JOHN H. RELETHFORD

50 GREAT MYTHS OF HUMAN EVOLUTION

UNDERSTANDING MISCONCEPTIONS ABOUT OUR ORIGINS

WILEY Blackwell

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To the next generation:
My sons and my daughters-in-law,
Benjamin, David, Zane, Krissy, and Rachel,
and my nieces and nephews,
Adam, Burton, Dana, Evan, Katie, Maya, Melinda,
Noah, and Rebecca
L'dor v'dor

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PREFACE

I find that many people have a strong desire to learn about human evolution and our origins as part of a larger interest in the human condition. There are many ways to contemplate the origin and destiny of humanity, including the arts, literature, philosophy, religion, and science. A strong education in the liberal arts teaches us that there are many different ways to consider our nature and our place in the universe. This book deals with one aspect of the quest to understand the nature of humanity—using science to understand our existence as biological and cultural organisms subject to the evolutionary forces that affect all living creatures.

This book is not meant to be a textbook or a technical monograph. It represents my attempt as a teacher (I am a college professor) to explain a complex subject in a relatively short amount of space (and with the goal that you will go beyond my brief introductions to read and research topics of interest in more depth). Myths, mistakes, and misconceptions provide the focus for a broader treatment of the concepts, methods, and evidence for the history of our species. Above all, the study of human evolution is the study of human history, in the broadest possible sense, and it applies to *all* of us. No matter what else separates us all, the origin and evolution of humans is a history that we all share.

For a long time, I was interested in writing a trade book on human evolution, but had a hard time getting started. I have written several books, but my previous works were either college textbooks or books that wound up going into more specialized areas. Although I enjoyed researching and writing such books, I still wanted to have something on a more general level covering a wide range of topics in human evolution. For a while, I thought about trying to put together a book on "The top *X* things you should know about human evolution," where *X* was usually some number between 10 and 20, but never got started. I needed a hook, or a push.

In January 2011, I got both a hook and a push. A long-time colleague and friend, Rosalie Robertson, who was then a senior editor at Wiley-Blackwell, approached me and asked if I was interested in submitting a prospectus for a book on the "50 Great Myths of Human Evolution." After some thought, I realized that I could discuss many of the concepts of human evolution, past and present, within the structure of a book focusing on myths and misconceptions about human origins and evolution. After an extended delay due to a bout with cancer, this book is the result of that initial conversation. I am grateful to Rosalie for her vision and imagination and her patience with my questions and concerns. Thank you, my friend.

I have also benefited from the hard work and dedication of many people that worked on this project at Wiley-Blackwell. Thanks to Ben Thatcher and Mark Graney, who were involved in the initial submission and review process, and to Mark Calley and Tanya McMullin. Special thanks to the project editor, Roshna Mohan, for her patience with my endless questions and concerns, and to the copy-editor, Alta Bridges, for keeping track of endless details and for making the text more readable. I thank those colleagues that reviewed the initial proposal: David Begun (University of Toronto), Robin Dunbar (University of Oxford), Paul Lurquin (Washinton State University), Fred Smith (Illinois State University), Simon Underdown (Oxford Brookes University), and Bernard Wood (George Washington University). I am very grateful to Clark Larsen (Ohio State University) for his reading of both the proposal and the entire manuscript as well as answering specific questions. I am also grateful to Deborah Bolnick (University of Texas) and P. Thomas Schoenemann (Indiana University) for their assistance.

Finally, I have to give thanks to my wife, Hollie Jaffe, for support and guidance throughout this book, my career, and my life.

INTRODUCTION

Myths and misconceptions (or how and why I wrote this book)

What is a myth, and what are the myths of human evolution? I started giving these questions some thought several years ago when I was approached by the publisher to submit a proposal for a book to be called "50 Great Myths of Human Evolution." They had already published a book on misconceptions in psychology entitled *50 Great Myths of Popular Psychology* and were interested in publishing more books along the same line, focusing on the "50 great myths" of various fields, including human evolution. I was intrigued by the suggestion, as I had been contemplating a general book on human origins and evolution for a while. However, I was a little apprehensive about how to approach the idea of "myths" in human evolution. Like many words, the term "myth" has both narrow and broad meanings. My apprehension stemmed from a narrow interpretation of myth.

