



NAME:

DATE:

EVOLUTION 101

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," and answer questions 1–5 below.

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

- a. Predation and the environment
- b. Reproduction and predation
- c. Reproduction and variation
- d. The environment and variation

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. What is happening in this image? How does it help to illustrate the concept of natural selection?**5. 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

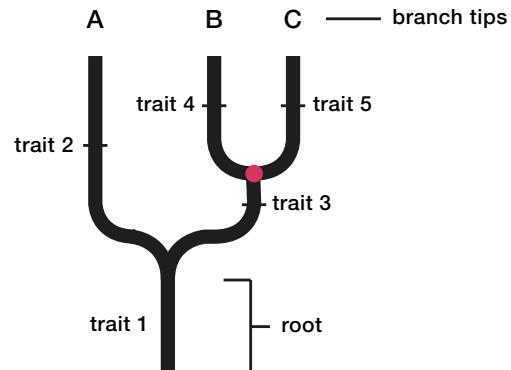
Introductory video: Watch the video to learn some tree basics and to get an overview for how the Build A Tree game works. Each level tasks you with building a phylogenetic tree—a small piece of the overall tree of life. A phylogenetic tree is a model of evolutionary relationships. Before you start the first level, “Red, green, and gecko,” use the tree below and the information in the introductory video to answer questions 1–5.

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?

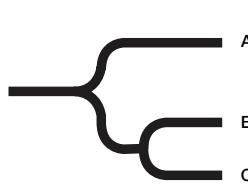
4. Which traits do A and B share? Which traits do B and C share?

A and B:

B and C:

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.

5. 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. In this level, be sure to read and follow the prompts. The prompts are there to help you get the hang of things. When you're done, answer questions 6–9 below before you move on to the next level, "Familiar faces."

- 6. 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
- 7. What trait do the mushroom and gecko share that the tree lacks?**
- 8. Draw your completed tree and an equivalent tree in the boxes provided. Equivalent trees look different from each other but show the same relationships. See question 5 from the introduction section for examples of equivalent trees.**

Completed Tree

Equivalent Tree

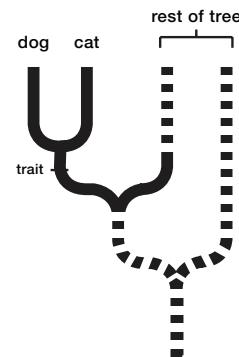
- 9. The pop-up question at the end of this level asks whether an animal or a plant is more closely related to a fungus. Why is the correct answer likely surprising to many people?**



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? Answer questions 10–11 below before you move on to the next level, “Tree of life: Vegetarian edition.”

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

- 11. 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, as shown. What biological trait could you use in the spot that is marked?**



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! Answer questions 12–13 before you move on to Mission 2, “Fossils—Rocking the Earth.”

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

- a. It has leaves.
- b. It's a vegetable.
- c. It uses spores to reproduce.
- d. It is a photosynthetic autotroph.

13. 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

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 and answer questions 1–2 below.

1. If these rock layers have been undisturbed, which layer is the oldest? Which layer is the youngest?
Mark your answer on the figure.



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

- Examples of transitional species
- A complete record of past life on Earth
- Physical proof of extinction and speciation
- 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. Answer questions 3–5 below before you move on to the next level, "One small step."

3. What is another name for the wishbone?

- a. Furcula
- b. Lucky bone
- c. Shoulder blade
- d. Sternum

4. 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

5. 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.

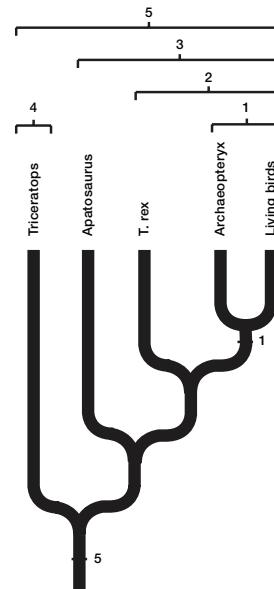
Imagine that you have a pair of scissors and can cut the tree. You can tell a group is a clade because it would only take one "snip" to make the group "fall off" the tree. Five different clades have been marked on the tree with brackets.

The clade marked 1 is clade Aves—the birds.

The clade marked 2 is clade Theropoda—the theropods.

Clades 2 and 3 are the two major groups of dinosaurs—clade Saurischia and clade Ornithischia.

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. Answer questions 6–9 below before you move on to the next level, “Origin of whales.”

