III. Short FAQs

❖ How long does it take for evolution to happen?

It depends on which organism is evolving and what kind of evolution you are interested in. Here are a few examples:

- Shift in gene frequency in bacterial populations (e.g., evolution into a largely antibiotic resistant strain): hours or days
- Shift in gene frequency in human populations (e.g., evolution favoring genes that let individuals digest milk): hundreds or thousands of years
- Early stages of speciation in flies: 200 years
- Evolutionary transition from fish ancestors to walking vertebrates: tens of millions of years

❖ How did life start?

Three and a half billion years ago, life originated in a series of small steps, each building upon the complexity that evolved previously. First, simple organic molecules formed, possibly near an oceanic hydrothermal vent or a hot spring. Then, molecules that could copy themselves evolved and began to undergo natural selection. Eventually those replicating molecules became enclosed within a cell membrane and evolved into organisms we would recognize as alive. Science can help us reconstruct the steps and natural processes through which life evolved.

❖ How do we get new species?

Though there many ways that new species can arise, biologists think that the following process is common: a population is split into two sub-populations by some geographic barrier, the two sub-populations evolve in isolation, and eventually the sub-populations evolve so many differences that—even if they were reunited—they would not or could not successfully mate with one another. At this point, speciation has occurred: a single ancestral species has evolved into two separate daughter species.

❖ Where does new variation come from?

The ultimate source of genetic variation is random mutation. Mutations are "random" in the sense that the sort of mutation that occurs cannot generally be predicted based upon the needs of the organism. So, for example, in the exhibit, the gene variants that caused some baby dinosaurs to have fuzz originally arose through the process of random mutation. However, once the gene variant was present in the population, it spread through the nonrandom process of natural selection. The offspring of two parents are all slightly different from one another because they each got slightly different combinations of gene versions from their parents—but the ultimate source of those gene versions is random mutation.

❖ What's the difference between microevolution and macroevolution?

Microevolution is what biologists call evolutionary change that occurs within a single population or species (e.g., an increase in the frequency of dinosaurs with tiny feathers from one generation to the next). Macroevolution is what biologists call evolutionary change that occurs on a scale that transcends the boundaries of a single species (e.g., the evolution and radiation of the dinosaur lineage into many different species of non-avian dinosaurs and birds). Despite their differences, evolution at both of these levels relies on the same, established mechanisms of evolutionary change: mutation, migration, *genetic drift*, and natural selection.

genetic drift—random changes in the gene frequencies of a population from generation to generation. This happens as a result of sampling error—some individuals just happen to reproduce more than others, not because they are "better," but just because they got lucky. This process causes gene frequencies in a population to drift around over time. Some genes may even "drift out" of a population (i.e., just by chance, some gene may reach a frequency of zero). In general, genetic drift has the effect of decreasing genetic variation within a population.

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❖ Who came up with the idea of evolution?

Charles Darwin championed the idea that species evolved from common ancestors, and he and Alfred Russel Wallace came up with the idea of natural selection as a mechanism of evolution, but other evolutionary ideas were around long before Darwin and Wallace. For example, in the 1700s, Georges-Louis Leclerc Buffon argued that life was extremely old and had changed over time, and in the early 1800s, Jean Baptiste Lamarck proposed several ideas about the mechanisms through which life might evolve.

❖ Do scientists still think that Darwin was right?