A narrow meaning of myth refers to the stories about Greek and Roman gods that I studied in a college mythology class. According to the online version of the *Oxford English Dictionary* (www.oed.com), a definition that would fit here is "A traditional story, typically involving supernatural beings or forces, which embodies and provides an explanation, etiology, or justification for something such as the early history of a society, a religious belief or ritual, or a natural phenomenon." This definition does not fit with what I wanted to do with this book as I wanted to go beyond the idea of simply examining stories about human origins, but instead wanted to look at different ideas and misconceptions

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regarding human evolution and, in particular, illustrate how scientific research often leads us to reject old ideas and consider new ones.

In this book, I use a broader definition of "myth" that is closer to the second definition given in the *Oxford English Dictionary*: "A widespread but untrue or erroneous story or belief; a widely held misconception; a misrepresentation of the truth." The myths in this book examine a number of ideas concerning human origins and evolution that fit this broader definition focusing on misconceptions—hence the subtitle of this book.

There are different types of misconceptions that exist when discussing human evolution. Some of these misconceptions are simply not true, but persist over time, such as the popular notion that much of our species' evolution was influenced by extraterrestrials (Myth 40). Some misconceptions arise from inaccuracies, incomplete data, and/or faulty assumptions, but somehow continue to perpetuate over time. An example from human evolution is the notion that the initial development of agriculture resulted in improved health (Myth 39), an idea possibly resulting from the faulty assumption that technological change in our species' evolution always results in progress across the board. Another common misconception is the idea that we no longer evolve (Myth 48), a conclusion reached only if we assume that our rapid cultural change completely negates biological change.

Many of the myths deal with topics that are not misconceptions at present, but refer instead to ideas that had once been considered accurate, but were later overturned because of new evidence and insights. Examples here include the idea that our early ancestor *Australopithecus* was a "killer ape" (Myth 17) and the notion that Neandertals walked bent over (Myth 29). Other myths look at ideas that have been questioned in recent times, but still remain on the table as possible hypotheses, such as the existence of only one species of the genus *Homo* two million years ago (Myth 21). These ideas are not "myths" in the classic narrow sense, but instead reflect shifts in consensus. Keep in mind that such shifts could in the future change further as new data become available. Ideas change as hypotheses are tested, and so might our conclusions on various myths and misconceptions. Today's "myth" might be tomorrow's consensus. It all depends on the evidence and the application of the scientific method.

The dynamic nature of science

Science means different things to people. Sometimes we narrowly equate "science" and "technology" such that recent developments in science often consist of lists of new inventions, drugs, and other important discoveries.

This is unfortunate because this narrow definition leaves out many interesting scientific discoveries (particularly those in human evolution) that have no direct or immediate practical benefit, but do inform us about the world and universe that we live in. It is also an unfortunate correspondence because, although science informs technology, that is not its only function or its essential nature.

At its core, science is a way of knowing, specifically a way of knowing about the natural world (including human behavior, as dealt with by the social and behavioral sciences). Although we sometimes think of science in terms of its direct benefits or the total accumulation of knowledge, it is most importantly a *process* that enables us to learn more about the physical world. Aspects of the scientific method will be described in a later myth, but, for the moment, we can break it down into a process of making observations, developing possible explanations for what we see (hypotheses), and testing them in some manner. Scientific evidence changes over time because this is a dynamic process as we ultimately discard hypotheses that have been rejected. In the general sense, a hypothesis is simply a proposed explanation. Some hypotheses can be supernatural (literally, "above nature") and invoke forces that we cannot directly perceive. To be a *scientific* hypothesis, we have to propose an explanation that is rooted in *natural* processes and is subject to testing.

A key feature of the scientific method is openness to being shown wrong. This does not mean that we *like* to have our hypotheses rejected (we don't) or that we don't resist new ideas and interpretations (we do). It means that ultimately we are open to sufficient evidence showing us that we were wrong, and that there might be a better way to look at things (although we might disagree with what is considered *sufficient*). In the jargon of the scientific method, we do not *prove* hypotheses so much as we fail to reject them (sort of like assuming someone is innocent until proven guilty). When a hypothesis is rejected in science, we throw it out and move on, coming up with a new explanation or modifying an old one. This is not always easy to do, as we are all subject to biases and feelings about pet hypotheses, but ultimately we reject or modify rejected hypotheses (or, if we do not, someone else will!).