6. For an animal that lives in shallow water, what is the advantage of having eyes on the top of its head?

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

- a. Both lacked digits
- b. Both lacked strong forearms
- c. Both had a humerus, radius, and ulna
- d. Both had eyes on the top of their heads

8. *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**

9. Animals commonly called reptiles, amphibians, birds, and mammals are all tetrapods—a term that means “four feet.” The transition from water to land is fascinating to scientists in part because it’s our history—the transition documents the evolution of tetrapods, and humans are tetrapods.

Tetrapods form a clade. Which of the following is true of tetrapods?

- a. Tetrapods are more complex than non-tetrapods.
- b. Tetrapods are more evolved than non-tetrapods.
- c. Tetrapods are more closely related to each other than to non-tetrapods.
- d. All of the above



Origin of whales: In the previous level, you looked at the transition from water to land and the evolution of tetrapods. 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. Answer questions 10–12 below before you move on to Mission 3, “DNA Spells Evolution.”

10. When did whale ancestors begin living full time in the water?

- a. After they nursed under water
- b. After they lost their hind legs
- c. Before they evolved gills
- d. Before they began eating a carnivorous diet

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

12. When two groups of organisms independently evolve similar adaptations, it's called convergent evolution. Sharks and whales both have streamlined bodies and tail flukes. How do we know that these similarities are because of convergent evolution? Hint: Whales are tetrapods. Are sharks?



MISSION 3 DNA Spells Evolution

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 and answer questions 1–5 below.

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 above

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 an 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. Answer questions 6–7 below before moving on to the next mission, “One fish, two fish, red fish, lungfish.”

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 in the boxes provided.

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 thought 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. Answer questions 8–10 below before you move on to the next level, “Where the tiny wild things are.”

position	1	2	3	4	5	6	7	8	9	10
Great white shark (outgroup)	C	-	C	T	-	-	-	-	-	T
Midas cichlid	C	-	C	C	-	-	-	-	-	T
S. American lungfish	T	-	C	C	-	-	-	-	-	A
W. Indian coelacanth	T	-	C	C	-	-	-	-	-	T
Western clawed frog	T	-	C	C	-	-	-	-	-	A

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. Answer questions 11–14 below before you move on to the next mission, "Biogeography—Where Life Lives."

position	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
<i>A. vinosum</i>	-	G	-	-	-	-	T	T	-	-	-	-	-	-	T
<i>D. radiodurans</i>	-	G	-	-	-	-	G	C	-	-	-	-	-	-	T
<i>M. acetivorans</i>	-	G	-	-	-	-	C	A	-	-	-	-	-	-	G
<i>P. aerophilum</i>	-	G	-	-	-	-	C	G	-	-	-	-	-	-	C
<i>S. solfataricus</i>	-	G	-	-	-	-	C	A	-	-	-	-	-	-	C
<i>T. thermophilus</i>	-	G	-	-	-	-	-	C	-	-	-	-	-	-	T

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. Can you tell from this tree whether a C at position 15 evolved before or after a T at position 15?
Explain your answer.**

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

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. Before you start the first level in this mission, "Saving Hawaiian treasure," watch the introductory video and answer Questions 1–4 below.

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
- b. Evolved from a single island species
- c. Interbred to form one new island species
- d. Each independently migrated to an island

3. What is Pangaea?

- a. An island in Hawaii
- b. An ancient supercontinent
- c. A species of Hawaiian honeycreeper
- d. An ancient common ancestor of birds

4. 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. Answer questions 5–8 below before you move on to the next level, "Cone rangers."

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

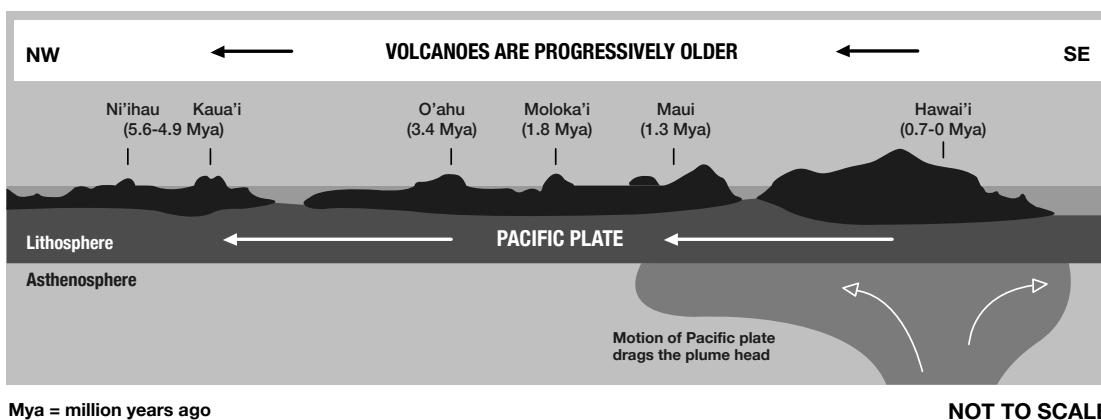
- a. An A at position 1
- b. An A at position 16
- c. A C at position 4
- d. A T at position 2

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

7. 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.

