to show that there was no conflict between the biblical account and evolution. The judge, however, limited the

trial to the question of whether Scopes had broken the law. Since Scopes had freely admitted to violating the Butler Act, his conviction was a foregone conclusion. Scopes was fined $100, not an inconsequential sum in 1925. The ACLU appealed the decision with the intention of carrying the case to the Supreme Court of the United States. The Tennessee Supreme Court upheld the constitutionality of the Butler Act but overturned the conviction on the technicality that the judge had imposed the fine, whereas Tennessee law stipulated that the jury must set the penalty. The case was never brought before a federal court.

The Scopes trial lasted for eight days and riveted the country's attention. It was not, however, a victory for evolution. A few states enacted anti-evolution bills after 1925, but, more important, evolution was largely removed from the biology curriculum, as publishers of high-school textbooks shied away from controversy. To some extent, evangelicals were marginalized and stereotyped as backward religious zealots. The opposition to evolution gradually shifted from the urban North to the South, where local school boards adopted anti-evolution policies. The Butler Act was not repealed until 1967.

The Evolution of Creation Science

Price's flood geology was the only scientific option for creationists when, in 1941, a group of evangelical scientists accepted an invitation from the Moody Bible Institute and founded the American Scientific Affiliation (ASA). Members of the ASA must have at least a bachelor's degree in science or engineering, or the history or philosophy of science. They must subscribe to certain Christian dogmas such as a belief in the Trinity and the "trustworthiness and authority" of the Bible, but also must agree that nature is intelligible and can be described scientifically. In its early years, the ASA favored creationism, but by the late 1950s began to drift toward theistic evolution. Today, many members of the ASA are theistic evolutionists, but the organization itself takes no position on evolution or any other scientific issue. Since 1949 the ASA has published a journal now known as *Perspectives on Science and Christian Faith*.

Evolution remained largely outside the high-school biology curriculum until the 1960s. In 1957, a previously complacent United States watched as the Soviet Union launched the first artificial satellite, *Sputnik*. Besides being a major blow to U.S. national pride, *Sputnik* caused concern that the United States was falling behind in science. The federal government therefore decided to overhaul the nation's science curriculum and improve the quality of high-school science textbooks. Thus, the National Science Foundation (NSF) assembled teams of scientists and teachers to write new textbooks. The Biological Sciences Curriculum Study (BSCS), in particular, found that evolution was largely absent from high-school textbooks. The first BSCS textbook appeared in 1963 and included evolution at its core.

The historian Ronald Numbers notes that most American fundamentalists at the time subscribed to gap theory or day-age theory, which implicitly made certain concessions to scientific thinking (see chapter 6). Most Christians accepted the conventional view of geologic time, and only a relatively few Seventh-Day Adventists adhered to Price's theory of flood geology. In 1961, however, Whitcomb and Morris published *The Genesis Flood*, which modernized Price's flood geology and argued that science should be subservient to scripture. Their argument found a willing ear among conservative fundamentalists; gap theory and day-age theory all but went extinct as flood geology descended, with modification, into scientific creationism and later begat creationist geology, biology, cosmology, and astrophysics. If they could not remove evolution from the science classroom, fundamentalists hoped to use scientific creationism as a wedge to include their religious views alongside evolution (see "Creation Science and the Courts," in this chapter).

In 1963, Morris and other creationists left the ASA and founded the Creation Research Society (CRS). Of the ten founders, six had Ph.D.s in biology or biochemistry, though none had credentials in geology. Although the CRS claims to be a scientific society, it requires its members to subscribe to the following beliefs: (1) The Bible is the word of God, "all its assertions are historically and scientifically true," and the account in Genesis "is a factual presentation of simple historical truths." (2) The basic *types* or *kinds* were created by God during creation week, and biological changes occur only within kinds. (Kind has never been defined properly; sometimes it appears to mean genus and sometimes family.) (3) The Noachian flood was a historical and worldwide event. A great many Americans have come to accept as true some or all of these views.

