Misconceptions about evolution

I. Misconceptions about evolutionary theory and processes

- **MISCONCEPTION: Evolution is a theory about the origin of life.**

  CORRECTION: Evolutionary theory *does* encompass ideas and evidence regarding life's origins (e.g., whether or not it happened near a deep-sea vent, which organic molecules came first, etc.), but this is not the central focus of evolutionary theory. Most of evolutionary biology deals with how life changed *after* its origin. Regardless of how life started, afterwards it branched and diversified, and most studies of evolution are focused on those processes.

- **MISCONCEPTION: Evolutionary theory implies that life evolved (and continues to evolve) randomly, or by chance.**

  CORRECTION: Chance and randomness *do* factor into evolution and the history of life in many different ways; however, some important mechanisms of evolution are non-random and these make the overall process non-random. For example, consider the process of natural selection, which results in adaptations — features of organisms that appear to suit the environment in which the organisms live (e.g., the fit between a flower and its pollinator, the coordinated response of the immune system to pathogens, and the ability of bats to echolocate). Such amazing adaptations clearly did not come about "by chance." They evolved via a combination of random and non-random processes. The process of mutation, which generates genetic variation, is random, but selection is non-random. Selection favored variants that were better able to survive and reproduce (e.g., to be pollinated, to fend off pathogens, or to navigate in the dark). Over many generations of random mutation and non-random selection, complex adaptations evolved. To say that evolution happens "by chance" ignores half of the picture. To learn more about the process of natural selection, visit our article on this topic. To learn more about random mutation, visit our article on DNA and mutations.

- **MISCONCEPTION: Evolution results in progress; organisms are always getting better through evolution.**

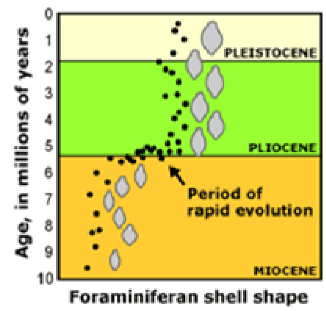
  CORRECTION: One important mechanism of evolution, natural selection, *does* result in the evolution of improved abilities to survive and reproduce; however, this does not mean that evolution is progressive — for several reasons. First, as described in a misconception below (link to "Natural selection produces organisms perfectly suited to their environments"), natural selection does not produce organisms perfectly suited to their environments. It often allows the survival of individuals with a range of traits — individuals that are "good enough" to survive. Hence, evolutionary change is not always necessary for species to persist. Many taxa (like some mosses, fungi, sharks, opossums, and crayfish) have changed little physically over great expanses of time. Second, there are other mechanisms of evolution that don't cause adaptive change. Mutation, migration, and genetic drift may cause populations to evolve in ways that are actually harmful overall or make them less suitable for their environments. For example, the Afrikaner population of South Africa has an unusually high frequency of the gene responsible for Huntington's disease because the gene version drifted to high frequency as the population grew from a small starting population. Finally, the whole idea of "progress" doesn't make sense when it comes to evolution. Climates change, rivers shift course, new competitors invade — and an organism with traits that are beneficial in one situation may be poorly equipped for survival when the environment changes. And even if we focus on a single environment and habitat, the idea of how to measure "progress" is skewed by the perspective of the observer. From a plant's perspective, the best measure of progress might be photosynthetic ability; from a spider's it might be the efficiency of a venom delivery system; from a human's, cognitive ability. It is tempting to see evolution as a grand progressive ladder with *Homo sapiens* emerging at the top. But evolution produces a tree, not a ladder — and we are just one of many twigs on the tree.

- **MISCONCEPTION: Individual organisms can evolve during a single lifespan.**

  CORRECTION: Evolutionary change is based on changes in the genetic makeup of populations over time. Populations, not individual organisms, evolve. Changes in an individual over the course of its lifetime may be developmental (e.g., a male bird growing more colorful plumage as it reaches sexual maturity) or may be caused by how the environment affects an organism (e.g., a bird losing feathers because it is infected with many parasites); however, these shifts are not caused by changes in its genes. While it would be handy if there were a way for environmental changes to cause adaptive changes in our genes — who wouldn't want a gene for malaria resistance to come along with a vacation to Mozambique? — evolution just doesn't work that way. New gene variants (i.e., alleles) are produced by random mutation, and over the course of many generations, natural selection may favor advantageous variants, causing them to become more common in the population.

- **MISCONCEPTION: Evolution only occurs slowly and gradually.**

  CORRECTION: Evolution occurs slowly and gradually, but it can also occur rapidly. We have many examples of slow and steady evolution — for example, the gradual evolution of whales from their land-dwelling, mammalian ancestors, as documented in the fossil record. But we also know of many cases in which evolution has occurred rapidly. For example, we have a detailed fossil record showing how some species of single-celled organism, called foraminiferans, evolved new body shapes in the blink of a geological eye, as shown at right.



  Similarly, we can observe rapid evolution going on around us all the time. Over the past 50 years, we've observed squirrels evolve new breeding times in response to climate change, a fish species evolve resistance to toxins dumped into the Hudson River, and a host of microbes evolve resistance to new drugs we've developed. Many different factors can foster rapid evolution — small population size, short generation time, big shifts in environmental conditions — and the evidence makes it clear that this has happened many times. To learn more about the pace of evolution, visit Evolution 101. To learn more about rapid evolution in response to human-caused changes in the environment, visit our news story on climate change , our news story on the evolution of PCB-resistant fish, or our research profile on the evolution of fish size in response to our fishing practices.

