LT: I can organize biodiversity that exists on Earth by building phylogenetic trees using morphology and DNA analysis to identify relationships between species. 4.3.1

Introduction: Evolution 101: https://www.youtube.com/watch?v=JUM6NOARlO4

You are about to play NOVA's Evolution Lab—a game that will help you to understand the ways scientists piece together the tree of life. But before you begin Mission 1, "Training Trees," watch the introductory video, "Evolution 101."

1. According to the video, what are the two key ingredients to natural selection?

2. What does "the fittest" mean in an evolutionary sense?

a) The strongest
b) The longest lived
c) The most reproductively successful
d) The best able to avoid being eaten

3. Evolution is:

a) Fixed in one direction
b) Completely random
c) Neither entirely fixed nor entirely random

4. According to the video, what is the goal of the tree of life?

a) To summarize the fossil record
b) To describe how natural selection works
c) To be a library of all life that has ever lived
d) To explain how all species are related to each other

Mission 1: Training Trees

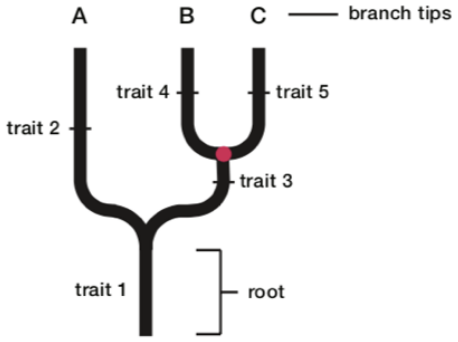
Introductory video: Watch the video to learn some tree basics and to get an overview for how the Build A Tree game works. Each level tasks you with building a phylogenetic tree—a small piece of the overall tree of life. A phylogenetic tree is a model of evolutionary relationships.

1. What does the circled node represent?

a) The common ancestor species of A and B
b) A speciation event
c) Both a and b

2. Which way does time run on this tree?

a) From root to branch tip
b) Across branch tips, from left to right



3. Which lived more recently in time, the common ancestor species of A and B or the common ancestor species of B and C? Explain.

4. Which traits do A and B share? Which traits do B and C share?

-A and B:
-B and C:

5. Use your answers to questions 3 and 4 to explain why B and C are more closely related to each other than A and C are.

6. There is more than one correct way to show relationships using a phylogenetic tree. Which of these trees shows the same exact relationships as the tree above? You may circle more than one.

Red, green, and gecko: Your first question is simple: Is a fungus more closely related to an animal or a plant? At first glance, many people might be tempted to say plant—but be careful! First impressions can be misleading.

7. Under a microscope, the cells of mushrooms, plants, and animals all have visible nuclei. This makes them all:

a) Autotrophs b) Heterotrophs c) Eukaryotic d) Prokaryotic

8. What trait do the mushroom and gecko share that the tree lacks?

9. Draw your completed tree and an equivalent tree. Equivalent trees look different from each other but show the same relationships. Review the Introduction and Mission 1 for examples of equivalent trees.

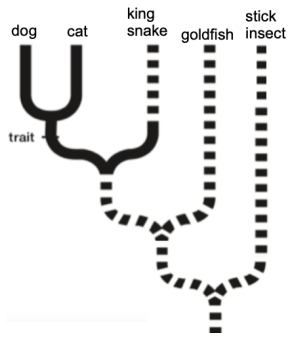
Completed Tree Equivalent Tree

10. The pop-up question at the end of this level asks whether an animal or a plant is more closely related to a fungus. Why is the correct answer likely surprising to many people?

Familiar faces: Let's take a look at some common animals—a dog, goldfish, snake, and stick insect. Think you know which ones share the most traits?

11. What is an amniote, and which animals on this tree are amniotes?

12. If you were to add a cat onto this tree, it would be placed so that the cat and dog are more closely related to each other than to anything else in the tree (insect, goldfish, and snake), as shown. What biological trait could you use in the spot that is marked and would separate the dog and cat from the insect, goldfish, and snake?



