CHAPTER

5

Why Should Students Learn Evolution?

"When you combine the lack of emphasis on evolution in kindergarten through 12th grade, with the immense popularity of creationism among the public, and the industry discrediting evolution, it's easy to see why half of the population believes humans were created 10,000 years ago and lived with dinosaurs. It is by far the biggest failure of science education from top to bottom."

—Randy Moore, Editor, *The American Biology Teacher*[1]

"This is an important area of science, with particular significance for a developmental psychologist like me. Unless one has some understanding of the key notions of species, variation, natural selection, adaptation, and the like (and how these have been discovered), unless one appreciates the perennial struggle among individuals (and populations) for survival in a particular ecological niche, one cannot understand the living world of which we are a part."

—Howard Gardner, Professor,
Harvard Graduate School of Education[2]

With all of the controversy over the teaching of evolution reported in the media, with parents confronting their children's science teachers on this issue, and with students themselves confronting their instructors in high schools and colleges, would it be best—and easiest—to just delete the teaching of evolution in the classroom? Can't students attain a well-rounded background in science without learning this controversial topic? The overwhelming consensus of biologists in the scientific community is "no." Why, then, should science students learn about evolution?

A simple answer is that evolution is the basic context of all the biological sciences. Take away this context, and all that is left is disparate facts without the thread that ties them all together. Put another way, evolution is the explanatory framework, the unifying theory. It is indispensable to the study of biology, just as the atomic theory is indispensable to the study of chemistry. The characteristics and behavior of atoms and their subatomic particles form the basis of this physical science. So, too, biology can be understood fully only in an evolutionary context. In explaining how the organisms of today got to be the way they are, evolution helps make sense out of the history of life and explains relationships among species. It is a useful and often essential framework within which scientists organize and interpret observations, and make predictions about the living world.

But this simple answer is not the entire reason why students should learn evolution. There are other considerations as well. Evolutionary explanations answer key questions in the biological sciences such as why organisms across species have so many striking similarities yet are tremendously diverse. These key questions are the *why* questions of biology. Much of biology explains *how* organisms work . . . how we breathe, how fish swim, or how leopard frogs produce thousands of eggs at one time . . . but it is up to evolution to explain the why behind these mechanisms. In answering the key *why* questions of biology, evolutionary explanations become an important lens through which scientists interpret data, whether they are developmental biologists, plant physiologists, or biochemists, to mention just a few of the many foci of those who study life.

Understanding evolution also has practical considerations that affect day-to-day life. Without an understanding of natural selection, students cannot recognize and understand problems based on this process, such as insect resistance to pesticides or microbial resistance to antibiotics. In a report released in June, 2000,[3] Dr. Gro Harlem Brundtland, Director-General of the World Health Organization, stated that the world is at risk of losing drugs that control many infectious diseases because of increasing antimicrobial resistance. The report goes on to give examples, stating that 98% of strains of gonorrhea in Southeast Asia are now resistant to penicillin. Additionally, 14,000 people die each year from drug-resistant infections acquired in hospitals in the United States. And in New Delhi, India, typhoid drugs are no longer effective against this disease. Such problems face every person on our planet, and an understanding of natural selection will help students realize how important their behavior is in either contributing to or helping stem this crisis in medical progress.

Evolution not only enriches and provides a conceptual foundation for biological sciences such as ecology, genetics, developmental biology, and systematics, it provides a framework for scientific disciplines with historical aspects, such as anthropology, astronomy, geology, and paleontology. Evolution is therefore a unifying theme among many sciences, providing students with a framework by which to understand the natural world from many perspectives.

As scientists search for evolutionary explanations to the many questions of life, they develop methods and formulate concepts that are being applied in other fields, such as molecular biology, medicine, and statistics. For example, scientists studying molecular evolutionary change have developed methods to distinguish variations in gene sequences within and among species. These methods not only add to the toolbox of the molecular biologist but also will have likely applications in medicine by helping to identify variations that cause genetic diseases. In characterizing and analyzing variation, evolutionary biologists have also developed statistical methods, such as analysis of variance and path analysis, which are widely used in other fields. Thus, methods and concepts developed by evolutionary biologists have wide relevance in other fields and influence us all daily in ways we cannot realize without an understanding of this important and central idea.