8. Geologists think that the Hawaiian Islands formed as the Pacific plate moved over a hotspot in Earth's crust, where molten rock from the mantle made its way to the surface, as modeled below.



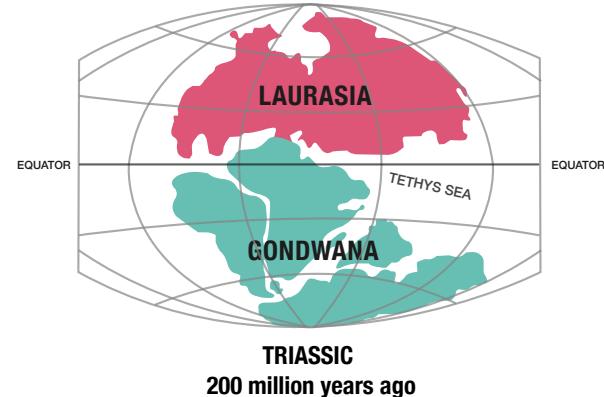
Would you expect a honeycreeper species that lives only on the island of Hawaii to have evolved before or after a honeycreeper species that lives on the islands of Hawaii, Maui, and Oahu? Explain your answer.

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.

Answer questions 9–12 below before moving on to the next level, "Kangas, gliders, and snakes, oh my!"



- 9. 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							

- 10. The pop-up question at the end of the level says that DNA testing led to the discovery that a tree in South America is genetically similar to one in Australia. In fact, these two trees are more closely related to each other than either one is to any other tree in this level—even trees that are found much closer. Which two trees are they talking about?**
- 11. What does finding *A. fibrosa* on modern-day Antarctica suggest about that continent's past climate?**
- 12. 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 called convergent evolution and it's the topic of this level. Play the level and answer questions 13–16 below before moving on to the next mission, "Tree of Life and Death."

- 13. 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						

- 14. Which of the species in this level represents the outgroup of the others? Explain your answer.**

- 15. Representatives from the three major groups of mammals are included on the phylogenetic tree in this level. What are the three groups called, and which animal(s) on the tree belong to each group?**

- 16. If flying squirrels were brought to Australia, what do you predict would happen?**

- They'd compete with sugar gliders for resources.
- They'd form a symbiotic relationship with sugar gliders.
- They'd interbreed with sugar gliders and produce offspring.
- They'd evolve to pouches and become identical to sugar gliders.



MISSION 5 Tree of 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. Before you start the first level in this mission, "Hosting blood flukes for dinner," watch the introductory video and answer questions 1–3.

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 above

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

3. What is HIV?

- a. The virus that causes Ebola
- b. The virus that causes AIDS
- c. A method of DNA sequencing
- d. An ancestor of humans and chimps

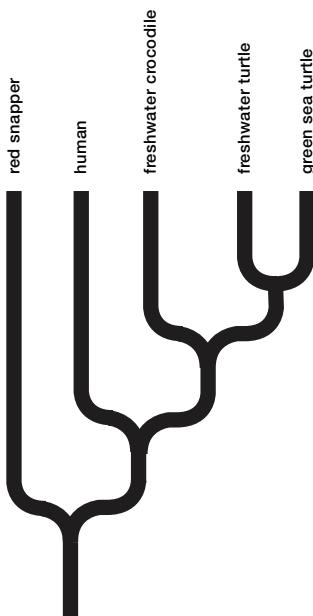
Hosting blood flukes for dinner: Blood flukes are the common name given to parasitic flatworms. Parasites rely on hosts, so it perhaps doesn't come as any surprise that a blood fluke often stays in lockstep with its host's evolution—even splitting into new species at the same time as its host. When a 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. Answer questions 4–7 below before you move on to the next level, "Fatal fangs."

position	1	2	3	4	5	6	7	8	9
<i>E. euzetzi</i>	-	A	-	T	-	-	G	C	-
<i>G. amoena</i>	-	T	-	T	-	-	C	C	-
<i>H. mehrai</i>	-	T	-	T	-	-	C	T	-
<i>S. mansoni</i>	-	T	-	T	-	-	C	T	-
<i>S. haematobius</i>	-	T	-	T	-	-	T	C	-