This is a radical way of thinking about the world. Many times, we use a very different process of making decisions—we start with a conclusion and then pick data to support our established point of view. In an ideal sense, science works in an opposite manner, collecting all available evidence to test a hypothesis rather than assuming it is correct or incorrect beforehand. Of course, we are all human and are thus likely to be swayed by irrelevant information, wishful thinking, and preexisting biases.

However, as a process that is practiced by the scientific community, we can work through those sources of bias and error. We have to be willing to be wrong and say we are wrong. This is a difficult stance to make, because we often prize people for being resolute and standing for their convictions—admirable qualities but more appropriate to moral and ethical decisions than for scientific analyses. Imagine, for example, someone were running for elected office and made a statement about subject "X" that "I think that X is correct, but I remain open to the possibility that I am wrong." I am willing to bet money that this person would not be elected, as we often have little patience for people being on the fence or capable of "flip flops." In science, however, you *have* to be open to new evidence and ways of explaining them, *provided there is sufficient evidence*. As new evidence accumulates, ideas are repeatedly tested and often changed or thrown out. Some of yesterday's conclusions are now today's myths. This also means that some of today's conclusions might be tomorrow's myths!

In this context, I am always concerned at some of the reaction given to new scientific discoveries that appear to reverse previous ideas and conclusions, be they in human evolution, medicine, astronomy, or some other scientific field. Some people note these changes in a negative light, pointing out previous "errors" in judgment and analysis, and are left wondering why anyone would pay scientists that get things wrong. Well, the truth of the matter is that this is the way science is *supposed* to work. Our knowledge progresses by making hypotheses and testing them, and then throwing them out when they no longer fit the evidence.

It is in this spirit that I discuss the "myths" of human evolution. To be sure, many of these are completely settled (in my view), but others can change depending on new data and analysis. I try to be clear throughout about my views on current consensus as well as some additional possibilities. A warning, however, is that given the dynamic nature of science, it is quite likely that new evidence will shed further light on many of the topics covered in this book and will become out of date between the time I write these words and you read them. That is what is supposed to happen.

Structure of the book

I have picked 50 "myths" about human evolution that I find useful, particularly in teaching about human origins and evolution. (There are many more that could be discussed, but I accepted the number "50" to be part of the publisher's "50 Great Myths" series of books.) Each myth is designed to address a broader issue of science and of *paleoanthropology* (the study of human origins and evolution). I have broken the book into four sections. The first part examines some general myths and misconceptions about the nature of how evolution works. The second part focuses on human origins, examining the fossil record for the time between the initial divergence of African ape and human ancestors and the beginning of the genus *Homo*, including the evolution of bipedalism (upright walking). The third part continues looking at the fossil record in terms of the genus *Homo*, those species (including us) with larger brains, smaller faces, and reliance on a stone tool technology. The fourth and final part of the book examines recent (the last 12,000 years), current, and future human evolution, including the history of different human populations. Because evolution is a cumulative process, it is best understood in a linear manner from start to finish. Although I have tried where possible to make some myths independent, everything flows much easier if you read these myths in sequence.

If the idea of reading 50 essays seems daunting, remember that each myth is very short! The purpose of each essay is to use a myth or misconception to introduce a general topic in human evolution and provide some preliminary background and explanation. Each myth starts with a short "status" statement of several sentences that summarizes the thrust of the myth, also indicating if the topic has been settled or if there is still discussion on it. Because each myth is designed to be short, do not expect these to be complete reviews. The topic of every single myth can (and has) filled books. *The myths here are designed to be short introductions only.*

Although short essays have their purpose, you might find that you want more detail on the overall topic or on some of the specifics, or to read someone else's take on the issue. I have provided references to the facts and ideas discussed in each myth in a series of endnotes that are listed at the end of each section. A complete list of references is provided at the end of the book. Many of these references are to papers in academic journals that might not be available in many public libraries, but should be available at many colleges and universities. Some are also available for free on the Internet.