Tree of life: Vegetarian edition: We often use the terms fruit and vegetable to describe the plants we eat; however, not many people know the real difference between them. If you're a botanist, a fruit isn't something sweet and delicious—it's the part of some plants that contains the seeds. This makes things like tomatoes, nuts, and squash fruits, technically! Any other part of a plant that we eat is called a vegetable. Some vegetables are roots, like carrots, and others are stems or leaves, like celery and lettuces. Being an animal yourself, it's often easy to overlook plants and their many interesting traits. In this level, you'll gain a new appreciation for some of the plants we eat. Things are getting more challenging now, so be sure to use the species and species compare tabs!

13. What makes the seaweed different from all the other plants on this tree?

14. The pop-up question at the end of this level asks whether a banana is more closely related to a lemon or an onion. Why might the correct answer be surprising to many people?

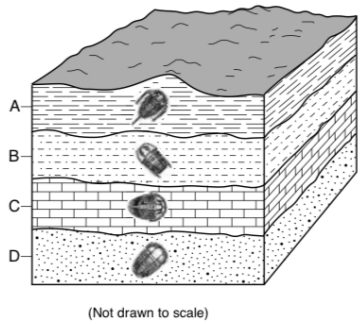
Mission 2: Fossils "Rocking the Earth": https://www.youtube.com/watch?v=rSWwmN5ozQ0

Introductory video: Fossils provide us with a historical record of life on Earth. There are many types of fossils, from extraordinary unaltered remains trapped in permafrost or amber, to subtle traces of past activities in the form of footprints and burrows. The fossils that we have found provide windows into the past and direct evidence of evolution. Before you start the first level in this mission, "Eating dinosaurs for dinner," watch the introductory video.

1. If these rock layers have been undisturbed, which layer is the oldest? Which layer is the youngest?

Rock Layer _____ is the oldest because…

Rock Layer _____ is the youngest because…



(Not drawn to scale)

2. According to the video, fossils provide each of the following except:

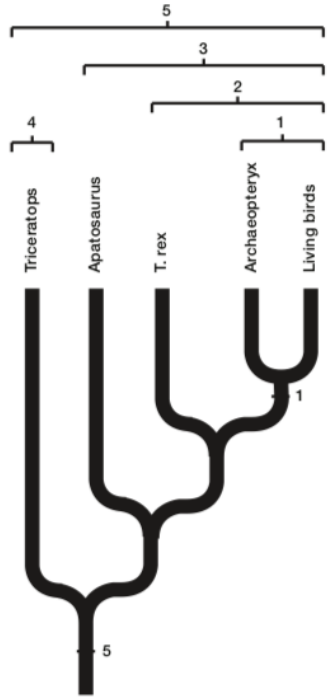
a) Examples of transitional species
b) A complete record of past life on Earth
c) Physical proof of extinction and speciation
d) Evidence that evolutionary change tends to be gradual

Eating dinosaurs for dinner: Has anyone ever told you that dinosaurs aren't extinct? It's true! They aren't. But how can that be? There are no *T. rexes* at the zoo, or *Triceratopses* roaming the plains. This level holds the key to understanding where today's dinosaurs are hiding—on our farms, in the trees, and on our dinner plates.

3. Today, it's widely accepted that all of the two-legged meat-eating dinosaurs known as theropods— including *T. rex* and *Albertosaurus*—had at least very simple fuzzy feathers covering their bodies. According to the tree you built, what distinguishes the feathers of modern birds and Archaeopteryx from the feathers of other theropods?

a) Barbs b) Fibers c) Filaments d) Shafts

4. A clade is a fancy word for any group in a phylogenetic tree that includes an ancestor and all of its descendants. A simplified dinosaur tree is to the right.



Imagine that you have a pair of scissors and can cut the tree. You can tell a group is a clade because it would only take one "snip" to make the group "fall off" the tree. Five different clades have been marked on the tree with brackets.
-The clade marked 1 is clade Aves—the birds.
-The clade marked 2 is clade Theropoda—the theropods.
-Clades 3 and 4 are the two major groups of dinosaurs—Saurischia clade and Ornithischia clade.
-Finally, clade 5 is clade Dinosauria—the dinosaurs.

a. Mark on the tree using numbers 2–4 where you can "snip" off each clade. Numbers 1 and 5 have been done for you.

b. *Triceratops* belongs to two of the marked clades on this tree: 4 and 5. This means that *Triceratops* is both an ornithischian (clade 4) and a dinosaur (clade 5). Which clades do birds belong to?

c. Use your answer to part b to explain why birds are dinosaurs.