In the 1970s, Morris edited a textbook, *Scientific Creationism*, and the Creation Research Society published *Biology: A Search for Order in Complexity* in an effort to insert their views into the public school classroom. In 1972, Morris and others founded the Institute for Creation Research (ICR), which proselytizes vigorously in favor of creation science, operates a museum and a publishing house, mails newsletters, and runs workshops. In addition, ICR operates a graduate school that offers degrees in astro-geophysics, biology, geology, and general science. The graduate school has not been accredited by the Western Association of Colleges and Schools, which accredits most other colleges and universities in California, but rather by an accrediting agency for Christian schools, which was founded by Morris himself.

Young-earth creationism is mostly a U.S. phenomenon, but in 1978 an Australian evangelical, Ken Ham, founded the Australian Creation Science Foundation. Ham came to work for the ICR in the United States in 1987 and eventually spun off Answers in Genesis (AIG), which he cofounded with Carl Wieland, a young-earth creationist. AIG founded branches in Australia,

Canada, New Zealand, South Africa, and the United Kingdom, but owing to a schism in 2005 Wieland now heads the non-U.S. branches, which have been renamed Creation Ministries International, while Ham still operates AIG in the United States. In 1986, the Canadian astrophysicist Hugh Ross founded Reasons to Believe, an old-earth creationist organization, but it has never had as much influence as the young-earth creationists.

Creation Science and the Courts

The religion clause of the First Amendment to the U.S. Constitution reads, "Congress shall make no law respecting an establishment of religion [the establishment clause], or prohibiting the free exercise thereof [the free-exercise clause]." The Fourteenth Amendment extends the protections of the Bill of Rights, which includes the First Amendment, to state governments. Thus, like the federal government, the state may not promote religion, nor may it prohibit the exercise of religion. The legal history of the creationism-evolution controversy in the United States has been shaped by establishment-clause jurisprudence.

In 1963, in a case that did not directly concern creation or evolution, the United States Supreme Court struck down a Pennsylvania law that required daily Bible readings in public schools. In *Abington School District v. Schempp*, the court ruled that a law must exhibit "a secular legislative purpose" and may neither advance nor inhibit religion; it found that the Pennsylvania law did not meet these criteria. Creationists responded with the argument that teaching evolution inhibited religion and fought for *balanced treatment*, that is, teaching creation science whenever evolution is taught in a public school.

In 1965, an Arkansas teacher, Susan Epperson, challenged her state's anti-evolution law on the grounds of free speech. She was joined in her suit by a parent who argued that his child had a constitutional right to study evolution. The case made its way to the United States Supreme Court, which ruled in *Epperson v. Arkansas* that the Arkansas law was unconstitutional because it proscribed teaching evolution on purely religious grounds.

In 1971, the Supreme Court struck down laws that permitted states to reimburse parochial schools for items such as textbooks, supplies, and teachers' salaries. In *Lemon v. Kurtzman*, the court enunciated what has become known as the *three prongs* of the *Lemon test*: If a law concerning religion or a religious institution is to pass constitutional muster, then (1) it must have a secular purpose, (2) it must not primarily advance or inhibit religion, and (3) it must not lead to "excessive government entanglement" with religion. All three prongs of the *Lemon* test must be satisfied if a law is to be constitutional under the establishment clause.

The *Lemon* test figured into the decision of Judge William Overton in *McLean v. Arkansas*. Arkansas passed a balanced-treatment law in 1981. The

Arkansas chapter of the ACLU promptly challenged the law and was joined by a panoply of both religious and scientific organizations. In *McLean*, the plaintiffs argued that the purpose of the law was not scientific but religious, because creation science was inherently religious. They put together a cast of expert witnesses that included a theologian, a palaeontologist, a geneticist, and a philosopher of science. The defense opted not to put Henry Morris of the Creation Research Society on the stand because his obviously religious point of view would have undermined their case. In early 1982, Judge Overton ruled that the Arkansas law violated all three prongs of the *Lemon* test. Specifically, he ruled that the legislators intended to promote a religious viewpoint; that the law's primary effect was to promote a religious view, because creation science is religion and not science; and finally that the law would initiate an excessive government entanglement with religion.