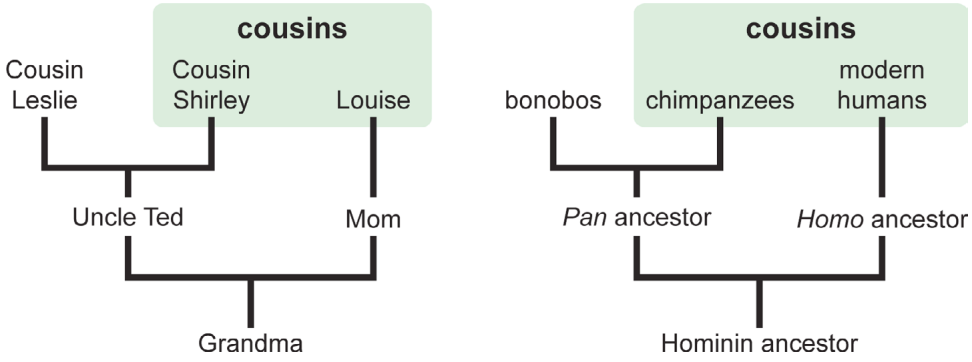
Many lines of evidence and decades of research support Darwin's central ideas—that evolution occurs through natural selection and that different species share common ancestors. In fact, Darwin's writing anticipated many of the key components of modern evolutionary theory. However, scientists now think that Darwin was wrong about some things (e.g., his ideas about the mechanism of inheritance). And, of course, Darwin didn't anticipate *all* parts of modern evolutionary theory (e.g., genetic drift). As scientists find new lines of evidence and new ways of explaining that evidence, their ideas about the how the world works change. This is a normal part of science—so the fact that scientists now reject some aspects of Darwin's thinking about evolution is not surprising and reflects normal scientific progress.

❖ What happened to the dinosaurs?

Some dinosaurs evolved into birds and remain alive today. However, many dinosaur lineages—along with tons of other sorts of organisms—went extinct about 65 million years ago at the end of the Cretaceous period. Their extinction was probably related to a massive asteroid that struck Earth and that may have thrown up a sun-blotting cloud of dust and ignited wildfires and/or oil deposits. Around the same time, the earth was also experiencing climate change and significant volcanic activity that may have further contributed to the extinctions.

❖ Did humans evolve from chimpanzees?

No. Humans did not evolve from chimpanzees. Humans and chimps are both modern organisms. Our relationship is more like that of cousins than that of children to their parents. We share a recent common ancestor with one another. That ancestor was neither chimp nor human—but it was an ape. This means that, technically, humans are considered to *be* apes—just as we are considered to be primates, mammals, vertebrates, and animals.



❖ Are humans still evolving?

Since evolution is simply changes in gene frequency in a population from one generation to the next, the answer to this question is almost certainly "yes." At the very least, the frequencies of different gene versions change a small amount each generation due to genetic drift. However, more significant evolutionary change may be occurring as well. For example, genes for resistance to HIV may be spreading in some populations, and other genes correlated with producing fewer offspring may be decreasing in frequency. Though this is an area of active research, one thing is for certain: modern humans have changed the ways that natural selection can act on us. Our ability to mediate our environments with technology—to keep ourselves warm, to treat

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diabetes with insulin, and to provide food for those without farming, hunting, or gathering skills, amongst a myriad of other cultural innovations—has changed our evolutionary landscape. So, for example, because of the availability of insulin in many developed countries, the gene versions that contribute to juvenile diabetes are no longer strongly selected against. But this sort of technological innovation doesn't necessarily mean that we've stopped evolving. It may just be indicative of the changing rules of the evolutionary game that we humans are playing today.

❖ Is evolution against religion?

The idea that one always has to choose between science and religion is incorrect. Of course, some religious beliefs explicitly contradict science (e.g., the belief that the world and all life on it were created in six literal days); however, most religious groups have no conflict with the theory of evolution or other scientific findings. In fact, many religious people, including theologians, feel that a deeper understanding of nature actually enriches their faith. Moreover, in the scientific community there are thousands of scientists who are devoutly religious and also accept evolution.

❖ Why doesn't this exhibit discuss God's role in evolution or creationism?

Religion and science are very different things. In science, only natural causes are used to explain natural phenomena, while religion deals with beliefs that are beyond the natural world. Creationism deals with supernatural explanations and so is not a part of science. Because this is a science exhibit in a science museum, it is only appropriate to address scientific explanations. This exhibit is not a denouncement of religion; in fact, many people have no problem at all reconciling acceptance of evolution with religious faith and find that an understanding of science enriches their appreciation of the natural world.

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IV. Correcting misconceptions

Many visitors are likely to have misconceptions about how evolution works and what its implications are. Evolution can be tricky to understand for many reasons:

- it may occur over huge lengths of time that we have no direct experience with
- it involves changes in species, which may seem like fixed entities on human timescales
- it depends on variation within a population, but that variation is often subtle and non-obvious
- it results in adaptations that are well suited for their function, but does not rely on a conscious agent trying, wanting, or intending those adaptive changes to occur

To make your job even more difficult, some Creationist groups actively promote misconceptions.