Evolution is not only a powerful and wide-reaching concept among the pure and applied sciences, it also permeates other disciplines such as philosophy, psychology, literature, and the arts. Evolution by means of natural selection, articulated amidst controversy in the mid-nineteenth century, has reached the twenty-first century having had an extensive and expansive impact on human thought. An important intellectual development in the history of ideas, evolution should hold a central place in science teaching and learning.

Why is evolution the context of the biological sciences—a unifying theory?

First, how does evolution take place? A key idea is that some of the individuals within a population of organisms possess measurable changes in inheritable characteristics that favor their survival. (These characteristics can be morphological, physiological, behavioral, or biochemical.) These individuals are more likely to live to reproductive age than are individuals not possessing the favorable characteristics. These reproductively advantageous traits (called *adaptive traits* or *adaptations*) are passed on from surviving individuals to their offspring. Over time, the individuals carrying these traits will increase in numbers within the population, and the nature of the population as a whole will gradually change. This process of survival of the most reproductively fit organisms is called *natural selection*.

The process of evolutionary change explains that the organisms of today got to be the way they are, at least in part, as the result of natural selection over billions of years and even billions more generations. Organisms are related to one another, some more distantly, branching from a common ancestor long ago, and some more recently, branching from a common ancestor closer to the present day. The fact that diverse organisms have descended from common ancestors accounts for the similarities exhibited among species. Since biology is the story of life, then evolution is the story of biology and the relatedness of all life.

How do evolutionary explanations answer key questions in the biological sciences?

Evolution answers the question of the unity and similarity of life by its relatedness and shared history. But what about its diversity? And how does evolution answer other key questions in the biological sciences? What are these questions and how does evolution answer the *why* question inherent in each?

Evolution explains the diversity of life in the same way that it explains its unity. As mentioned in the preceding paragraphs, some individuals within a population of organisms possess measurable changes in inheritable characteristics that favor their survival. These adaptive traits are passed on from surviving individuals to their offspring. Over time, as populations inhabit different ecological niches, the individuals carrying adaptive traits in each population increase in numbers, and the nature of each population gradually changes. Such divergent evolution, the splitting of single species into multiple, descendant species, accounts for variation. There are different modes, or patterns, of divergence, and various reproductive isolating mechanisms that contribute to divergent evolution. However, the result is the same: Populations split from common ancestral populations and their genetic differences accumulate.

What are some other key questions in biology that are answered by evolution? One key question asks why form is adapted to function. Evolutionary theory tells us that more organisms that have parts of their anatomy (a long, slender beak, for instance) better adapted to certain functions (such as capturing food that lives deep within holes in rotting tree trunks) will live to reproductive age in greater numbers than those with less-well-adapted beaks. Therefore, the organisms with better-adapted beaks will pass on the genes for these features to greater numbers of offspring. Eventually, after numerous generations, natural selection will result in a population that has long slender beaks adapted to procuring food. Thus, anatomical, behavioral, or biochemical traits (the "forms") fit their functions because form fitting function is adaptive. But this idea leads us to yet another important question: Why do organisms have a variety of nonadaptive features that coexist amidst those that are adaptive?

During the course of evolution, traits that no longer confer a reproductive advantage do not disappear in the population unless they are reproductively disadvantageous. A population of beige beach birds that escaped predation because of protective coloration will not change coloration if this population becomes geographically isolated to a grasslands environment, unless the now useless beige coloration allows the birds to be hunted and killed more easily. In other words, if beige coloration is not a liability in the new environment, the genes that code for this trait will be passed on by all surviving birds in this grasslands niche. Even as the population of birds changes over generations, the genes for beige feathers will be retained in the population as long as this trait confers no reproductive disadvantage (and as long as mutation and genetic drift do not result in such a change).