One small step: There have been a number of dramatic transitions over the history of life. After a few billion years of nothing but single-celled organisms, multicellular life developed. Organisms evolved tissues and organs. Plants developed spores, flowers, and seeds. Animals developed complex neurological systems and external and internal skeletons. And, of course, bacteria evolved novel methods to live just about everywhere on Earth.
One of these great transitions is the subject of this level. Have you ever heard of an animal called *Tiktaalik*? How about *Acanthostega*? They are but two of the many remarkable fossils we have that document the transition of animal life from water to land. Complete tasks 5–7 below before you move on to the next level, "Origin of whales."

5. According to the tree you just built, what is the first trait that helped aquatic species evolve into creatures that live on land?

6. We know that *Tiktaalik* is more closely related to *Acanthostega* than it is to *Eusthenopteron* because *Tiktaalik* and *Acanthostega*:

7. *Ichthyostega* is a 370-million-year-old fossil from Greenland. *Ichthyostega* had digits, eyes on the top of its head, and strong, armlike bones. It also had no gills and a reduced tail—traits it had in common with *Tulerpeton*. *Acanthostega*, *Eusthenopteron*, and *Tiktaalik* all had gills and full tails.

Use the abbreviations provided to draw a phylogenetic tree that includes *Ichthyostega*.

A = *Acanthostega* **E =** *Eusthenopteron* **I =** *Ichthyostega* **Tu =** *Tulerpeton* **Ti =** *Tiktaalik*	**D =** digits **E =** eyes on top of a flat head **G/T =** loss of gills and a reduced tail **S =** strong, armlike bones

Origin of whales: In the previous level, you looked at the transition from water to land and the evolution of tetrapods, a term that means "four feet." Several groups of tetrapods went on to make the reverse trip—they headed back to the water.
In this level, you'll put together a tree that summarizes some of the changes that occurred as a group of mammals, closely related to the modern-day hippopotamus, returned to the sea.

8. Which of the following species does not have tail flukes?

a) Blue whales
b) Dorudon
c) Pakicetus
d) Killer whales

9. Whales are tetrapods—but living whales do not have four limbs. What is a more accurate way to describe tetrapods?

a) Animals that have at least two limbs
b) Animals that have four limbs at some point in their lives
c) Animals that descended from a four-limbed ancestor
d) Animals that evolved the ability to survive without limbs

Mission 3: DNA Spells Evolution: https://www.youtube.com/watch?v=uI_Q1kjmfxo

Introductory video: Since its discovery in 1953, DNA has revolutionized the study of evolutionary relationships. Darwin didn't know about DNA. He couldn't explain how traits were passed from one generation to the next—he just knew that they were. Were Darwin alive today, he'd no doubt be astonished at how much we can learn about the natural world without even leaving the lab. Before you start the first level in this mission, "Frog legs and fish eggs," watch the introductory video.

1. For a mutation to affect evolution, it must:

a) Provide a benefit to the organism
b) Involve more than one chromosome
c) Be able to get passed from parent or offspring
d) Be neutral—neither help nor harm the organism

2. What is evolution?

a) An increase in complexity over time
b) The tendency of species to improve over time
c) Any change to the genetic composition of a population
d) All of the previous

3. "An organism that is closely related to the group you're interested in, but not a part of it. A way to establish a basis of comparison for a trait analysis." This is a definition of:

a) An ancestor b) A marker c) An outgroup d) A stem group

4. When you compare the DNA of two closely related organisms, would you expect their DNA to be more similar or less similar than the DNA of two distantly related organisms? Explain your answer.

5. Fossils almost never contain DNA. So how can we know how closely or distantly related fossil organisms are to living organisms?

Frog legs and fish eggs: When scientists compare DNA, there are usually thousands upon thousands—or even millions—of nucleotide bases involved. A computer then scans the sequences and aligns them in the way that provides the best match. In some cases, the computer will add "blank" spaces to improve alignment. Such spaces represent nucleotides that were added or deleted as opposed to changed in one or more lineages.