- **MISCONCEPTION: Because evolution is slow, humans cannot influence it.**

  CORRECTION: As described in the misconception about evolutionary rates above, evolution sometimes occurs quickly. And since humans often cause major changes in the environment, we are frequently the instigators of evolution in other organisms. Here are just a few examples of human-caused evolution for you to explore:

  — Several species have evolved in response to climate change.

  — Fish populations have evolved in response to our fishing practices.

  — Insects like bedbugs and crop pests have evolved resistance to our pesticides.

  — Bacteria, HIV, malaria, and cancer have evolved resistance to our drugs.

- **MISCONCEPTION: Genetic drift only occurs in small populations.**

  CORRECTION: Genetic drift has a larger effect on small populations, but the process occurs in all populations — large or small. Genetic drift occurs because, due to chance, the individuals that reproduce may not exactly represent the genetic makeup of the whole population. For example, in one generation of a population of captive mice, brown-furred individuals may reproduce more than white-furred individuals, causing the gene version that codes for brown fur to increase in the population — not because it improves survival, just because of chance. The same process occurs in large populations: some individuals may get lucky and leave many copies of their genes in the next generation, while others may be unlucky and leave few copies. This causes the frequencies of different gene versions to "drift" from generation to generation. However, in large populations, the changes in gene frequency from generation to generation tend to be small, while in smaller populations, those shifts may be much larger. Whether its impact is large or small, genetic drift occurs *all* the time, in *all* populations. It's also important to keep in mind that genetic drift may act at the same time as other mechanisms of evolution, like natural selection and migration. To learn more about genetic drift, visit Evolution 101. To learn more about population size as it relates to genetic drift, visit this advanced article.

- **MISCONCEPTION: Humans are not currently evolving.**

  CORRECTION: Humans are now able to modify our environments with technology. We have invented medical treatments, agricultural practices, and economic structures that significantly alter the challenges to reproduction and survival faced by modern humans. So, for example, because we can now treat diabetes with insulin, the gene versions that contribute to juvenile diabetes are no longer strongly selected against in developed countries. Some have argued that such technological advances mean that we've opted out of the evolutionary game and set ourselves beyond the reach of natural selection — essentially, that we've stopped evolving. However, this is not the case. Humans still face challenges to survival and reproduction, just not the same ones that we did 20,000 years ago. The direction, but not the fact of our evolution has changed. For example, modern humans living in densely populated areas face greater risks of epidemic diseases than did our hunter-gatherer ancestors (who did not come into close contact with so many people on a daily basis) — and this situation favors the spread of gene versions that protect against these diseases. Scientists have uncovered many such cases of recent human evolution. Explore these links to learn about:

  — genetic evidence regarding recent human evolution

  — the recent evolution of adaptations that allow humans to thrive at high altitudes

  — the recent evolution of human genetic traits that protect against malaria

  — the recent evolution of lactose tolerance in humans

- **MISCONCEPTION: Species are distinct natural entities, with a clear definition, that can be easily recognized by anyone.**

  CORRECTION: Many of us are familiar with the biological species concept, which defines a species as a group of individuals that actually or potentially interbreed in nature. That definition of a species might seem cut and dried — and for many organisms (e.g., mammals), it works well — but in many other cases, this definition is difficult to apply. For example, many bacteria reproduce mainly asexually. How can the biological species concept be applied to them? Many plants and some animals form hybrids in nature, even if they largely mate within their own groups. Should groups that occasionally hybridize in selected areas be considered the same species or separate species? The concept of a species is a fuzzy one because humans invented the concept to help get a grasp on the diversity of the natural world. It is difficult to apply because the term species reflects our attempts to give discrete names to different parts of the tree of life — which is not discrete at all, but a continuous web of life, connected from its roots to its leaves. To learn more about the biological species concept, visit Evolution 101. To learn about other species concepts, visit this side trip.

II. Misconceptions about natural selection and adaptation

- **MISCONCEPTION: Natural selection involves organisms trying to adapt.**

  CORRECTION: Natural selection leads to the adaptation of species over time, but the process does not involve effort, trying, or wanting. Natural selection naturally results from genetic variation in a population and the fact that some of those variants may be able to leave more offspring in the next generation than other variants. That genetic variation is generated by random mutation — a process that is unaffected by what organisms in the population want or what they are "trying" to do. Either an individual has genes that are good enough to survive and reproduce, or it does not; it can't get the right genes by "trying." For example bacteria do not evolve resistance to our antibiotics because they "try" so hard. Instead, resistance evolves because random mutation happens to generate some individuals that are better able to survive the antibiotic, and these individuals can reproduce more than other, leaving behind more resistant bacteria. To learn more about the process of natural selection, visit our article on this topic. To learn more about random mutation, visit our article on DNA and mutations.

- **MISCONCEPTION: Natural selection gives organisms what they need.**

  CORRECTION: Natural selection has no intentions or senses; it cannot sense what a species or an individual "needs." Natural selection acts on the genetic variation in a population, and this genetic variation is generated by random mutation — a process that is unaffected by what organisms in the population need. If a population happens to have genetic variation that allows some individuals to survive a challenge better than others or reproduce more 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 survive anyway (but not evolve via natural selection) or it may die out. But it will not be granted what it "needs" by natural selection. To learn more about the process of natural selection, visit our article on this topic. To learn more about random mutation, visit our article on DNA and mutations.