These preceding examples do not cover all the key questions of biology (of course), but do show that such key questions are really questions about evolution and its mechanisms. Only evolutionary theory can answer the *why* questions inherent in these themes of life.

How does understanding evolution help us understand processes that affect our health and our day-to-day life? And how are evolutionary methods applied to other fields?

As mentioned earlier, without an understanding of natural selection, students cannot recognize and understand problems based on this process, such as insect resistance to pesticides or microbial resistance to antibiotics. Additionally, it is only through such understanding that scientists can hope to find solutions to these serious situations. Scientists know that the underlying cause of microbial resistance to antibiotics is improper use of these drugs. As explained in the World Health Organization report *Overcoming Antimicrobial Resistance*, in poor countries antibiotics are often used in ways that encourage the development of resistance. Unable to afford the full course of treatment, patients often take antibiotics only until their symptoms go away—killing the most susceptible microbes while allowing those more resistant to survive and reproduce. When these most resistant pathogens infect another host, antibiotics are less effective against the more resistant strains. In wealthy countries such as the United States, antibiotics are overused, being prescribed for viral diseases for which they are ineffective and being used in agriculture to treat sick animals and promote the growth of those that are well. Such misuse and overuse of antibiotics speeds the process whereby less resistant strains of bacteria are wiped out and more resistant strains flourish.[4]

In addition to developing resistance to antibiotics and other therapies, pathogens can evolve resistance to the body's natural defenses. The virulence of pathogens (the ease with which they cause disease) can also evolve rapidly. Understanding the coevolution of the human immune system and the pathogens that attack it help scientists track and predict disease outbreaks.

Understanding evolution also helps researchers understand the frequency, nature, and distribution of genetic disease. Gene frequencies in populations are affected by selection pressures, mutation, migration, and random genetic drift. Studying genetic diseases from an evolutionary standpoint helps us see that even lethal genes can remain in a population if there is a reproductive advantage in the heterozygote, as in the case of sickle-cell anemia and malaria.

Sickle-cell anemia is one of the most common genetic disorders among African Americans, having arisen in their African ancestors. It has also been observed in persons whose ancestors came from the Mediterranean basin, the Indian subcontinent, the Caribbean, and parts of Central and South America (particularly Brazil). The sickle-cell gene has persisted in these populations, even though the disease eventually kills its victims, because carriers who inherit a single defective gene are resistant to malaria. Those with the sickle-cell gene have a survival advantage in regions of the world in which malaria is prevalent, which are the regions of the ancestral populations listed previously. Although many of these peoples have since migrated from these areas, this ancestral gene still persists within their populations.

Scientists are also working to identify gene variations that cause genetic diseases. Molecular evolutionary biologists have developed methods to distinguish between variations in gene sequences that affect reproductive fitness and variations that do not. To do this, scientists analyze human DNA sequences and DNA sequences among closely related species. The Human Genome Project, a worldwide effort to map the positions of all the genes and to sequence the over 3 billion DNA base pairs of the human genome, is providing much of the data for this effort and also is allowing scientists to study the relationships between the structure of genes and the proteins they produce. (On June 26, 2000, scientists announced the completion of the "working draft" of the human genome. The working draft covers 85% of the genome's coding regions in rough form.[5])

Some diseases are caused by interaction between genes and environment (lifestyle) factors. Genetic factors may predispose a person to a disease. For example, America's number one killers, cardiovascular disease and cancer, have both genetic and environmental causes. However, the complex interplay between genes and environmental factors in the development of these diseases makes it difficult for scientists to study the genetics of these diseases. Nevertheless, using evolutionary principles and approaches, scientists have developed a technique called *gene tree analysis* to discover genetic markers that are predictive of certain diseases. (Genetic markers are pairs of alleles whose inheritance can be traced through a pedigree [family tree].) Analyses of gene trees can help medical researchers identify the mutations in genes that cause certain diseases. This knowledge helps medical researchers understand the cause of the diseases to which these genes are linked and can help them develop treatments for such illnesses.