Michael Ruse, a philosopher of science, testified on behalf of the prosecution. Relying on Ruse's testimony, Overton additionally ruled that the "essential characteristics" that make a subject scientific are these: "(1) It is guided by natural law; (2) It has to be explanatory by reference to natural law; (3) It is testable against the empirical world; (4) Its conclusions are tentative, i.e.[,] are not necessarily the final word; and (5) It is falsifiable." He found that scientific creationism fails on all counts. His ruling was not appealed.

In 1982, Louisiana passed its own balanced-treatment act, which was similar to the Arkansas statute, but its framers hoped they had sanitized it of any taint of religion. The ACLU challenged the law, and the Federal District Court ruled the law unconstitutional because it advanced a religious view, inasmuch as it required creation science to be taught in the public schools if evolution was taught there. Ultimately, in 1987, in *Edwards v. Aguillard*, the United States Supreme Court struck down the Louisiana act as unconstitutional, writing, "The preeminent purpose of the Louisiana Legislature was clearly to advance the religious viewpoint that a supernatural being created humankind."

Edwards v. Aguillard thus killed the balanced-treatment approach once and for all. Creationists had to try a different tactic to get around the Constitution, and they found comfort in one line in the majority opinion, which said that "teaching a variety of scientific theories about the origins of humankind to schoolchildren might be validly done with the clear secular intent of enhancing the effectiveness of science instruction." They found further comfort when Justice Antonin Scalia wrote in dissent, "The people of Louisiana, including those who are Christian fundamentalists, are quite entitled, as a secular matter, to have whatever scientific evidence there may be against evolution presented in their schools, just as Mr. Scopes was entitled to present whatever scientific evidence there was for it." These two sentences foreshadowed two new stratagems: relabeling creationism as "intelligent design" and campaigning for

"critical thinking." The *Edwards* decision was followed by a handful of other court decisions to the effect that a school district may require a teacher to teach biology and prohibit a teacher from teaching creationism.

In 1994, the Tangipahoa, Louisiana, Parish Board of Education adopted a policy that "the [biology] lesson to be presented, regarding the origin of life and matter, is known as the Scientific Theory of Evolution and should be presented to inform students of the scientific concept and not intended to influence or dissuade the Biblical version of Creation or any other concept." The board further recognized "that it is the basic right and privilege of each student to form his/her own opinion or maintain beliefs taught by parents on this very important matter of the origin of life and matter. Students are urged to exercise critical thinking and gather all information possible and closely examine each alternative toward forming an opinion." In 1997, in *Freiler v. Tangipahoa Parish Board of Education*, the Federal District Court, in addressing this statement, ruled that the Board of Education was endorsing religion by implicitly conveying the message that evolution is a religion that may contradict the religious beliefs of the students. The decision was upheld in 1999 by the Court of Appeals, and the Supreme Court declined to review the case.

In 2002, the Cobb County, Georgia, school district mandated that biology textbooks be supplemented with a sticker that read, "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." In Federal District Court, Judge Clarence Cooper found in *Selman v. Cobb County School District* that the sticker violated the second prong of the *Lemon* test: its primary effect was to advance religion. Owing to concern about the evidence submitted during the trial, the Court of Appeals vacated the decision and sent it back to the District Court. The case was eventually settled when the school district agreed not to replace the stickers (which had been removed after the trial court's decision), not to take any further action to deprecate evolution, and to pay over $160,000 toward the plaintiffs' attorneys' fees.