4. Use the information on the species tabs to complete the table below.

Parasite	Host
<i>E. euzetzi</i>	
<i>G. amoena</i>	
<i>H. mehrai</i>	
<i>S. mansoni</i>	
<i>S. haematobius</i>	

5. A phylogenetic tree of the hosts is shown below. Draw your phylogenetic tree from this level next to it.





6. Compare and contrast the host tree and the parasite tree. Where do they match up? Where are there differences?

7. In what way do these trees suggest that some of these species of blood flukes have switched hosts?



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. Answer questions 8–10 below before moving on to the next level, “Dawn of a modern pandemic.”

8. 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					

9. 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

10. 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?

- a. A
- b. B
- c. C
- d. D



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. Answer questions 11–15 below before you move on to the next mission, “You Evolved, Too.”

position	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Chimp SIV-TAN1 (outgroup)	G	—	—	—	—	—	A	—	—	—	A	—	—	C
Gorilla SIV	T	—	—	—	—	—	A	—	—	—	A	—	—	G
HIV-1 group M	C	—	—	—	—	—	T	—	—	—	A	—	—	G
HIV-1 group N	A	—	—	—	—	—	T	—	—	—	A	—	—	G
HIV-1 group P	T	—	—	—	—	—	A	—	—	—	A	—	—	G
Chimp SIV-MB897	C	—	—	—	—	—	T	—	—	—	A	—	—	G
Chimp SIV-EK505	A	—	—	—	—	—	T	—	—	—	A	—	—	G

11. 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?

12. 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.

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

14. Based on your phylogenetic tree, how many times—at a minimum—do you infer that an HIV virus has jumped hosts to humans? Explain your answer.

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

**MISSION 6 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? Answer questions 3–5 below before you move on to the next level, “Back to skull.”

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. The closest living relatives to orangutans are:
 - a. Chimpanzees
 - b. Gorillas
 - c. Humans
 - d. Chimpanzees, gorillas, and humans equally

5. 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. Complete the level and answer questions 6–10 below before moving on to the final level, “Inside out of Africa.”

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

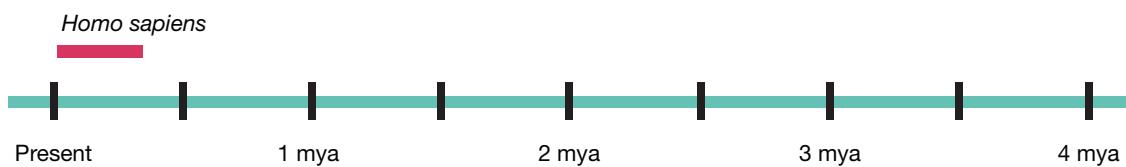
- a. Large braincase
- b. Midsized braincase
- c. More upright face
- d. Smaller canine teeth

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

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

8. 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
<i>Australopithecus afarensis</i>	3.85–2.95 million years ago
<i>Homo erectus</i>	1.89 million years ago–143,000 years ago
<i>Homo neanderthalensis</i>	400,000–40,000 years ago
<i>Homo sapiens</i>	200,000 years ago–present



mya= millions of years ago; 0.5 mya = 500,000 years ago

9. At least how many Homo species shared the planet 500,000 years ago?

10. 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?



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. Answer questions 11–13 below before you move on to the conclusion video.

position	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Dinka	G	-	-	-	-	G	-	A	-	-	C	G	C	-	-	T	-	-	-	-	G
Italian	G	-	-	-	-	G	-	G	-	-	T	C	T	-	-	T	-	-	-	-	G
Khoisan	G	-	-	-	-	G	-	A	-	-	T	G	T	-	-	C	-	-	-	-	G
P.N. Guinean	A	-	-	-	-	G	-	A	-	-	T	C	T	-	-	T	-	-	-	-	G
Yoruba	G	-	-	-	-	G	-	A	-	-	T	G	C	-	-	T	-	-	-	-	A

11. 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*

12. 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

13. No fossils of *Homo neanderthalensis* have been found in Africa, but many African populations have traces of Neanderthal DNA. If Neanderthals were never in Africa (which is a possibility, though fossils may yet be found), how can the presence of Neanderthal DNA be explained?

**Conclusion: Evolution Continues**

You've completed all of the missions! There is just one thing left to do. Watch the conclusion video and then answer this final question: What is the most surprising thing you have learned while playing through these missions? What is one thing that you'd like to learn more about?