In general, I urge people interested in more detail on any of these subjects (or scientific subjects in general) to focus primarily on peer-reviewed journal papers and books. The peer-review process means that others in the field have examined the papers in terms of the soundness of the data, analyses, and arguments made. Peer review is a form of quality control and a researcher has to convince his or her peers that they have made the case for a particular conclusion. This is critical in modern times where anything and everything can be distributed on the Internet, often without any review. This does not make things on the Internet necessarily incorrect, but you have no guarantee of accuracy either. Peer review helps, as does looking at web pages that are connected to well-established scientific journals, magazines, and organizations (unless, of course, you subscribe to the notion that the scientific community consists of individuals involved in conspiracies, in which case I am not sure you will enjoy this book!).

1 IDEAS ABOUT EVOLUTION

In order to explore the myths of human evolution, we need to start with a brief review of how evolution works. It turns out that many of the myths of human evolution are related to misconceptions about the process of evolution in a general sense, starting with what is likely the biggest one of all—that evolution is "just a theory." This section of the book examines some common misconceptions of the process of evolution.

Myth #1 Evolution is a theory, not a fact

Status: This is a myth based on a misunderstanding about the use of the word "theory" in the natural sciences. When we state something is a theory, such as evolutionary theory, atomic theory, or the theory of gravitation, we are not suggesting that it may or may not exist (a more popular use of the word "theory"). Instead, we are talking about a hypothesis that has been tested repeatedly and has stood the test of time without being rejected.

Of all the myths about evolution, perhaps the one that we hear more than any other is the idea that evolution is a theory and not a fact. Most often, this myth is expressed as the statement "It's just a theory" or the somewhat longer "It's a theory, not a fact." By contrasting fact and theory, we are forced into an either-or situation. Either evolution is indeed a fact or it is a theory. We then must choose between one side and the other. According to popular logic, if we accept evolution as a theory then it is not necessarily a demonstrated fact. The logic works here only if we

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define the word "theory" as an unsupported or unproven hypothesis or explanation. In other words, if we classify evolution as "just a theory," it implies that evolution may or may not exist. In terms of human evolution (that aspect of evolution that tends to upset folks more than, say, elephant evolution because it is personal), the statement that evolution is "just a theory" means that humans may or may not have evolved. If we cannot tell, then evolution (including human evolution) is therefore not a fact. It is, according to this logic, at best an opinion.

Although much of the above may seem logical and perfectly reasonable, the argument rests on an underlying assumptions that "theory" means an untested hypothesis or mere opinion and that something can be either a fact or a theory. It turns out that our more popular use of the word "theory" is not what it means in the context of scientific thought. Evolution is actually both a fact and a theory. In my introductory course on biological anthropology, I ask the class on the first day to raise their hands if they think evolution is a fact. I then ask the class to raise their hands if they think evolution is a theory. I then tell them "Congratulations! All of you are correct. Evolution is *both* a fact and a theory." This statement can cause some consternation in anyone who is used to facts and theories being considered in terms of an either-or proposition. In order to see the mistake being made by this proposition, we need to consider a bit of the underlying philosophy and method of the natural sciences and explore briefly what we mean by fact, hypothesis, and theory.

To most of us, the definition of "fact" is pretty straightforward. A fact is a verifiable truth—something we can all observe and agree on. The key feature here is that facts must be capable of being verified. If I say that there are trees in my yard, you can actually look and see if this is true. Some facts are easy to verify and we will all agree with little or no argument. For example, if we drop an object, such as a pencil, it will drop to the ground. We call this fact gravity. Sometimes facts are contingent upon a more exact definition. In the case of gravity, the pencil would have to be dropped while standing on something of sufficient mass to generate sufficient gravitational force to attract the pencil. Sometimes facts are tricky because they are not directly observable with our senses. We can easily see a pencil dropping, but what of the fact that infectious diseases are caused by bacteria and viruses that are not visible to the human eye. Of course, we easily accept the existence of such microorganisms because we have developed microscopes and other technology to make our observations. However, imagine you were alive during the fourteenth century and someone explained to you that the Black Death (bubonic plague) was caused by a bacterium, something that could not be seen except with a microscope (that had not yet been invented). I suspect that most people at that time would have rejected this idea because the plague bacterium could not be observed with the naked eye.