In this level, you'll get the hang of analyzing DNA by looking at a tiny 4-base snippet. A dash (–) represents either a blank space added to improve alignment or a position that is not important for the analysis you've been asked to do. To make things easier, the information from the species compare tab is shown below. However, don't forget to read the species tabs—they might help you.

Position	1	2	3	4
Midas cichlid (outgroup)	-	C	C	-
W. Indian coelacanth	-	C	T	-
Western clawed frog	-	C	T	-

6. Draw your completed tree and an equivalent tree.

Completed Tree

Equivalent Tree

7. True or false: "The change from a T to a C at position 3 caused all of the changes that exist between the cichlid and coelacanth/frog." Explain your answer.

One fish, two fish, red fish, lungfish: For a long time, scientists though that coelacanths were the closest living relatives to amphibians. Coelacanths have big fleshy fins and hinged jaws, two traits they share with fossils of ancestral amphibians. When they went to analyze the DNA, however, they got a surprise. Take a look at the data yourself and see what you come up with.

8. Does the DNA support the hypothesis that the coelacanth is the closest living relative to amphibians, such as frogs? If it does, explain how. If it does not, provide an alternative hypothesis suggested by the DNA data.

9. Which do you consider more convincing evidence, DNA or physical features? Why?

10. To which organism(s) on the tree is the coelacanth most closely related?

a) Frog b) Lungfish c) Cichlid and shark equally d) Frog and lungfish equally

Where the tiny wild things are: Even with a microscope, most people can't tell the difference between an archaea and a bacterium. Crack open their DNA, however, and the differences become pretty obvious—and you don't even need a microscope, just a computer to crunch the data. We've kept things pretty simple in this level, though, so you'll only need your eyes and some brainpower. There is no outgroup on this level, so pay extra attention to the comparison data provided.

11. What distinguishes bacteria from archaea?

a) All archaea live in extreme environments, and bacteria do not.
b) All archaea are unicellular, and some bacteria are multicellular.
c) Archaean DNA is made up a different set of nucleotide bases than is bacterial DNA.
d) Archaean cell walls are made up of different compounds than are bacterial cell walls.

12. *A. vinosum* is most closely related to which organism(s)?

13. Why was examining DNA better than considering physical traits?

a) Physical traits in single-celled organisms are hard to examine.
b) Organisms that behave differently can be genetically similar.
c) Certain traits evolve multiple times in multiple species, and DNA helps us track those changes.
d) All of the above

14. The pop-up question at the end of this level asks why examining DNA is better than considering physical traits. However, remember that it's not always possible. When do you have to rely on physical traits instead of DNA?

Mission 4: Biogeography Where Life Lives: https://www.youtube.com/watch?v=2UQC5ts6hUs

Introductory video: Life does not stay in one place. Organisms spread out and move around. Plant seeds and fungal spores are carried by the wind and animals cover great distances in search of food. And bacteria? Well, bacteria are just everywhere. But it isn't just organisms that move—the planet's tectonic plates move, too. The goal of biogeography is to piece together all of these movements to discover and explain the past and present distribution of life on Earth. It's a big puzzle with as many moving pieces as there are species that have ever lived.

1. How do organisms come to live on newly formed volcanic islands?

2. The Galápagos finches are an example of an array of species that:

a) Migrated to an island as a group c) Interbred to form one new island species
b) Evolved from a single island species d) Each independently migrated to an island

3. Explain how a close relative of an African plant came to be living in the tropical Pacific.

Saving Hawaiian treasure: You have more than likely heard about the famous Galápagos finches and how they help to illustrate a common pattern in evolution. You may not be as familiar with the honeycreepers of Hawaii, but their story is remarkably similar. In this level, you will again use DNA evidence to piece together a phylogenetic tree. Remember to use the outgroup to help you. Be careful, because from now on, you won't need to use all of the traits provided.

4. The common ancestor of the Po'ouli and common rosefinch most likely had:

a) An A at position 1 b) An A at position 16 c) A C at position 4 d) A T at position 2

5. When and how do scientists think that the common rosefinch came from Asia to Hawaii?

6. There were originally more than 56 species of honeycreeper on the Hawaiian Islands. Today, there are just 18, and many are critically endangered, like the Po'ouli. What most likely happened to the other 38 species of honeycreeper?

a) They went extinct.
b) They migrated back to Asia.
c) They evolved camouflage and we cannot find them.
d) They evolved to live underground and we cannot find them.