- **MISCONCEPTION: Humans can't negatively impact ecosystems, because species will just evolve what they need to survive.**

  CORRECTION: As described in the misconception above, natural selection does not automatically provide organisms with the traits they "need" to survive. Of course, *some* species may possess traits that allow them to thrive under conditions of environmental change caused by humans and so may be selected for, but others may not and so may go extinct. If a population or species doesn't happen to have the right kinds of genetic variation, it will not evolve in response to the environmental changes wrought by humans, whether those changes are caused by pollutants, climate change, habitat encroachment, or other factors. For example, as climate change causes the Arctic sea ice to thin and break up earlier and earlier, polar bears are finding it more difficult to obtain food. If polar bear populations don't have the genetic variation that would allow some individuals to take advantage of hunting opportunities that are not dependent on sea ice, they could go extinct in the wild.

- **MISCONCEPTION: Natural selection acts for the good of the species.**

  CORRECTION: When we hear about altruism in nature (e.g., dolphins spending energy to support a sick individual, or a meerkat calling to warn others of an approaching predator, even though this puts the alarm sounder at extra risk), it's tempting to think that those behaviors arose through natural selection that favors the survival of the species — that natural selection promotes behaviors that are good for the species as a whole, even if they are risky or detrimental for individuals in the population. However, this impression is incorrect. Natural selection has no foresight or intentions. It simply selects among individuals in a population, favoring traits that enable individuals to survive and reproduce, yielding more copies of those individuals' genes in the next generation. Theoretically, in fact, a trait that is advantageous to the individual (e.g., being an efficient predator) could become more and more frequent and wind up driving the whole population to extinction (e.g., if the efficient predation actually wiped out the entire prey population, leaving the predators without a food source).

So what's the evolutionary explanation for altruism if it's not for the good of the species? There are many ways that such behaviors can evolve. For example, if altruistic acts are "repaid" at other times, this sort of behavior may be favored by natural selection. Similarly, if altruistic behavior increases the survival and reproduction of an individual's kin (who are also likely to carry altruistic genes), this behavior can spread through a population via natural selection. To learn more about the process of natural selection, visit our article on this topic.

Advanced students of evolutionary biology may be interested to know that selection can act at different levels and that, in some circumstances, species-level selection may occur. However, it's important to remember that, even in this case, selection has no foresight and is not "aiming" at any outcome; it is simply favoring the reproducing units that are best at leaving copies of themselves in the next generation. To learn more about levels of selection, visit our side trip on this topic.

- **MISCONCEPTION: The fittest organisms in a population are those that are strongest, healthiest, fastest, and/or largest.**

  CORRECTION: In evolutionary terms, *fitness* has a very different meaning than the everyday meaning of the word. An organism's evolutionary fitness does not indicate its health, but rather its ability to get its genes into the next generation. The more fertile offspring an organism leaves in the next generation, the fitter it is. This doesn't always correlate with strength, speed, or size. For example, a puny male bird with bright tail feathers might leave behind more offspring than a stronger, duller male, and a spindly plant with big seed pods may leave behind more offspring than a larger specimen — meaning that the puny bird and the spindly plant have higher evolutionary fitness than their stronger, larger counterparts. To learn more about evolutionary fitness, visit Evolution 101.

- **MISCONCEPTION: Natural selection is about survival of the very fittest individuals in a population.**

  CORRECTION: Though "survival of the fittest" is the catchphrase of natural selection, "survival of the fit enough" is more accurate. In most populations, organisms with many different genetic variations survive, reproduce, and leave offspring carrying their genes in the next generation. It is not simply the one or two "best" individuals in the population that pass their genes on to the next generation. This is apparent in the populations around us: for example, a plant may not have the genes to flourish in a drought, or a predator may not be quite fast enough to catch her prey every time she is hungry. These individuals may not be the "fittest" in the population, but they are "fit enough" to reproduce and pass their genes on to the next generation. To learn more about the process of natural selection, visit our article on this topic. To learn more about evolutionary fitness, visit Evolution 101.

- **MISCONCEPTION: Natural selection produces organisms perfectly suited to their environments.**

  CORRECTION: Natural selection is not all-powerful. There are many reasons that natural selection cannot produce "perfectly-engineered" traits. For example, living things are made up of traits resulting from a complicated set of trade-offs — changing one feature for the better may mean changing another for the worse (e.g., a bird with the "perfect" tail plumage to attract mates maybe be particularly vulnerable to predators because of its long tail). And of course, because organisms have arisen through complex evolutionary histories (not a design process), their future evolution is often constrained by traits they have already evolved. For example, even if it were advantageous for an insect to grow in some way other than molting, this switch simply could not happen because molting is embedded in the genetic makeup of insects at many levels. To learn more about the limitations of natural selection, visit our module on misconceptions about natural selection and adaptation.

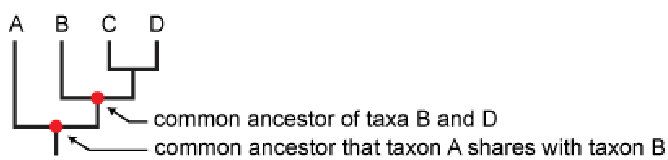
- **MISCONCEPTION: All traits of organisms are adaptations.**

  CORRECTION: Because living things have so many impressive adaptations (incredible camouflage, sneaky means of catching prey, flowers that attract just the right pollinators, etc.), it's easy to assume that *all* features of organisms must be adaptive in some way — to notice something about an organism and automatically wonder, "Now, what's that *for*?" While some traits are adaptive, it's important to keep in mind that many traits are not adaptations at all. Some may be the chance results of history. For example, the base sequence GGC codes for the amino acid glycine simply because that's the way it happened to start out — and that's the way we inherited it from our common ancestor. There is nothing special about the relationship between GGC and glycine. It's just a historical accident that stuck around. Others traits may be by-products of another characteristic. For example, the color of blood is not adaptive. There's no reason that having red blood is any better than having green blood or blue blood. Blood's redness is a by-product of its chemistry, which causes it to reflect red light. The chemistry of blood may be an adaptation, but blood's color is not an adaptation. To read more about explanations for traits that are not adaptive, visit our module on misconceptions about natural selection and adaptation. To learn more about what traits are adaptations, visit another page in the same module.