Observing something, either directly with our senses or with technology, is a start in establishing a fact, but you need to remember that facts must be verified. Sometimes in the history of science, we find that our basic facts change when more observations are made. At one time, for example, it was thought that humans had 24 pairs of chromosomes, but over time, more advanced methods revealed that we actually had 23 pairs of chromosomes. At one time, a fossil known as Piltdown Man (discussed in Myth 13) was thought to be a fact supporting the then-popular view that humans evolved large brains before losing certain ape-like features of the teeth. In this case, inconsistency with other facts, development of better ways to date the individual fossils making up Piltdown Man, and other pieces of evidence pointed out that it was not a fact, but instead a fake. Someone (whose identity is still not known with certainty) faked the whole thing. Again, such lessons show us that science requires verification even with basic facts.

What about theory? Before considering the different meanings of the word "theory," we need to start with the idea of a hypothesis. Science is not simply an accumulation of facts about the physical universe. We also try to explain what we see. A hypothesis is just a tentative explanation of the facts. For example, why does a pencil fall to the floor when I let it go? In order to make my point about the nature of a hypothesis and how it ties into science, I am going to state an obviously ridiculous hypothesis to explain the falling pencil. Imagine that I have placed a magnet inside the pencil and then held it over a spot on the floor under which I have buried a very powerful magnet. When I let go of the pencil, the magnetic forces cause the pencil to drop to the floor. I imagine as you are reading this, you are thinking that this hypothesis is one of the silliest things you have ever heard, and so ridiculous that even discussing it is a complete waste of time. Yes, it is ridiculous and it is clearly false, but the interesting thing here is that my wacky idea is actually a good scientific hypothesis because it can be tested. There are a number of ways to test this hypothesis. Break open the pencil or dig under the floor to find there are no magnets. Use a device (such as a compass) and fail to detect any localized magnetic force. Or, in perhaps the most simple but also most elegant test, drop your own pencil (or shoe or baseball) and find that they all drop to the ground without any magnets being placed inside of them.

In each case, the hypothesis has been tested and has been rejected. We then have to move on to another hypothesis. Each time we develop a hypothesis we try to determine some way to test it. Science is continually involved with the testing and retesting of hypotheses, looking for hypotheses that have stood the test of time. In the natural sciences, we use the word "theory" to indicate a hypothesis, or set of hypotheses, that has been tested repeatedly and has not been rejected. We might continue to refine the theory, but the basic elements are widely agreed upon and unlikely to change.

This definition of theory contrasts with the popular idea that a theory is a hypothesis or just a guess and that the subject of the theory may or may not exist. However, when you hear the phrase "theory of gravity," do you think that gravity may or may not exist? Of course not. To take another example, consider atomic theory in chemistry. Does the inclusion of the word "theory" make you think, "Well, atoms are only a theory and they may or may not exist"? I doubt any reader takes this stand. The elements of atomic theory have been tested and have held up over time. The same is true for evolution. The basic ideas regarding the mechanisms of evolution (described in later myths) have been confirmed and form the basis for modern evolutionary theory. As with gravity and atoms, evolution is both a fact and a theory. Arguing that something has to be one or the other is a misuse of the scientific method.

Historically, we associate part of modern evolutionary theory with the insights of the nineteenth-century naturalist, Charles Darwin, who contributed to our understanding of both the fact of evolution and part of the underlying mechanism for evolutionary change. By Darwin's time, many in the scientific community were coming to grips with evidence showing changes due to evolution. The spread of the Industrial Revolution had led to increased mining and quarrying activity. As people dug into the earth, they found many fossils of creatures that did not fit nicely and neatly into their views on variation. Imagine, for example, you were digging in your backyard and found the skull of a cow. How would you explain it? Depending on where you live, the explanation might be very simple—perhaps your property was once a farm where cows lived and died. Or, imagine you unearthed a skull of a modern human. Although such a discovery might lead to all sorts of speculations about the identify and fate of the person you found, the simple truth is that finding a modern human skull in the ground is not likely to be an earth-shattering discovery.