As a docent, you can help clarify these issues by familiarizing yourself with some common misconceptions and following these tips:

- Actively listen to visitors' viewpoints.
- As you offer explanations, be sure to recognize what is correct or reasonable about the visitor's viewpoint. A learner can modify and rebuild their existing conceptions into more productive and accurate concepts.
- Avoid telling visitors that they are simply "wrong."
- Multiple concrete examples often help learners grasp abstract concepts.
- Avoid reinforcing misconceptions. Don't use intentional language (e.g., needs, wants, tries) to explain how adaptations came about.
- Be respectful but clear about how science works and what is and is not science.
- Recognize when to end the conversation.

❖ Misconception: Evolution means that life changed randomly or by chance.

Response: Chance is certainly a factor in evolution, but there are also non-random evolutionary mechanisms. Random mutation is the ultimate source of genetic variation; however, natural selection is not random. For example, some aquatic animals are more likely to survive and reproduce if they can move quickly through water. Speed helps them to capture prey and escape danger. Animals such as sharks, tuna, dolphins and ichthyosaurs have evolved streamlined body shapes that allow them to swim fast. As they evolved, individuals with more streamlined bodies were more likely to survive and reproduce. Individuals that survive and reproduce better in their environment will have more offspring (displaying the same traits) in the next generation. That's non-random selection. To say that evolution happens "by chance" ignores half of the picture.

Exhibit examples: Feathered dinosaurs didn't evolve randomly. The genes for feathers spread because feathered dinosaurs were able to leave behind more offspring than those without feathers. That's not random.

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❖ Misconception: Natural selection involves organisms "trying" or "wanting" to adapt.

Response: Natural selection leads to adaptation, but the process doesn't involve "trying." Natural selection relies on heritable genetic variation and selection among variants present in a population. Either an individual has genes that are good enough to survive and reproduce, or it does not — but it can't get the right genes by "trying."

Exhibit examples: Feathered dinosaurs didn't try to acquire feathers. It doesn't matter how much an unfeathered dinosaur might need them or want them; it can only get feathers if it happens to inherit the genes for feathers from its parents. Trying, wanting, and needing have nothing to do with it.

❖ Misconception: Acquired characteristics can be inherited.

Response: Traits that organisms acquire through interactions with the environment (e.g., strong muscles through exercise, short hair through a haircut, the ability to speak Swahili through Swahili lessons) are not passed on to offspring. Only traits encoded somewhere in the parents' genes can be inherited, and interacting with the environment in these ways (exercising, visiting a barber, Swahili lessons) cannot affect the content of one's genes. You might wonder then, where new genetic traits come from if not the environment. New genetic traits can only be acquired through mutation and *recombination*. Random mutation alters the DNA of reproductive cells, and recombination creates new combinations of genes within those cells. The offspring that are produced by those cells will then carry new gene versions or new combination of genes, and this may affect what traits they have. The new traits have nothing to do with the sort of environment the parent has experienced, but are instead the product of random processes. The new traits may or may not be a good fit for the environment. If they are a good fit, natural selection will increase their frequency in subsequent generations, and if they are not, their bearers are unlikely to produce many offspring.

recombination—a process in which pairs of chromosomes swap DNA with one another. This happens during gamete formation. A single parent cell (containing two sets of chromosomes) will form four daughter cells (with one complete set of chromosomes each). In the process of forming these daughter cells, recombination happens so that the chromosomes the daughter cells have are "mosaic," composed of different pieces of the parent cells' chromosomes. Recombination is important for evolution because it brings new combinations of genes together—a source of variation for natural selection to act upon.

Exhibit examples: In Charlie's story, baby dinosaurs get feathers because they inherit them from their parents, not because they experience cold weather. Similarly, the moths in *Who survives* don't become dark or light because of the color of the tree bark they sit on. Furthermore, a number of the discovery boxes emphasize that genetic inheritance is the reason that offspring have the traits they do.