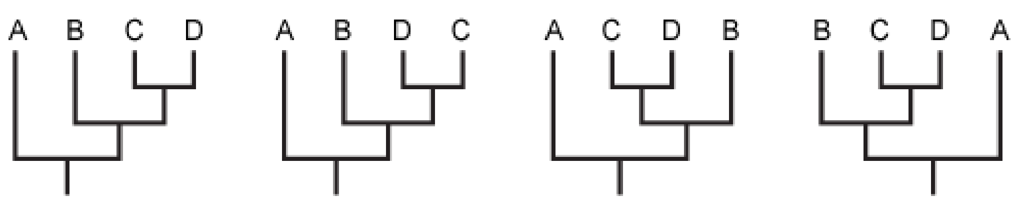
III. Misconceptions about evolutionary trees

- **MISCONCEPTION: Taxa that are adjacent on the tips of phylogeny are more closely related to one another than they are to taxa on more distant tips of the phylogeny.**

  CORRECTION: In a phylogeny, information about relatedness is portrayed by the pattern of branching, not by the order of taxa at the tips of the tree. Organisms that share a more recent branching point (i.e., a more recent common ancestor) are more closely related than are organisms connected by a more ancient branching point (i.e., one that is closer to the root of the tree). For example, on the tree below, taxon A is adjacent to B and more distant from C and D. However, taxon A is equally closely related to taxa B, C, and D. The ancestor/branch point shared by A and B is the same as the ancestor/branch point shared by A and C, as well as by A and D. Similarly, in the tree below, taxon B is adjacent to taxon A, but taxon B is actually more closely related to taxon D. That's because taxa B and D share a more recent common ancestor (labeled on the tree below) than do taxa B and A.



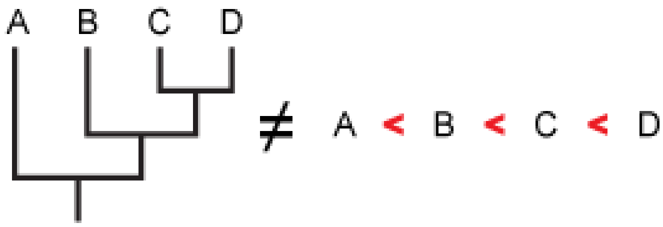
  It may help to remember that the same set of relationships can be portrayed in many different ways. The following phylogenies are all equivalent. Even though each phylogeny below has a different order of taxa at the tips of the tree, each portrays the same pattern of branching. The information in a phylogeny is contained in the branching pattern, not in the order of the taxa at the tips of the tree.



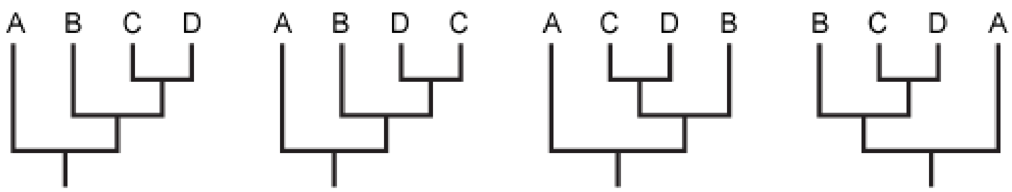
  To learn more phylogenetics, visit our advanced tutorial on the topic.

- **MISCONCEPTION: Taxa that appear near the top or right-hand side of a phylogeny are more advanced than other organisms on the tree.**

  CORRECTION: This misconception encompasses two distinct misunderstandings. First, when it comes to evolution, terms like "primitive" and "advanced" don't apply. These are value judgments that have no place in science. One form of a trait may be *ancestral* to another more *derived* form, but to say that one is primitive and the other advanced implies that evolution entails progress — which is not the case. For more details, visit our misconception on this topic. Second, an organism's position on a phylogeny only indicates its relationship to other organisms, not how adaptive or specialized or extreme its traits are. For example, on the tree below, taxon D may be more or less specialized than taxa A, B, and C.



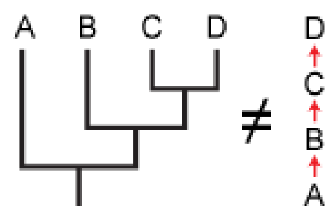
  It may help to remember that the same set of relationships can be portrayed in many different ways. The information in a phylogeny is contained in the branching pattern, not in the order of the taxa at the tips of the tree. The following phylogenies are all equivalent, but have different taxa positioned at the right-hand side of the phylogeny. There is no relationship between the order of taxa at the tips of a phylogeny and evolutionary traits that might be considered "advanced."



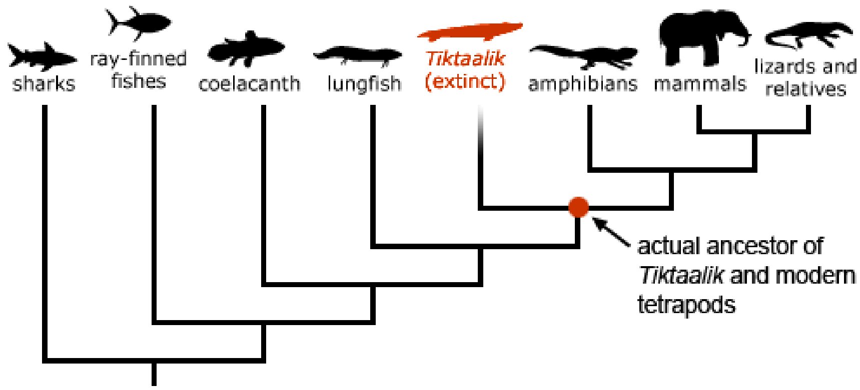
To learn more phylogenetics, visit our advanced tutorial on the topic.