However, what would you do if you found the remains of a creature that no longer lived, such as the bones of a dinosaur? This discovery implies that there were creatures that once existed but have since become extinct (which turns out to be quite common—we now know that over

99 percent of all species that have ever lived have become extinct). How do you explain this extinction? You then notice upon further examination that the bones of the creature you discovered are similar to, but not identical to, living creatures. For example, if you look at fossil remains from many millions of years ago, you will find creatures that are clearly similar to horses, but instead have three toes on each foot, as compared with the single toe typically found in modern horses. Or, in the case of human evolution, we can go back 2 million years ago in Africa and find creatures that are very similar to us in terms of how they walked and their basic body anatomy, but have smaller brains and larger faces. As we examine the fossil record even further, we see examples of trends over time, such as a reduction in the number of horse toes or the increase in the brain size of bipeds. Such trends are clear examples of evolution (and more will be presented throughout this book). How do you explain such facts?

Darwin was one of those who sought an explanation for change over time. Darwin made two very important contributions. First, he collected data confirming the fact of evolution as revealed from field studies of living organisms, the fossil record, and the comparative anatomy of different species, among other sources of evidence. His result was a convincing argument that all living species were related through a process of what he termed "descent with modification." The mechanism that Darwin proposed (natural selection) will be dealt with in later myths, but here we just focus on the fact that natural selection was a hypothesis relying on natural phenomena that explained the observed facts. As with all scientific hypotheses, Darwin's idea has been tested repeatedly. Because it has survived without refutation, the concept of natural selection has been elevated to the status of a scientific theory. Once more, keep in mind that the word "theory" has a very specific meaning here and does not mean something that may or may not exist.

The final point about Darwin's idea is that even though it forms part of modern evolutionary theory, his concept of natural selection is not the entire answer. Although Darwin got a lot right, he also had questions that remained unanswered during his life. The tentative nature of scientific explanation can be frustrating to those seeking a final definitive answer, but it is the basic nature of scientific inquiry with which we continue to refine our explanations. The theory of evolution is no exception. We do not have all the answers, but continue to seek them through the scientific process. However, although scientists continue to debate the details of the evolutionary process, there is agreement on both the fact of evolution as well as the basic explanation of how evolution happens. The details of the evolutionary process are described briefly in the next myth.

Myth #2 Evolution is completely random

Status: This is a myth because it implies that evolution is a chance event. Although some aspects of evolution (such as mutation) have a random element, other aspects, such as natural selection, are not random. Whether an individual survives and reproduces or not depends on their evolutionary fitness relative to their local environment. Like many natural processes, evolution has both nonrandom and random components.

A common misconception of the evolutionary process is that it is random; that is, due to chance. Taken to an extreme, this misconception can lead to a rejection of evolution altogether. After all, how could something as complex as the human body (or any other organism) be due to chance? That is analogous to scattering thousands of Scrabble™ tiles at random and having them spell out the Declaration of Independence. Complex sentences or biological structures, such as the human body, would seem to defy randomness, which many people equate with something "just happening." Part of the confusion may lie with the fact that some parts of the evolutionary process are random. However, having some randomness in parts of a process is not the same as an entire process being random. To be more specific, the origin of initial genetic variation is random, but the outcome is not. To see the distinction here, we need to look more closely at how evolution works.

As described in the last myth, Darwin's most significant contribution to the theory of evolution is the description of natural selection. Darwin noted that there is considerable biological variation in living creatures, something that we can all see easily. For example, not all birds look alike, but vary in terms of size, color, and other physical traits. As you walk down the street, you will see the same is true of humans; people vary in terms of size, shape, body proportions, skin color, hair color, and many other characteristics. This is even more apparent when looking beyond observable physical traits and we consider genetic traits where people vary in terms of blood types, blood proteins, and DNA markers, among others. Variation is all around us in the natural world; an observation that Darwin was able to tie to environmental differences.