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❖ Misconception: Genes can skip generations.

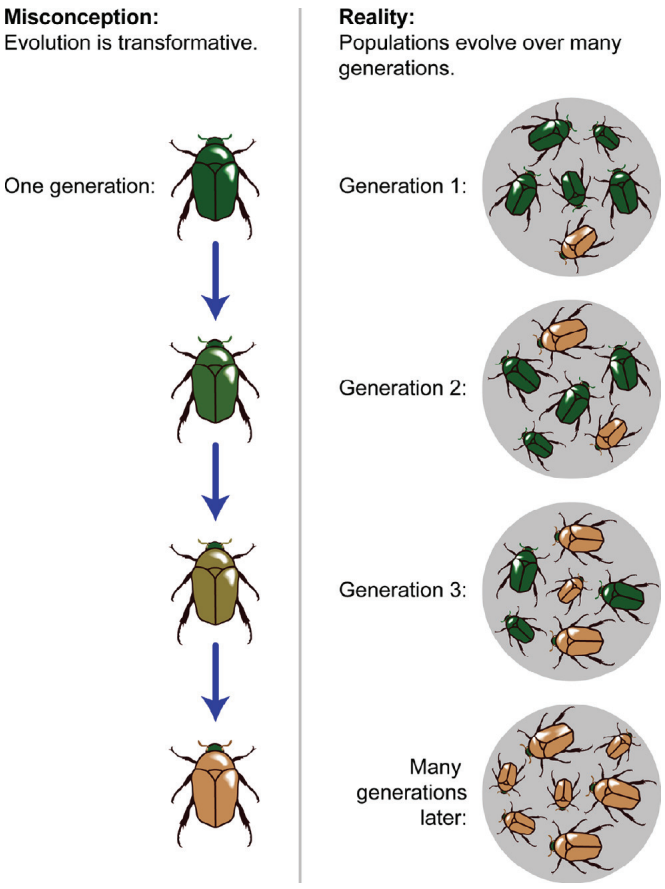
Response: You've probably observed traits that seem to "skip" generations (e.g., a grandma and granddaughter both have red hair while the mother has brown hair), but this doesn't mean that the genes that encode those traits are jumping around. We all inherit half of our genetic material from our mothers and half from our fathers. Whether or not the traits encoded in our genes actually show up in our bodies often depends on exactly what combination of gene versions we get from our parents. You might carry one gene for red hair (that you inherited from your mom)—but if you inherited a gene for brown hair from your dad, you won't have red hair. In other words, you can "carry" the gene for red hair without actually having red hair. The gene itself is still there—it didn't "skip" you. Genes can "go stealth" for many generations if they never happen to wind up in combination with the right gene version. So a great-great-great-grandma might pass the gene for red hair on to her great-great-great-granddaughter without the trait showing up in any of the intervening generations.

Exhibit examples: One of the discovery boxes (*Pieces of the past*) mentions features that skip generations. Other discovery boxes deal with genetic inheritance. It is important that you, as a docent, keep in mind the actual mechanisms behind inheritance to help visitors overcome their misconceptions.

❖ Misconception: Evolution is transformative; individual organisms evolve.

Response: Populations evolve over the course of generations; individuals do not evolve within the course of single lifetime. Of course, an individual may change over the course of his or her life through growth and development—but this is different from biological evolution. In biological evolution the frequency of different traits in a population changes from generation to generation.

Exhibit examples: Charlie's story clearly illustrates that the evolution of feathers takes place over the course of many generations, not an individual's lifetime. Furthermore, text in the main exhibit is designed to clarify this point.



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❖ Misconception: Evolution is like a climb up a ladder of progress; organisms are always getting better.

Response: It is true that natural selection weeds out individuals that are unfit in a particular situation, but for evolution, "good enough" is good enough. No organism has to be perfect. For example, many groups of organisms (like some mosses, protists, fungi, sharks, opossums, and crayfish) have changed little over great expanses of time. They are not marching up a ladder of progress. Rather, they are fit enough to survive and reproduce, and that is all that is necessary to ensure their existence. Other taxa may have changed and diversified a great deal — but that doesn't mean they got "better." After all, climates change, rivers shift course, new competitors invade — and what was "better" a million years ago, may not be "better" today. What works well in one location might not work so well in another. There is no universal scale that we can use to measure which organisms are "better" than others.