- **MISCONCEPTION: Taxa that are nearer the bottom or left-hand side of a phylogeny represent the ancestors of the other organisms on the tree.**

  CORRECTION: On phylogenies, ancestral forms are represented by branches and branching points, not by the tips of the tree. The tips of the tree (wherever they are located — top, bottom, right, or left) represent descendents, and the tree itself represents the relationships among these descendents. In the phylogeny at right, taxon A is the cousin of taxa B, C, and D — not their ancestor.



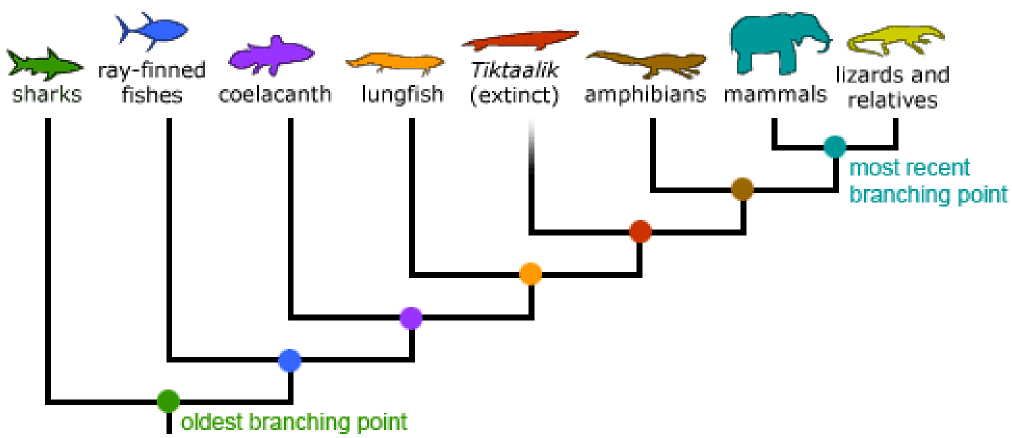
  This is true even if the organisms shown on the phylogeny are extinct. For example, *Tiktaalik* (shown on the phylogeny at the top of the next page) is an extinct, fish-like organism that is closely related to the ancestor of modern amphibians, mammals, and lizards. Though *Tiktaalik* is extinct, it is not an ancestral form and so is shown at a tip of the phylogeny, not as a branch or node. The actual ancestor of *Tiktaalik*, as well as that of modern amphibians, mammals, and lizards, is shown on the phylogeny on the next page.



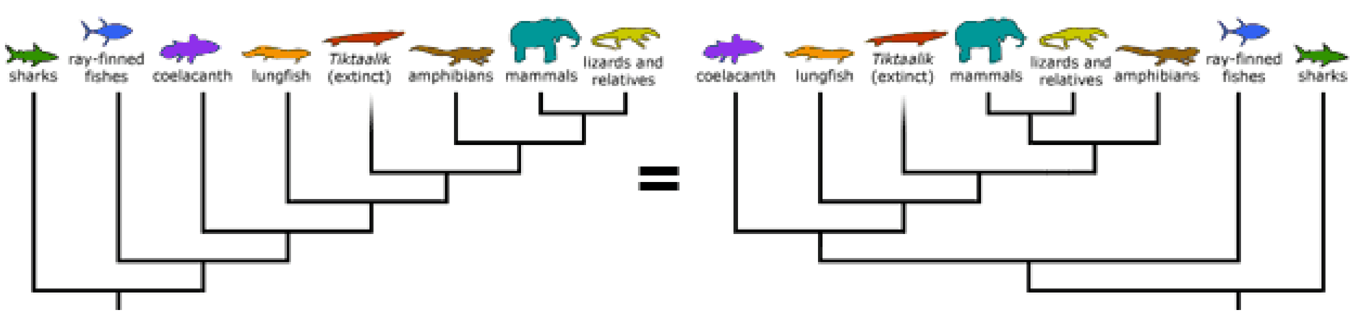
To [learn more phylogenetics](), visit our advanced tutorial on the topic.

- **MISCONCEPTION: Taxa that are nearer the bottom or left-hand side of a phylogeny evolved earlier than other taxa on the tree.**

  CORRECTION: It is the order of branching points from root to tip on a phylogeny that indicate the order in which different clades split from one another — not the order of taxa at the tips of the phylogeny. On the phylogeny below, the earliest and most recent branching points are labeled.



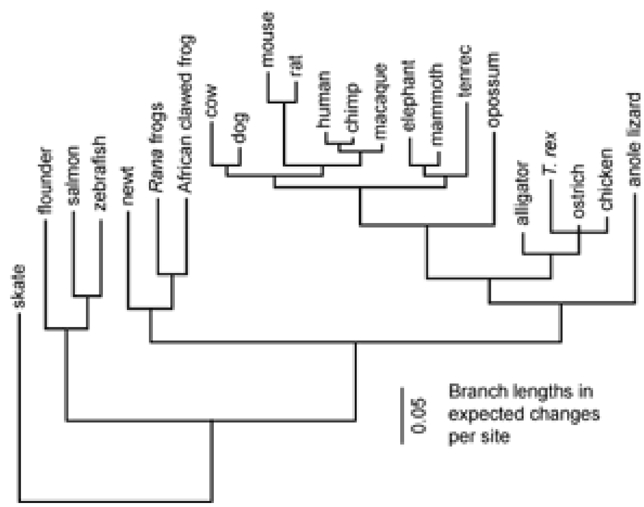
  Usually phylogenies are presented so that the taxa with the longest branches appear at the bottom or left-hand side of the phylogeny (as is the case in the phylogeny above). These clades are connected to the phylogeny by the deepest branching point and *did* diverge from others on the phylogeny first. However, it's important to remember that the same set of relationships can be represented by phylogenies with different orderings of taxa at the tips and that taxa with long branches are not always positioned near the left or bottom of a phylogeny (as shown below).