How is evolution indispensable to the subdisciplines of biology and how does it enrich them?

Organizing life, for example, a process on which Linnaeus worked as he grouped organisms by morphological characteristics, continues today with processes that reflect evolutionary relationships. Systematics, the branch of biology that studies the classification of life, does so in the context of evolutionary relationships. Cladistics, the predominant method used in systematics today, classifies organisms with respect to their phylogenetic relationships—those based on their evolutionary history. Therefore, students who do not understand evolution cannot understand modern methods of classification.

Developmental biology is another example of a biological subdiscipline enriched by an evolutionary perspective. In fact, some embryological phenomena can be understood only in the light of evolutionary history. For example, why terrestrial salamanders go through a larval stage with gills and fins that are never used is a question answered by evolution.[6] During evolution, as new species (e.g., terrestrial salamanders) evolve from ancestral forms (e.g., aquatic ancestors), their new developmental instructions are often added to developmental instructions already in place. Thus, patterns of development in groups of organisms were built over the evolutionary history of those groups, thus retaining ancestral instructions. This process results in the embryonic stages of particular vertebrates reflecting the embryonic stages of those vertebrates' ancestors.

The study of animal behavior is enriched by an evolutionary perspective as well. Behavioral traits also evolve, and like morphological traits they are often most similar among closely related species. Phylogenetic studies of behavior have provided examples of how complex behaviors such as the courtship displays of some birds have evolved from simpler ancestral behaviors. Likewise, the study of human behavior can be enhanced by an evolutionary perspective. Evolutionary psychologists seek to uncover evolutionary reasons for many human behaviors, searching through our ancestral programming to determine how natural selection has resulted in a species that behaves as it does.

There are many sciences with significant historical aspects, such as anthropology, astronomy, geology, and paleontology. Geology, for example, is the study of the history of the earth, especially as recorded in the rocks. Paleontology is the study of fossils. Inherent in the work of the geologist and the paleontologist are questions about the relationships of modern animals and plants to ancestral forms, and about the chronology of the history of the earth. Evolution provides the framework within which these questions can be answered.

What do science and education societies say about the study of evolution?

Instructors often look to scientific societies for answers to many questions regarding their teaching. There is one aspect of teaching on which the scientific societies agree and are emphatic. Evolution is key to scientific study, and should be taught in the science classroom. The National Research Council, part of the National Academy of Science, identified evolution as a major unifying idea in science that transcends disciplinary boundaries. Its publication *National Science Education Standards* lists biological evolution as one of the six content areas in the life sciences that are important for all high school students to study.[7] Likewise, the American Association for the Advancement of Science identified the evolution of life as one of six major areas of study in the life sciences in its publication *Benchmarks for Scientific Literacy*.[8] The National Science Teachers Association, the largest organization in the world committed to promoting excellence and innovation in science teaching and learning, published a position statement on the teaching of evolution in 1997, which states that "evolution is a major unifying concept of science and should be included as part of K–College science frameworks and curricula."[9] The National Association of Biology Teachers, a leading organization in life science education, also issued a position statement on the teaching of evolution in 1997, which states that evolution has a "central, unifying role . . . in nature, and therefore in biology. Teaching biology in an effective and scientifically honest manner requires classroom discussions and laboratory experiences on evolution."[10] Evolution has been identified as the unifying theme of biology by almost all science organizations that focus on the biological sciences.[11]

So why should students learn evolution? Eliminating evolution from the education of students removes the context and unifying theory that underpins and permeates the biological sciences. Students thus learn disparate facts in the science classroom without the thread that ties them together, and they miss the answers to its underlying *why* questions. Without an understanding of evolution, they cannot understand processes based on this science, such as insect resistance to pesticides and microbial resistance to antibiotics. Students will not come to understand evolutionary connections to other scientific fields, nor will they fully understand the world of which we are a part. Evolution is, in fact, one of the most important concepts in attaining scientific literacy.