Exhibit examples: The relative scale of what is "better" in evolutionary terms is illustrated by Charlie's story. Flying is obviously advantageous for many birds, but wasn't "better" for kiwis. Many of the other exhibit features emphasize that what is advantageous depends on the situation the organism is in (e.g., the "best" color for moths depends on the color of the tree bark and the "best" beak shape for birds depends on the food sources available).

❖ Misconception: Evolution always leads to increased complexity.

Response: Not necessarily. Sometimes it does. Sometimes it doesn't. If we simply compare the forms of life that were probably around 3.5 billion years ago to the life forms that are around today, it is obvious that the "average" level of complexity is higher today than it was at life's origins. (Although this is probably just because, when life started out, it was at its lowest limit of complexity. It had nowhere to go but up!) On the other hand, there are many cases of simplification in evolution—for example, some insects have lost their wings through the course of their evolutionary history. And keep in mind that a lot of "simple" organisms are still around and are incredibly successful. The entire history of life could be referred to as the "Age of Bacteria" because bacteria have been, and still are, ubiquitous since the beginning of life on Earth.

Exhibit examples: Though the ability to fly is arguably more advanced or "complex" than not being able to fly, some birds (including the kiwi) have lost this ability through evolution.

❖ Misconception: Natural selection gives organisms what they "need."

Response: Natural selection has no intentions or senses; it cannot sense what a species "needs." If a population happens to have the genetic variation that allows some individuals to survive a particular challenge better than others, then those individuals will have more offspring in the next generation, and the population will evolve. If that genetic variation is not in the population, the population may still survive (but not evolve much) or it may die out. But it will not be granted what it "needs" by natural selection.

Exhibit examples: In Charlie's story, baby dinosaurs get feathers because they inherit them from their parents, not because they need them for protection from cold weather. Similarly, the moths in Who survives don't become dark or light because they need that color for camouflage.

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❖ Misconception: Evolution is "just" a theory.

Response: Scientific theories are explanations that are based on lines of evidence, enable valid predictions, and have been tested in many ways. In contrast, there is also a popular definition of theory — a "guess" or "hunch." These conflicting definitions often cause unnecessary confusion about evolution.

❖ Misconception: Evolution is a theory in crisis and is collapsing as scientists lose confidence in it.

Response: Scientists do not debate *whether* evolution (descent with modification) took place, but they do argue about *how* it took place. Details of the processes and mechanisms are vigorously debated. Antievolutionists may hear the debates about *how* evolution occurs and misinterpret them as debates about *whether* evolution occurs. Evolution is sound science and is treated accordingly by scientists and scholars worldwide.

❖ Misconception: Gaps in the fossil record disprove evolution.

Response: The fact that some transitional fossils are not preserved does not disprove evolution. Evolutionary biologists do not *expect* that all transitional forms will be found and realize that many species leave no fossils at all. Lots of organisms don't fossilize well, and the environmental conditions for forming good fossils are not that common. So, scientists actually *expect* that for many evolutionary changes, there will be gaps in the record. Also, scientists *have* found many transitional fossils. For example, there are many fossils of transitional organisms between whales and their terrestrial mammal ancestors.

Exhibit examples: Paleontologists have discovered many fossils of transitional organisms that help us understand how modern birds evolved from their non-flying dinosaur ancestors. *Archaeopteryx* and *Bambiraptor* are examples.

❖ Misconception: Evolutionary theory is incomplete and is currently unable to give a total explanation of life.

Response: Evolutionary science is a work in progress. New discoveries are made and explanations are adjusted when necessary. And in this respect, evolution is just like all other sciences. Research continues to add to our knowledge. While we don't know everything about evolution (or any other scientific discipline, for that matter), we do know a great deal about the history of life, the pattern of lineage-splitting through time, and the mechanisms that have caused these changes. And more will be learned in the future. To date, evolution is the only well-supported explanation for life's diversity.