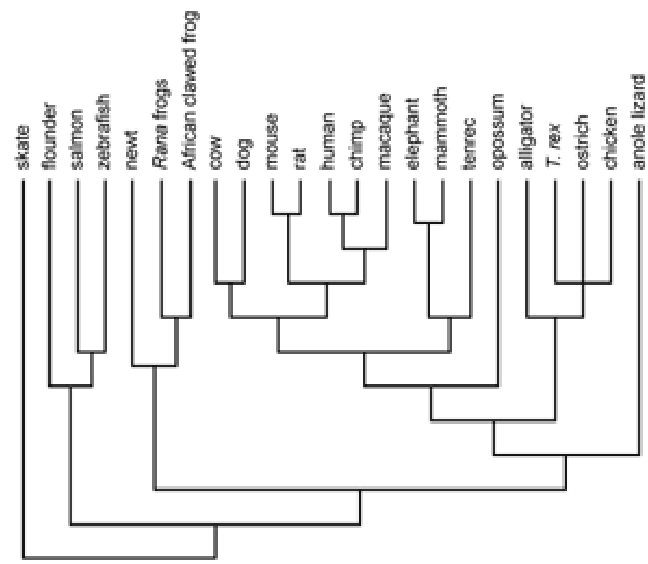


  It's also important to keep in mind that substantial amounts of evolutionary change may have occurred in a lineage after it diverged from other closely related lineages. This means that the characteristics we associate with these long-branched taxa today may not have evolved until substantially after they were a distinct lineage. For more on this, see the misconception below. To learn more phylogenetics, visit our advanced tutorial on the topic.

- **MISCONCEPTION: A long branch on a phylogeny indicates that the taxon has changed little since it diverged from other taxa.**

  CORRECTION: In most phylogenies that are seen in textbooks and the popular press, branch length does not indicate anything about the amount of evolutionary change that has occurred along that branch. Branch length usually does not mean anything at all and is just a function of the order of branching on the tree. However, advanced students may be interested to know that in the specialized phylogenies where the branch length *does* mean something, a longer branch usually indicates either a longer time period since that taxon split from the rest of the organisms on the tree or *more* evolutionary change in a lineage! Such phylogenies can usually be identified by either a scale bar or the fact that the taxa represented don't line up to form a column or row. In the phylogeny on the left below,[1] each branch's length corresponds to the number of amino acid changes that evolved in a protein along that branch. On longer branches, the protein collagen seems to have experienced more evolutionary change than it did along shorter branches. The phylogeny on the right shows the same relationships, but branch length is not meaningful in this phylogeny. Notice the lack of scale bar and how all the taxa line up in this phylogeny.

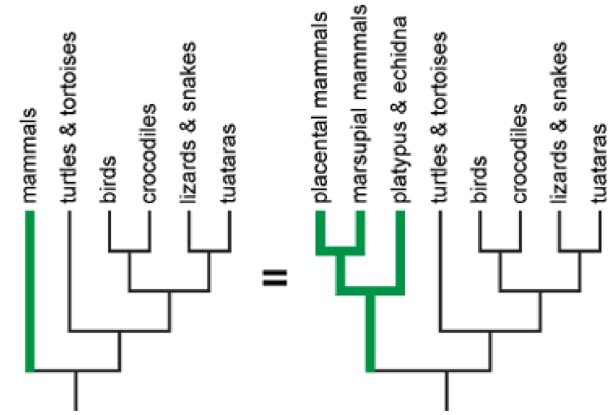




  The misconception that a taxon on a short branch has undergone little evolutionary change probably arises in part because of how phylogenies are built. Many phylogenies are built using an "outgroup" — a taxon outside the group of interest. Sometimes a particular outgroup is selected because it is thought to have characteristics in common with the ancestor of the clade of interest. The outgroup is generally positioned near the bottom or left-hand side of a phylogeny and is shown without any of its own close relatives — which causes the outgroup to have a long branch. This means that organisms thought to have characteristics in common with the ancestor of a clade are often seen with long branches on phylogenies. It's important to keep in mind that this is an artifact and that there is no connection between long branch length and little evolutionary change.

  It may help to remember that often, long branches can be made to appear shorter simply by including more taxa in the phylogeny. For example, the phylogeny on the left at the top of the next page focuses on the relationships among reptiles, and consequently, the mammals are shown as having a long branch. However, if we simply add more details about relationships among mammals (as shown on the right), no taxon on the phylogeny has a particularly long branch. Both phylogenies are correct; the one on the right simply shows more detail regarding mammalian relationships.

[1] From Organ, C.L., M.H. Schweitzer, W. Zheng, L.M. Freimark, L.C. Cantley, and J.M. Asara. 2008. Molecular phylogenetics of mastodon and *Tyrannosaurus rex. Science* 320(5875):499. DOI:10.1126/science.1154284



To learn more phylogenetics, visit our advanced tutorial on the topic.