Cone rangers: Before Pangaea, there was Gondwana. Gondwana was a massive continent made up of what are today Africa, the Arabian Peninsula, Antarctica, Australia, India, Madagascar, and South America. Gondwana eventually joined up with another ancient continent, Laurasia, to form Pangaea about 300 million years ago.
Pangaea broke up for good about 175 million years ago and, eventually, so did Gondwana. As Gondwana's landmasses broke away from one another, they carried with them a set of organisms that would face changing conditions as the plates moved across Earth's surface. Could this movement be a key to why similar species live thousands of miles apart?
Play the level to find out.

7. Complete the table—called a character matrix—below. Place a check (✓) if the species has the trait and leave it blank if it does not. In the final column, use the species tabs to write the location of the species.

	compound cones	cone scales w/o wings	large bladelike leaves	pollen w/o air sacs	smaller scaly leaves	small fleshy cones	location
A. *fibrosa*							
Bois bouchon							
Coral reef pine							
Monkey puzzle tree							
Norfolk Island pine							
Parana pine							
Pino hayuelo							

8. What does finding *A. fibrosa* on modern-day Antarctica suggest about that continent's past climate?

9. Why did *A. fibrosa* likely go extinct?

Kangas, gliders, and snakes, oh my!: When a single species diversifies and forms many different but closely related species, the process is called adaptive radiation. Galápagos finches are the result of adaptive radiation. Adaptive radiations occur as species adapt to slightly different environmental conditions. But what about the reverse, or when very distantly related species come to look similar because they live in similar environments? That is call convergent evolution and it's the topic of this level.

10. Complete the character matrix below. Place a check (✓) if the species has the trait and leave it blank if it does not. In the final column, use the species tabs to write the location of the species. Some have already been filled in for you.

	vertebrate	gives birth to live young	pouch	prolonged development in womb	"warm-blooded"	location
Elephant						Asia, Africa
Flying squirrel						
Kangaroo						
Platypus						Australia
Rat snake						North America
Sugar glider						

11. Which of the species in this level represents the outgroup of the others? Explain your answer.

Mission 5: Tree of Life and Death: https://www.pbssocal.org/programs/nova-labs/nova-labs-tree-life-and-death/
Introductory video: Despite the skyscrapers we build, the medicines we make, and the landscapes we dominate, humans are connected to other living things—and we aren't invincible. In fact, some of smallest things of all can cause us tremendous harm. Thankfully, by understanding how we are connected, we can use our giant brains to help fight back.

1. What is a parasite?

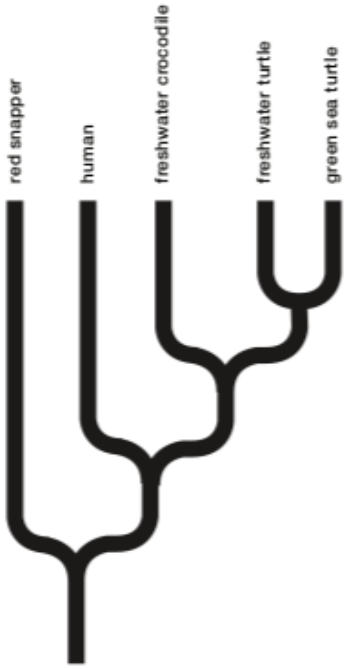
a) An organism that can cause disease in another organism
b) An organism that gains energy and nutrients from another organism
c) An organism that requires another organism to complete its life cycle
d) All of the previous

2. What do you think the narrator means when he says, "The host and the parasite are always in this really intimate dance together?"

Hosting blood flukes for dinner: Blood flukes are the common name given to parasitic flatworms. Parasites rely on hosts, so it perhaps doesn't come as any surprise that a blood fluke often stays in lockstep with its host's evolution— even splitting into new species at the same time as its host. When a parasite and host speciate together, it's called cophyly. When a host and parasite do not speciate together, it may suggest that the parasite has evolved to rely on a different host. Clues to both patterns are found in the phylogenetic tree that you'll build in this level.