Darwin also relied on the observation that more organisms are born than will survive to adulthood. For example, if a fish lays 100 eggs, it is a certainty that not all 100 offspring will survive to adulthood. Most will die, but some will survive. The same process of differential survival is true of all species—some individuals survive and reproduce, thus continuing the species, whereas others die before reaching reproductive age or fail to reproduce. Darwin tied together the observation of differential survival with the observation of variation. Given variation within a species, in a specific environment some individuals will be more likely to survive and reproduce than others. Imagine, for example, that there is variation in the size and shape of the beak of a bird in an environment where the main source of food is large seeds that are tough to crack open to eat. In such a case, those birds that have the most powerful beaks are most likely to eat and hence to survive. Consequently, the birds that are better adapted will contribute more to the next generation than those that are less adapted to the specific environment. Over time, the genetic characteristics of the population will change and large, powerful beaks will become more common.

The principles of natural selection are often best understood by analogy to the process of animal domestication. Imagine, for example, that you have just inherited a pig farm and you decide to go into the business of raising pigs for sale as food. When you first arrive on your new farm, you will notice that there is variation in the size of the pigs. Some of the pigs may be large and fat whereas others may be small and scrawny. Over time, you will sell off some pigs and keep others for breeding stock (because you want to produce additional generations of pigs). Keep in mind that you get a better price for the larger pigs. Which pigs do you sell and which pigs do you keep as breeders? If you are interested in long-term profitability you will ignore an impulse to sell the large pigs right away and instead you will keep them as breeders because of the common knowledge that, all other things being equal, larger pigs will produce larger offspring. This is not a perfect correlation, but it is strong enough that people have relied on this principle of selective breeding to feed themselves in the 12,000 years since agriculture has existed. The idea is simple enough to use even without knowledge of the underlying genetics—breed for the characteristic of interest and it will become more common over time, be it the size of pigs, speed of a horse, disposition of a dog, or many other traits. This selection is not random—the farmer does not roll dice or flip coins to pick which pigs are breeders.

Darwin recognized how this process of selection could lead to evolution, where the change over time was due to the farmer selecting who lived to reproduce and who did not. He also recognized that the same process could happen in nature, but where the selection was not the product of conscious manipulation by a human being, but was instead due to interaction with the environment. Those organisms that are better adapted to a given environment are more likely to survive and reproduce and will then pass on their characteristics in greater numbers to the next generation. Unlike the artificial selection that occurs due to the intervention of the farmer, this selection occurs in nature and is therefore termed natural selection.

A classic example of natural selection acting upon variation is found in studies of the coloration of the peppered moth in England. At one time, most of the moths of this species were light-colored, but a very small number were dark in color. The light color was more common because it was adaptive; the light color acted as camouflage when the moths rested on the light-colored tree trunks. Because these moths blended in, they were less likely to be seen by birds, unlike the dark-colored moths that were more visible and thus more likely to be eaten. Here, selection acted to maintain the light color over time and most dark-colored moths were selected out of the gene pool. Whether a moth was eaten or not was not random.

However, scientists also noted what happened when the environment changed because of industrial pollution killing off lichen on the trees, exposing the underlying dark color. At this point, the selective balance shifted and light-colored moths were then at a disadvantage and dark-colored moths were at an advantage. Each generation the proportion of dark-colored moths increased until they were the most common form as the population became better adapted to the environment.[1] Although this is a relatively small amount of change, the process of natural selection can apply to larger changes over geologic time, leading to major divergences.

Darwin's model of natural selection leaves out one important question—where does variation come from in the first place? Why are some pigs bigger than others? Why are some moths darker and some lighter? Darwin did not have the answer about the origin of variation; he noted its existence and then described how natural selection could act upon this variation, but lacked the insights of twentieth-century genetics that show us that the ultimate cause of genetic variation is the process of mutation.

A mutation is a random change in the genetic code, DNA. Mutations can occur for a number of reasons including the effect of background cosmic radiation, leading to an error in how the DNA is being copied. The DNA consists of sequences of four chemical bases and can be thought of as analogous to an alphabet with four letters that spells out the instructions that regulate all processes of life, ranging from the structure of proteins to the development of an organism. Some mutations involve a change in one of the letters (bases), while others can involve duplication or deletion of larger DNA sequences. Still other mutations involve movement of DNA sequences from one chromosome to another. Following the alphabet analogy, mutations act to change the message being transmitted.