IV. Misconceptions about population genetics

- **MISCONCEPTION: Each trait is influenced by one Mendelian locus.**

  CORRECTION: Before learning about complex or quantitative traits, students are usually taught about simple Mendelian traits controlled by a single locus — for example, round or wrinkled peas, purple or white flowers, green or yellow pods, etc. Unfortunately, students may assume that *all* traits follow this simple model, and that is not the case. Both quantitative (e.g., height) and qualitative (e.g., eye color) traits may be influenced by multiple loci and these loci may interact with one another and may not follow the simple rules of Mendelian dominance. In terms of evolution, this misconception can be problematic when students are learning about Hardy-Weinberg equilibrium and population genetics. Students may need frequent reminders that traits may be influenced by more than one locus and that these loci may not involve simple dominance.

- **MISCONCEPTION: Each locus has only two alleles.**

  CORRECTION: Before learning about complex traits, students are usually taught about simple genetic systems in which only two alleles influence a phenotype. Because students may not have made connections between Mendelian genetics and the molecular structure of DNA, they may not realize that many different alleles may be present at a locus and so may assume that all traits are influenced by only two alleles. This misconception may be reinforced by the fact that students usually focus on diploid genetic systems and by the use of upper and lowercase letters to represent alleles. The use of subscripts to denote different alleles at a locus (as well as frequent reminders that loci may have more than two alleles) can help correct this misconception.

V. Misconceptions about evolution and the nature of science

- **MISCONCEPTION: Evolution is not science because it is not observable or testable.**

  CORRECTION: This misconception encompasses two incorrect ideas: (1) that all science depends on controlled laboratory experiments, and (2) that evolution cannot be studied with such experiments. First, many scientific investigations do not involve experiments or direct observation. Astronomers cannot hold stars in their hands and geologists cannot go back in time, but both scientists can learn a great deal about the universe through observation and comparison. In the same way, evolutionary biologists can test their ideas about the history of life on Earth by making observations in the real world. Second, though we can't run an experiment that will tell us how the dinosaur lineage radiated, we *can* study many aspects of evolution with controlled experiments in a laboratory setting. In organisms with short generation times (e.g., bacteria or fruit flies), we can actually observe evolution in action over the course of an experiment. And in some cases, biologists have observed evolution occurring in the wild. To learn more about rapid evolution in the wild, visit our news story on climate change, our news story on the evolution of PCB-resistant fish, or our research profile on the evolution fish size in response to our fishing practices. To learn more about the nature of science, visit the *Understanding Science* website.

- **MISCONCEPTION: Evolution is 'just' a theory.**

  CORRECTION: This misconception stems from a mix-up between casual and scientific use of the word *theory*. In everyday language, *theory* is often used to mean a hunch with little evidential support. Scientific theories, on the other hand, are broad explanations for a wide range of phenomena. In order to be accepted by the scientific community, a theory must be strongly supported by many different lines of evidence. Evolution is a well-supported and broadly accepted scientific theory; it is not 'just' a hunch. To learn more about the nature of scientific theories, visit the *Understanding Science* website.

- **MISCONCEPTION: Evolutionary theory is invalid because it is incomplete and cannot give a total explanation for the biodiversity we see around us.**

  CORRECTION: This misconception stems from a misunderstanding of the nature of scientific theories. *All* scientific theories (from evolutionary theory to atomic theory) are works in progress. As new evidence is discovered and new ideas are developed, our understanding of how the world works changes and so too do scientific theories. While we don't know everything there is to know 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. Evolutionary theory, like any scientific theory, does not yet explain everything we observe in the natural world. However, evolutionary theory does help us understand a wide range of observations (from the rise of antibiotic-resistant bacteria to the physical match between pollinators and their preferred flowers), does make accurate predictions in new situations (e.g., that treating AIDS patients with a cocktail of medications should slow the evolution of the virus), and has proven itself time and time again in thousands of experiments and observational studies. To date, evolution is the only well-supported explanation for life's diversity. To learn more about the nature of scientific theories, visit the *Understanding Science* website.

- **MISCONCEPTION: Gaps in the fossil record disprove evolution.**

  CORRECTION: While it's true that there are gaps in the fossil record, this does not constitute evidence against evolutionary theory. Scientists evaluate hypotheses and theories by figuring out what we would expect to observe if a particular idea were true and then seeing if those expectations are borne out. If evolutionary theory were true, then we'd expect there to have been transitional forms connecting ancient species with their ancestors and descendents. This expectation has been borne out. Paleontologists *have* found many fossils with transitional features, and new fossils are discovered all the time. However, if evolutionary theory were true, we would not expect *all* of these forms to be preserved in the fossil record. Many organisms don't have any body parts that fossilize well, the environmental conditions for forming good fossils are rare, and of course, we've only discovered a small percentage of the fossils that might be preserved somewhere on Earth. So scientists *expect* that for many evolutionary transitions, there will be gaps in the fossil record. To learn more about testing scientific ideas, visit the *Understanding Science* website. To learn more about evolutionary transitions and the fossils that document them, visit our module on this topic.

VI. Misconceptions about the acceptance of evolution

- **MISCONCEPTION: The theory of evolution is flawed, but scientists won't admit it.**

  CORRECTION: Scientists have studied the supposed "flaws" that anti-evolution groups 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 the evidence. As scientists gather new evidence and as new perspectives emerge, evolutionary theory continues to be refined, but that doesn't mean that the theory is flawed. Science is a competitive endeavor, and scientists would be eager to study and correct "flaws" in evolutionary theory if they existed. For more on how evolutionary theory changes, see our misconception on this topic above.