3. Use the information on the species tabs to complete the table.

Parasite	Host
E. *euzeti*	
G. *amoena*	
H. *mehrai*	
S. *mansoni*	
S. *haematobius*	



4. A phylogenetic tree of the hosts is shown.
Draw your phylogenetic tree to show the parasites.

5. Compare and contrast the host tree and the parasite tree.

6. Which of the following statements is a logical description for the evolution of parasites?

a) Parasites evolve in a way that is completely different from their hosts.
b) Parasites evolve in a way that parallels the evolution of their host.
c) Parasites spread to a species that is not closely related.

Fatal fangs: The more closely related two snakes are, the more similar their venoms tend to be. In some cases, the venoms are so similar that an antivenom for one will work on the other. In this level, an unknown three-foot-long snake just bit Tyler. If you can identify that snake's closest relative, you can administer the right antivenom—before it's too late.

7. Complete the character matrix below:

	nucleotide at position 3	nucleotide at position 8	gap between fangs	single undertail scales	treat with antivenom
Black whip snake					
Fierce snake					
King brown snake					
Taipan snake					
Tiger snake					
Unknown snake					

8. Which snake is most closely related to the unknown snake that bit Tyler?

a) Black whip snake b) Fierce snake c) King brown snake d) Tiger snake

9. If you were bitten by a snake that had a gap between its fangs but a double row of scales under its tail, which antivenom would be best to administer?

Dawn of a modern pandemic: Viruses are strange, and the more we learn about them, the stranger they seem to get. Considered by many as not quite an "organism" because they can't reproduce outside of a host or generate their own energy, viruses are everywhere—on every surface and inside every living thing. Contrary to what most people think, however, many viruses are harmless. Some are likely even helpful! HIV, however, is not harmless—at least not to humans. Where did it come from? Figuring that out is your job in this level.

10. A Cameroonian woman living in Paris was the first to be diagnosed with HIV-1 P in 2009. Which ape virus is most closely related to HIV-1 P?

11. Based on your completed tree, how can you distinguish HIV-1 M from HIV-1 N?

a) HIV-1 M has a C at position 1; HIV-1 N has an A.
b) HIV-1 M has an A at position 11; HIV-1 N has a G.
c) HIV-1 M has a G at position 14; HIV-1 N has a T.
d)HIV-1 M has a T at position 7; HIV-1 N has an A.

12. How do scientists think that SIV has jumped hosts to humans?

13. Viruses such as HIV reproduce rapidly. What is the connection between reproduction rate and evolution?

Mission 6: You Evolved, Too: https://www.pbssocal.org/programs/nova-labs/nova-labs-you-evolved-too/

Introductory video: In his 1871 book, *Descent of Man*, Charles Darwin predicted that evidence would be found in Africa that would link modern man to apes. Finally, in the 1950s, such a discovery was made by Mary and Louis Leakey in what is today Tanzania. Since then, fossil evidence and DNA analyses have piled on the support. Today, there is no doubt as to our close kinship with chimpanzees, with whom we shared an ancestor about 6–7 million years ago. This mission is all about our evolution over those past 6–7 million years. Before you start the first level in this mission, "Planet of the apes," watch the introductory video and answer questions 1–2 based on your background knowledge.

1. Chimpanzees are:

a) Less evolved than humans
b) Direct ancestors of humans
c) The closest living relatives to humans
d) Both a and b

2. Which of the following is a correct statement about human evolution?

a) Humans did not evolve.
b) Humans have evolved and continue to evolve.
c) Humans evolved until about 5 million years ago, but no longer evolve.
d) Humans have evolved and continue to evolve socially, but not biologically.

Planet of the apes: You probably don't have any issue distinguishing a human from a chimpanzee, gorilla, or orangutan. But you might if you were looking at DNA instead of physical traits. The differences you see are caused by a shockingly tiny proportion of our DNA—who knew that just a few Gs, As, Ts, and Cs could do so much?

position	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Chimpanzee	–	–	G	–	–	–	–	T	–	T	–	–	G	–	–	–	G	–	–	–
Gorilla	–	–	T	–	–	–	–	T	–	T	–	–	T	–	–	–	G	–	–	–
Human	–	–	G	–	–	–	–	A	–	T	–	–	G	–	–	–	G	–	–	–
Orangutan	–	–	G	–	–	–	–	T	–	T	–	–	T	–	–	–	T	–	–	–

3. This data set shows all of the nucleotide differences in a 500-base sequence. Approximately what percentage of DNA do humans have in common with a chimpanzee?

a) 1/500 = 0.2%
b) 5/500 = 1%
c) 495/500 = 99%
d) 499/500 = 99.8%

4. True or false: "Gorillas are more closely related to chimpanzees and orangutans than they are to humans." Explain your answer.