Intelligent-Design Creationism

In 1989, the little-known Foundation for Thought and Ethics published a supplementary biology textbook, *Of Pandas and People*. The book uses mostly standard young-earth creationist arguments, stripped of their overtly religious language, to try to refute the theory of evolution. *Of Pandas and People* was the first systematic presentation of intelligent-design creationism and was in preparation when the Supreme Court handed down the *Edwards* decision. The book later morphed into the slick volume *The Design of Life* (2007).

Intelligent-design creationism began in earnest with the publication of *Darwin on Trial*, by Phillip Johnson, in 1991. Johnson, then a law professor at

the University of California at Berkeley, repeated many of the arguments of young-earth creationism but stressed that science uses only naturalistic explanations and arbitrarily—indeed, dogmatically—rules out the supernatural (see chapter 4). Johnson thus clearly states his intention to defeat naturalism. In 1996, he helped found the Center for Science and Culture (initially the Center for the Renewal of Science and Culture) at the Discovery Institute, a well-funded right-wing think tank. In 1998, the Discovery Institute drafted the Wedge Document, which, though labeled top secret, was shortly leaked on the Internet and later authenticated by Barbara Forrest, a philosophy professor at Southeastern Louisiana University. The Wedge Document describes a campaign to destroy scientific materialism and its supposed destructiveness to morality and culture, and to replace it with a theistic understanding of nature. The thin edge of the Wedge was Johnson's *Darwin on Trial*; Johnson's next book, *The Wedge of Truth: Splitting the Foundations of Naturalism*, appeared in 2000.

The Wedge strategy included a five-year plan to publish thirty books and one hundred technical papers, as well as to "pursue possible legal assistance" to force intelligent-design creationism into the public schools. After more than a decade, various fellows of the Discovery Institute have published a number of books, all of which were dismissed by reputable scientists, but they have initiated no original scientific research that supports the concept of intelligent design. Although its religious orientation is explicit, the long-term plan outlined in the Wedge Document also displays the Discovery Institute's political agenda very clearly. In ten years, the Wedge strategy was to be extended to ethics, politics, theology, the humanities, and the arts. The ultimate goal of the Discovery Institute is to "overthrow" materialism and "renew" American culture to reflect right-wing Christian values.

Attacks on Evolution

In 1996, Michael Behe, a biology professor at Lehigh University, published the book *Darwin's Black Box*. Behe argued that certain biochemical structures, such as the bacterial flagellum and the human blood-clotting system, were *irreducibly complex* and could not have evolved by natural selection (see chapter 8). His arguments have been refuted many times, and he has never satisfactorily responded to his critics. William Dembski, who has Ph.D.s in both mathematics and philosophy, developed a mathematical formalism that both subsumed Behe's argument and purported to put it on a sound mathematical basis. Using a smokescreen of complex terminology, Dembski advanced an oversimplified probabilistic argument and concluded, in effect, that an organism could not have been assembled in one fell swoop. Later, Dembski misused the no-free-lunch theorems (see chapter 8) in an effort to show that evolution was impossible.

In 2002, Jonathan Wells, a fellow at the Discovery Institute, published *Icons of Evolution: Science or Myth? Why Much of What We Teach about Evolution Is Wrong*. Wells entered graduate school and earned a Ph.D. in religious studies from Yale University with the specific intention to "destroy Darwinism"; he later earned a second Ph.D. in molecular and cellular biology. His studies at Yale were funded by the Unification Church. In *Icons*, Wells identifies ten case studies that he claims are commonly used as exemplars in high-school biology textbooks to illustrate the theory of evolution, labels them icons, and purports to show that they are used not as illustrations but as evidence.

Eugenie Scott of the National Center for Science Education has examined the textbooks that Wells cites and found that most of them either do not include Wells's exemplars or do not use them in the manner that Wells describes. Wells's book has nevertheless been used to pressure school boards to drop certain biology textbooks; anecdotal evidence suggests that excellent exemplars of evolution, such as the peppered moth (see chapter 1), are being removed from textbooks because of disinformation promulgated by creationists like Wells.