- **MISCONCEPTION: Evolution is a theory in crisis and is collapsing as scientists lose confidence in it.**

  CORRECTION: Evolutionary theory is not in crisis; scientists accept evolution as the best explanation for life's diversity because of the multiple lines of evidence supporting it, its broad power to explain biological phenomena, and its ability to make accurate predictions in a wide variety of situations. Scientists do not debate *whether* evolution took place, but they do debate many details of *how* evolution occurred and occurs in different circumstances. 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: Most biologists have rejected 'Darwinism' and no longer agree with the ideas put forth by Darwin and Wallace.**

  CORRECTION: It is true that we have learned a lot about evolution since Darwin's time. Today, we understand the genetic basis for the inheritance of traits, we can date many events in the fossil record to within a few hundred thousand years, and we can study how evolution has shaped development at a molecular level. These advances — ones that Darwin likely could not have imagined — have expanded evolutionary theory and made it much more powerful; however, they have not overturned the basic principles of evolution by natural selection and common ancestry that Darwin and Wallace laid out, but have simply added to them. It's important to keep in mind that elaboration, modification, and expansion of scientific theories is a normal part of the process of science. For more on how evolutionary theory changes, see our misconception on this topic above.

VII. Misconceptions about the implications of evolution

- **MISCONCEPTION: Evolution leads to immoral behavior.**

  CORRECTION: Evolution does not make ethical statements about right and wrong. Some people misinterpret the fact that evolution has shaped animal behavior (including human behavior) as supporting the idea that whatever behaviors are "natural" are the "right" ones. This is not the case. It is up to us, as societies and individuals, to decide what constitutes ethical and moral behavior. Evolution simply helps us understand how life has changed and continues to change over time — and does not tell us whether these processes or the results of them are "right" or "wrong". Furthermore, some people erroneously believe that evolution and religious faith are incompatible and so assume that accepting evolutionary theory encourages immoral behavior. Neither are correct. For more on this topic, check out the misconception below. To learn more about the idea that science cannot make ethical statements, visit the *Understanding Science* website.

- **MISCONCEPTION: Evolution supports the idea of 'might makes right' and rationalizes the oppression of some people by others.**

  CORRECTION: 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. Social Darwinism suggests that society should allow the weak and less fit to fail and die and that this is good policy and 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. In this case, science was misapplied to promote a social and political agenda. While Social Darwinism as a political and social orientation has been broadly rejected, the scientific idea of biological evolution has stood the test of time. Visit the Talk Origins Archives for more information on Social Darwinism.

- **MISCONCEPTION: If students are taught that they are animals, they will behave like animals.**

  CORRECTION: Part of evolutionary theory includes the idea that all organisms on Earth are related. The human lineage is a small twig on the branch of the tree of life that constitutes all animals. This means that, in a biological sense, humans are animals. We share anatomical, biochemical, and behavioral traits with other animals. For example, we humans care for our young, form cooperative groups, and communicate with one another, as do many other animals. And of course, each animal lineage also has behavioral traits that are unique to that lineage. 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.

VIII. Misconceptions about evolution and religion

- **MISCONCEPTION: Evolution and religion are incompatible.**

  CORRECTION: Because of some individuals and groups stridently declaring their beliefs, it's easy to get the impression that science (which includes evolution) and religion are at war; however, the idea that one always has to choose between science and religion is incorrect. People of many different faiths and levels of scientific expertise see no contradiction at all between science and religion. For many of these people, science and religion simply deal with different realms. Science deals with natural causes for natural phenomena, while religion deals with beliefs that are beyond the natural world.

  Of course, some religious beliefs explicitly contradict science (e.g., the belief that the world and all life on it was created in six literal days *does* conflict with evolutionary theory); 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. For concise statements from many religious organizations regarding evolution, see Voices for Evolution on the NCSE website. To learn more about the relationship between science and religion, visit the *Understanding Science* website.

IX. Misconceptions about teaching evolution

- **MISCONCEPTION: Teachers should teach "both sides" of the evolution issue and let students decide—or give equal time to evolution and creationism.**

  CORRECTION: Equal time does not make sense when the two "sides" are not equal. Religion and science are very different endeavors, and religious views do not belong in a science classroom at all. In science class, students should have opportunities to discuss the merits of arguments and evidence within the scope of science. For example, students might investigate and discuss exactly where birds branched off of the tree of life: before dinosaurs or from within the dinosaur clade. In contrast, a debate pitting a scientific concept against a religious belief has no place in a science class and misleadingly suggests that a "choice" between the two must be made. The "fairness" argument has been used by groups attempting to insinuate their religious beliefs into science curricula. To learn more about the idea that evolution and religion need not be incompatible, see the misconception above. To learn more about why religious views on creation are not science and so do not belong in science classrooms, visit the *Understanding Science* website.

- **MISCONCEPTION: Evolution is itself religious, so requiring teachers to teach evolution violates the first amendment.**

  CORRECTION: This fallacious argument is based on the idea that evolution and religion are fundamentally the same since they are both "belief systems." This idea is simply incorrect. Belief in religious ideas is based on faith, and religion deals with topics beyond the realm of the natural world. Acceptance of scientific ideas (like evolution) is based on evidence from the natural world, and science is limited to studying the phenomena and processes of the natural world. Supreme Court and other Federal court decisions clearly differentiate science from religion and do not permit the advocacy of religious doctrine in science (or other public school) classes. Other decisions specifically uphold a school district's right to require the teaching of evolution. For additional information on significant court decisions involving evolution education, visit the NCSE website. To learn more about the difference between science and religion, visit the *Understanding Science* website.discussed so far.