Exhibit examples: It is true that scientists continue to investigate many questions regarding bird evolution—but that is the normal way that science works. The existence of open questions in this field does not mean that scientists have any doubts about the overarching theory of evolution.

❖ Misconception: The theory of evolution is flawed, but scientists won't admit it.

Response: Scientists have examined the supposed "flaws" that creationists claim exist in evolutionary theory and have found no support for these claims. These "flaws" are based on misunderstandings of evolutionary theory or misrepresentations of evidence. Scientists continue to refine the theory of evolution, but that doesn't mean it is "flawed." Science is a very competitive endeavor and if "flaws" were discovered, scientists would be more than glad to point them out.

Some of Darwin's ideas have been rejected or modified since his time. For example, we now know that

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Darwin's ideas about the mechanism of inheritance were simply wrong, and his idea that evolution generally proceeds at a slow, deliberate pace has been modified to include the idea that evolution can proceed at a *relatively* rapid pace under some circumstances. In this sense, "Darwinism" is continually being modified. Modification of theories to make them more representative of how things work is the role of scientists and of science itself.

Thus far, however, there have been no credible challenges to the basic Darwinian principles that evolution proceeds primarily by the mechanism of natural selection acting upon variation in populations and that different species share common ancestors. Scientists have not rejected Darwin's natural selection, but have improved and expanded it as more information has become available.

❖ Misconception: Evolution is not science because it is not observable or testable.

Response: Evolution is observable and testable. The misconception here is that science is limited to controlled experiments that are conducted in laboratories by people in white lab coats. Actually, much of science is accomplished by gathering evidence from the real world and inferring how things work. Astronomers cannot hold stars in their hands and geologists cannot go back in time, but in both cases scientists can learn a great deal by using multiple lines of evidence to make valid and useful inferences about their objects of study. The same is true of the study of the evolutionary history of life on Earth, and as a matter of fact, some mechanisms of evolution *are* studied through direct experimentation, as they are in more familiar sciences.

Exhibit examples: The evolutionary ideas presented in this exhibit have been thoroughly tested. In fact some of the lines of evidence that test them (fossils of transitional forms, homologous structures) are presented here.

❖ Misconception: Evolution leads to immoral behavior. If children are taught that they are animals, they will behave like animals.

Response: We humans share anatomical and biochemical traits with other animals, and there are many behaviors that we share—we care for our young, we form cooperative groups, etc. There are other behaviors that are specific to particular animals. In this sense, humans act like humans, slugs act like slugs, and squirrels act like squirrels. It is unlikely that children, upon learning that they are related to all other animals, will start to behave like jellyfish or raccoons. Evolution does not make ethical statements about right and wrong. It simply helps us understand how life has changed and continues to change over time. It is up to us, as societies and individuals, to decide what constitutes ethical and moral behavior.

❖ Misconception: Evolution supports the idea that 'might makes right' and rationalizes the oppression of some people by others.

Response: In the nineteenth and early twentieth centuries, a philosophy called "Social Darwinism" arose from a misguided effort to apply lessons from biological evolution to society. According to this view, society should allow the weak and less fit to fail and die, and that this is not only good policy, but morally right. Supposedly, evolution by natural selection provided support for these ideas. Pre-existing prejudices were rationalized by the notion that colonized nations, poor people, or disadvantaged minorities must have deserved their situations because they were "less fit" than those who were better off. This misapplication of science was used to promote social and political agendas. The "science" of Social Darwinism was refuted. Biological evolution has stood the test of time, but Social Darwinism has not.

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❖ Misconception: Evolution and religion are incompatible.

Response: Religion and science are very different things. In science, only natural causes are used to explain natural phenomena, while religion deals with beliefs that are beyond the natural world. The misconception that one always has to choose between science and religion is incorrect. Of course, some religious beliefs explicitly contradict science (e.g., the belief that the world and all life on it were created in six literal days); however, most religious groups have no conflict with the theory of evolution or other scientific findings. In fact, many religious people, including theologians, feel that a deeper understanding of nature actually enriches their faith. Moreover, in the scientific community there are thousands of scientists who are devoutly religious and also accept evolution.