Mutations can occur in any cell and interfere with biological function (such as leading to cancer). From an evolutionary perspective, we are interested in mutations that are transmitted through sex cells (sperm and egg in bisexually reproducing organisms).

Natural selection acts upon mutations. If a mutation is harmful to the organism that inherits it, hindering survival or reproduction, it can be eliminated through natural selection. Selection thus acts to weed out harmful effects. On the other hand, if a mutation leads to an advantage, it can be selected for and increase in frequency over time. Putting mutation and natural selection together, we get a picture of mutations generating variation that is then filtered by natural selection, leading to the reduction in frequency of harmful mutations and the increase in frequency of helpful mutations. (The actual picture can get much more complicated, but this view suffices for now.)

We can now turn to the question asked at the beginning of this myth—is evolution a random process? This question does not have a single yes or no answer. Mutation is a random process. Mutations do not appear when they are needed. (For example, a dark-color moth mutation did not appear in the moth population just because the environment changed.) Although we can measure the probability of a mutation occurring in any given organism in any given generation, we do not know for sure whether a specific DNA sequence will mutate or not at any given point in time. Think of the analogy of flipping a coin. If you are using a fair coin (no magic tricks allowed), you know that the coin will land heads up or tails up. For our purposes, the outcome is random. Although we do know that the probability of getting heads or tails is 50 : 50, we do not know beforehand whether any specific coin flip will be heads or tails. In terms of the moth example, whether a mutation leading to dark coloration appeared in a given generation or not is a random process. It is a matter of luck.

Does this mean that evolution is random and everything we see around us resulted merely from a series of chance events? Absolutely not. The fact that mutation is random simply means that the initial generation of variation is random, not the outcome. Remember, natural selection is not a random process. Whether an organism will survive and reproduce or not is a function of its adaptive value (what we call "fitness") in a given environment. When the trees in England became darker, the difference between survival of dark-colored and light-colored moths was not a matter of chance, but instead a direct outcome because of differences in fitness (because light-colored moths were more likely to be eaten). Although the direction of evolutionary change may change as the environment changes (as in the case of the peppered moth), this is not a random change. Although evolution does have a random component (mutation), the direction of evolutionary change due to natural selection is not a random outcome. Think of this difference in terms of how humans domesticated corn (or any other plant or animal). Humans altered the evolutionary course of corn to produce kernels that were large and stayed on the cob. They did this by the process of artificial selection acting upon the variation in corn that was available in nature. Although the initial origin of this variation was a random event due to mutation, the outcome of domesticated corn was not.

The discussion of how evolution works continues with the next myth. For the moment, it is important to discard ideas that the evolutionary process has to be entirely random or nonrandom. Evolution has both random and nonrandom (deterministic) components. It does not have to be just one or the other. To pursue an analogy with life, consider the movie *Forrest Gump*, where the title character muses about whether people have a destiny (deterministic) or whether we are "all just floating around accidental-like on a breeze" (random). Forrest wisely concludes, "Maybe both is [*sic*] happening at the same time."[2]

Myth #3 All evolutionary changes are adaptive

Status: This is a myth that results from equating the entire evolutionary process with natural selection acting upon mutations. Not all evolutionary changes reflect adaptation. There is also random fluctuation over time, known as genetic drift. Evolutionary biologists all agree that both selection and drift are important, although there is debate over the relative influence of each.

As described in the previous myth, natural selection is a powerful agent of evolutionary change, acting upon mutations to decrease the frequency of harmful mutations and increase the frequency of helpful mutations. Over time, species become better adapted to their environments, as seen in numerous field studies of living organisms. An example from the human species is the global distribution of skin color, where native populations at or near the equator tend to be the darkest, and populations farther away from the equator, north or south, are increasingly lighter. This pattern correlates with the global distribution of ultraviolet radiation. The story of skin color adaptation will be explored in detail in a later myth (Myth 42), but the point here is that variation in skin color can be explained by adaptation through natural selection to ultraviolet radiation.