Back to skull: Animals more closely related to modern humans than to modern chimpanzees are called hominins. All members of the hominin group are extinct except one—us, *Homo sapiens*. In the not-too-distant past, there were several other Homo species living on Earth; a couple of them lived at the same time as *Homo sapiens*. There were also many species of our closest extinct cousins, the Australopithecines, and several other hominin species as well.
Although rarely even close to complete specimens, hominin fossils have told us a great deal about our extinct relatives. In this level, you'll explore features of various hominin skulls to learn about some of the things that make us —and other members of our genus *Homo*—human.

5. According to the completed tree, which of the following traits is shared among all species in the genus Homo, but no others?

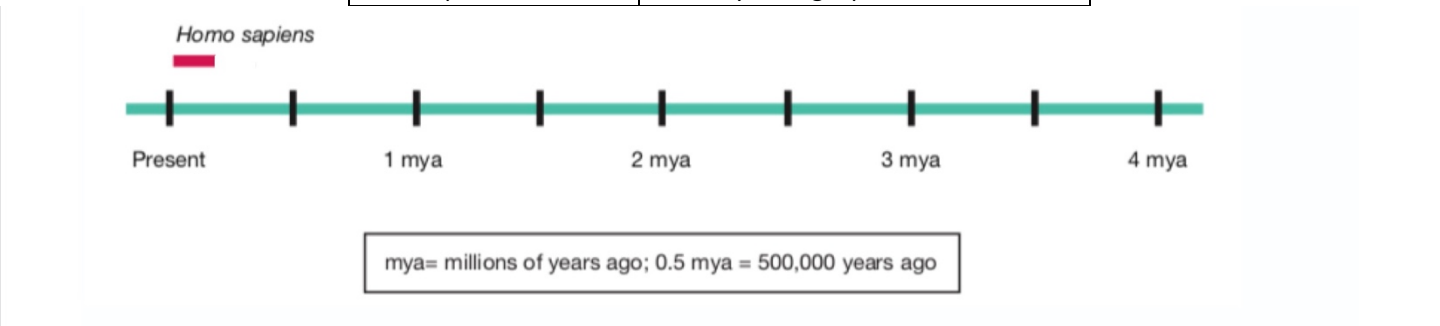
a) Large braincase b) Midsized braincase c) More upright face d) Smaller canine teeth

6. The first hominin species to spread out of Africa was:

a) The chimpanzee b) *H. erectus* c) *H. neanderthalensis* d) *H. sapiens*

7. The date ranges for each of the hominins in this puzzle are given below. Plot them on the timeline given. One has been done for you.

Species	Known Date Range
Australopithecus afarensis	3.85–2.95 million years ago
Homo erectus	1.89 million years ago–143,000 years ago
Homo neanderthalensis	400,000–40,000 years ago
Homo sapiens	200,000 years ago–present



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8. A common misconception is that humans evolved from chimpanzees. It can therefore be confusing to some people that there are still chimpanzees. How could you use a tree diagram like the one you generated in this level to explain the correct relationship between living chimps and living humans?

9. There is significant genetic evidence to suggest that interbreeding occurred between *Homo neanderthalensis* and which other species?

a) Australopithecus afarensis b) *Homo erectus* c) *Homo habilis* d) *Homo sapiens*

Inside out of Africa: Most hominin species, including *Homo sapiens*, arose in Africa. It is sometimes possible to extract DNA from ancient humans (of our species and closest cousins) for analysis. The oldest hominin DNA ever sequenced came from a 400,000-year-old thighbone. Comparisons among ancient remains and populations of humans around the world have yielded insights into when and how various *Homo* species migrated out of Africa.

10. Yoruba peoples are most closely related to which other population from the phylogenetic tree?

a) Dinka b) Italian c) Papua New Guinean d) Dinka and Papua New Guinean equally