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V. Avoiding potential pitfalls

As a docent, guide, or museum professional, visitors look to you as an authority on the material in the exhibit. When you talk about evolution with visitors, try to avoid these language pitfalls:

- **Function not purpose**. The purpose of a hammer is to pound nails. One function of a hand is to hold a hammer. Designed tools have purposes, but evolved structures and behaviors of living things have functions. Talking about the "purpose" of feathers suggests that they were designed by someone.
- **Adapted not designed**. Use of the word "design" may imply that living things are designed and that there is a plan at work. The use of terms like "structure" and "adaptation" are more appropriate. For example, "How is a kiwi designed to eat insects?" could be replaced by, "How is a kiwi adapted to eating insects?" or, "What structures and behaviors aid a kiwi in eating insects?"
- **Specialized not advanced/ancestral not primitive**. "Advanced" and "primitive" remind us of progress or steps on a ladder—but that's not how evolution works. Opossums, for example, have retained some traits of the ancestral marsupial, but they are not primitive mammals. They are well adapted to their omnivorous lifestyle and are every bit as successful as other modern mammals. Similarly, it would be incorrect to describe non-avian dinosaurs as primitive and birds as advanced. Instead, you can just say that birds evolved from dinosaur ancestors, while recognizing that many dinosaur lineages evolved specialized traits that suited their lifestyles.
- **Theory vs. hypothesis.** A theory is a broad, natural explanation for a wide range of phenomena. Theories are concise, coherent, systematic, predictive, and broadly applicable, often integrating and generalizing many hypotheses. Gravitational theory, for example, attempts to explain the nature of gravity. Cell theory explains the workings of cells. Evolutionary theory explains the history of life on Earth. Theories accepted by the scientific community (as evolution is) are generally strongly supported by many different lines of evidence, but may be modified with new evidence and perspectives. A hypothesis, on the other hand, is a proposed explanation for a fairly narrow set of phenomena. Hypotheses may come and go by the thousands, but theories often remain to be tested and modified for decades or centuries. To describe evolution as "just" a theory misleads people about the status of theories in science and the importance of evolution to an accurate scientific understanding of biology.
- **Believe vs. accept.** In the museum, you may be asked "Do you believe in evolution?" Since we associate the word *belief* with faith, this can be a tricky question. Scientists generally prefer the term *accept* which implies that the idea in question is supported by evidence. If asked this question, you might explain the difference between *believe* and *accept* and say that you accept the fact that the Earth is very old and life has changed over billions of years because that is what the evidence tells us.
- **Adapt vs. learn.** Colloquially, we might say that we adapt to cold weather by putting on more clothing. Unfortunately, visitors may apply this definition to evolution, resulting in the erroneous impression that evolution consists of individuals changing their behavior or learning over the course of a lifetime. By using the word *adapt* only when referring to actual evolutionary change, you can avoid this pitfall. Along the same lines, don't say that some dinosaurs "learned" to fly, when you really mean that they evolved the ability to fly.
- **Ancestor vs. relative** When we fail to distinguish between an ancestor and a relative, we set visitors up for confusion. For example, humans and chimps are related, but humans did not evolve from chimps any more than chimps evolved from humans. Similarly, birds do have dinosaur ancestors—but not all dinosaurs are in birds' ancestral lineage. For example, pigeons and *T. rex* are evolutionary cousins; pigeons did not evolve from *T. rex*.
- **Evolution vs. development.** Development is the process that occurs as a living thing grows up. Evolution is a change of gene frequency in a population over generations. It is more correct to say that some dinosaurs *evolved* the ability to fly than that they *developed* the ability to fly.

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VI. Dealing with controversy in the museum

❖ Why the controversy?

There is no scientific controversy over evolution: biologists agree that evolution is the most useful and well-supported explanation for life's diversity and history available. However, some organizations in this country actively promote the rejection of evolution. These groups and like-minded individuals have created a social controversy over evolution. Social objections to evolutionary theory frequently cite its supposed incompatibility with belief in supernatural beings, like God, and the fear that people will see the explanations offered by evolutionary theory as replacements for the potential role of a supernatural being in generating the diversity of life.