Teach the Controversy

With the publication of the books by Johnson, Behe, Dembski, and Wells, the Discovery Institute thus manufactured a controversy and demanded that it be taught under the rubric of critical thinking: If evolution is taught, then intelligent-design creationism must also be taught.

In 1999, the Kansas Board of Education removed all references to evolution from that state's science standards. Science organizations warned of a serious loss in the quality of science education. Two years later, a new Board of Education reinstated evolution. The Board changed hands again and in 2005 adopted new standards that portrayed evolution as a theory in crisis. The new standards mirrored the Discovery Institute's Critical Analysis of Evolution strategy. In response, both the National Academy of Sciences and the National Science Teachers Association withdrew permission to use their copyrighted materials in the standards. Earlier in the year, the Board had held a series of hearings that was attended by most of the prominent figures in intelligent-design creationism but was boycotted by mainstream scientists. In November 2005, the Kansas Board of Education changed the science standards to state that evolution is a theory, not a fact; to consider supernatural explanations as part of science; and to require students to be informed of the purported controversy. In 2006, the composition of the Board changed again, and in 2007, the original 2005 standards were reinstated.

In 2002, meanwhile, the Ohio State Board of Education hosted a nonbinding discussion of evolution involving Jonathan Wells and Stephen Meyer of the Discovery Institute for the creationist side and biologist Kenneth Miller

of Brown University and physicist Lawrence Krauss of Case Western Reserve University on the side of science. The board adopted a set of science standards that included a clause concerning critical analysis of evolution; an apparently innocuous clause, it singled out evolution among all the sciences and provided a handhold for anti-evolutionism. In 2004, the board approved grade-10 lesson plans that were based on the Discovery Institute's Critical Analysis of Evolution and purported to provide an opportunity for critical analysis of Darwin's theory. The board eventually dropped the lesson plans and the standard, partly in response to a contemporaneous school board case, to which we now turn.

In Dover, Pennsylvania, several members of the school board expressed concern about the teaching of evolution. The school board voted to amend its policy by adding the following language: "Students will be made aware of the gaps/problems in Darwin's theory and of other theories of evolution including, but not limited to, intelligent design. Note: Origins of life is [sic] not taught." The Thomas More Law Center, a right-wing Christian organization, offered to represent the board if its policy was challenged. To implement that policy, the board required teachers to read to their biology classes a statement, "Because Darwin's Theory [*sic*] is a theory, it is still being tested as new evidence is discovered. The Theory [*sic*] is not a fact. Gaps in the Theory [*sic*] exist for which there is no evidence. . . . Intelligent design is an explanation of the origin of life that differs from Darwin's view. The reference book, *Of Pandas and People*[,] is available for students to see if they would like to explore this view in an effort to gain an understanding of what intelligent design actually involves. . . . [S]tudents are encouraged to keep an open mind. The school leaves the discussion of the origins of life to individual students and their families." District science teachers unanimously refused to read the statement in class; it was read instead by school administrators.

Lawyers from the ACLU, Americans United for the Separation of Church and State, and the law firm Pepper Hamilton filed suit on behalf of concerned parents and teachers in December 2004. The case, *Kitzmiller v. Dover Area School District*, was heard in 2005 by Judge John E. Jones III, an appointee of George W. Bush. The Foundation for Thought and Ethics, the publisher of the book *Of Pandas and People*, petitioned to intervene as a codefendant, citing potential losses if the plaintiffs won the suit, but Jones rejected their petition because it was not timely and because they had not shown that the existing defendants would not adequately represent their interests. Three expert witnesses for the defense ultimately declined to testify in a dispute over legal representation.