The most important thing to remember in all this is that **there doesn't have to be a conflict between evolution and religion.** Many scientists both believe in higher powers and accept evolution, and many religious groups have made explicit statements regarding the compatibility of their views with evolutionary theory and their support for evolution education. In general, **scientific theories (including evolution) offer explanations for the natural world around us, while religion deals with the supernatural world; the two deal with separate domains.** The tools of science can only help us learn about the natural world; they cannot inform us about the nature of the supernatural and what supernatural entities may or may not exist, which are matters of personal faith.

❖ What beliefs might be encountered?

Most controversy you are likely to encounter will come from Creationists. There are a variety of groups that promote different versions of Creationism. Here are a few of the most common sorts of beliefs:

- that the Earth and all of its species were created in their current forms less than 10,000 years ago.
- that different "kinds" of animals (e.g., cats) were created and then evolved into different species over long periods of time.
- that humans were created, but other organisms evolved.
- that a supernatural being has intervened in evolution

Intelligent Design (ID) is a Creationist movement that masquerades as science. ID proponents claim that structural complexity cannot arise through natural causes (like evolution), but requires the direct hand of a designer. They claim that structures such as bacterial flagella, events such as the origin of life, and major innovations such as the establishment of the basic animal body forms are too complex to be explained naturally. Thus, ID demands that a role be left for the intelligent designer, implied but not always stated to be God.

Intelligent Design isn't science for a variety of reasons. Science deals with the natural world, but ID relies on the existence of a designer—i.e., a supernatural being. Science deals with testable ideas, but since ID involves an unpredictable supernatural being, it is not testable. Science relies on feedback from the scientific community, but ID proponents reject the feedback of the scientific community and largely fail to participate in that community. Scientific ideas lead to ongoing research, but ID has not inspired ongoing scientific research. The scientific community, the United States judicial system, many religious organizations, and educational groups across the country have identified ID as a religious movement and not as science.

❖ Strategies

- Learn about evolution. Review the information in this guide and in other resources. Get comfortable explaining it to others.
- Don't avoid using the word *evolution*. This is a science museum and evolution is an accepted scientific theory. By treating the subject matter-of-factly, you help communicate the scientific consensus on evolution to visitors.

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- Actively listen to visitors' viewpoints. Create an environment for a respectful exchange of views.
- Be respectful but clear about how science works and what is and is not science.
- Don't get frustrated, defensive, or try to win an argument with a devoted Creationist. If the atmosphere of a conversation becomes tense or charged, acknowledge that you have different views or that a science museum is not the place to have a philosophical or religious debate, and leave the area. Always be respectful.
- Recognize when to end the conversation.
- Recognize probes designed to frustrate you. Some Creationist groups rely on a set of arguments that misinterpret scientific evidence and ideas. However, few people who use these arguments understand their details. If you hear something like the probes below, a response asking the person to explain his or her meaning or the details of the argument may defuse the situation.

Common Creationist probes:

- Wasn't the **Miller-Urey experiment** on the origins of life wrong?
- Doesn't the **second law of thermodynamics** make the evolution of complex organisms impossible?
- Don't the **Cambrian explosion fossils** show that major animal groups originated fully formed without precursors?
- Isn't the idea of homology (that organisms often share traits because they were inherited from a common ancestor) **circular or tautological**?
- Don't **mutations destroy information**? How could mutations lead to new genetic information?
- I heard that those **drawings of similar vertebrate embryos were faked** and that the early developmental stages of different vertebrate groups are not very similar.
- If **we evolved from monkeys**, why are there still monkeys?
- Isn't the **bacteria flagellum irreducibly complex**?
- Why do scientists claim that ***Archaeopteryx* is the missing link** between dinosaurs and birds when it's not?
- Weren't the **peppered moth photos staged**?
- I heard that Darwin's finches on the Galapagos evolved during droughts but then reversed their evolution once the drought was over. So there was **no net evolution** . . .
- Mutant fruit flies with an extra pair of wings are sometimes used as an example of evolution, but those **mutant wings have no muscles and aren't functional**.
- **Scientists are still arguing about which species are human ancestors.** If they can't get their story straight, why should we believe them?

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