The plaintiffs argued that several school board members had religious motivations and therefore that the board policy was unconstitutional. Additionally, Barbara Forrest, the philosophy professor who had authenticated

the Wedge Document, showed that early drafts of the book *Of Pandas and People* used the words *creationist* or *creationism* approximately one hundred times. A later draft, drawn up after the 1987 *Edwards* decision, replaced all instances of "creationist" with "design proponent." Indeed, one apparently hasty cut-and-paste operation morphed "creationists" into the transitional form "cdesignproponentsists." Thus did creationism evolve into intelligent design.

Judge Jones found for the plaintiffs. He ruled that intelligent design is "a religious view, a mere re-labeling of creationism, and not a scientific theory." He gave short shrift to the argument that the school board's policy was not advocating the teaching of intelligent-design creationism but merely making students aware of it. Finally, Jones ruled that "the secular purposes claimed by the board amount to a pretext for the board's real purpose, which was to promote religion in the public school classroom, in violation of the Establishment Clause." In the November elections before the verdict, a school board favoring evolution was elected, so the decision was not appealed. The school district, however, was left with a $2 million debt for attorney's fees and court costs. The plaintiffs' legal team settled for $1 million, plus one dollar for each of the eleven plaintiffs.

Creationists may be expected to change their tactics again in the wake of the *Kitzmiller* decision. As we go to press, a half-dozen or so state boards of education are considering policies that use the rubric of *academic freedom* to mandate teaching the "strengths and weaknesses" of evolution, but not of any other subjects. The proponents of such mandates deny that their motivation is religious. In 2008, Governor Bobby Jindal of Louisiana, a biology major from Brown University and a Rhodes scholar, signed a law that allowed the State Board of Elementary and Secondary Education to "assist teachers, principals, and other school administrators to create and foster an environment within public elementary and secondary schools that promotes critical thinking skills, logical analysis, and open and objective discussion of scientific theories being studied including, but not limited to, evolution, the origins of life, global warming, and human cloning." The bill further allows a teacher to "use supplemental textbooks and other instructional materials to help students understand, analyze, critique, and review scientific theories in an objective manner," at the discretion of the local school board. Perhaps in a case of protesting too much, the law affirms, "This Section shall not be construed to promote any religious doctrine, promote discrimination for or against a particular set of religious beliefs, or promote discrimination for or against religion or nonreligion."

Conclusion

Until the development of a truly scientific theory of evolution in the nineteenth century, most scholars and theologians probably thought that the

plants and animals they saw around them had been designed by the Creator. Darwin and Wallace's theory made such an assumption unnecessary. In the United States, many religious believers came to terms with the new theory of evolution, for example, by developing gap and day-age theories. In the early 1900s, however, many evangelical Christians began to drift toward fundamentalism and became suspicious of evolution. Evolution was not a major factor in their thinking after the Scopes trial, if only because it had largely disappeared from the high-school curriculum. After the launch of *Sputnik* in 1957, when biology curriculums began to stress evolution, opposition grew, and creationists developed, in turn, flood geology, scientific creationism, and intelligent-design creationism. State and local school boards tried many stratagems to discredit evolution or to inject some form of creationism into the high-school science curriculum. They were prevented from doing so primarily by strong legal action on the part of evolution supporters.

In succeeding chapters, we will show that all the substantive claims of creationism, including, in particular, intelligent-design creationism, are false. To that end, we will first investigate how science works and then how pseudoscience works. Only after we understand both science and pseudoscience can we hope to understand creationism.

THOUGHT QUESTIONS

1. Do most people change their minds when presented with new evidence? Or do they deny the evidence or try to explain it away? Is this a natural reaction? What is the best way to overcome this obstacle? What do you do?
2. What if the weight of evidence or the weight of informed opinion clearly supports one position over another? Must the second opinion be given equal time with the first? What if a majority of the population supports the second opinion? Explain your answers.
3. Are high-school students competent to evaluate the arguments in a purely scientific controversy? Laypersons in general? Who is competent?