# The Vertebrate Clade Race: Tactile Version

# Based on: D. W. Goldsmith (2003) American Biology Teacher 9: 679-682

# A variation of Baum, D., Jenkins, K. (2020). [Vertebrate Clade Race](http://dx.doi.org/10.25334/D9GX-PC46). QUBES Educational Resources. [doi:10.25334/D9GX-PC46](http://dx.doi.org/10.25334/D9GX-PC46)

## Teacher Notes

Reading phylogenies is a cognitively challenging task. This activity helps students overcome common misconceptions, allowing them to use phylogenies to understand evolutionary relationships as scientists do. In this activity students map a basic phylogeny and then explore the evolutionary concepts represented by the map. This activity is a variation on an activity by Baum and Jenkins which was itself a variation of The Great Clade Race (Goldsmith, 2001).

## Level

This activity is appropriate for students from third grade through college. The follow up discussion will vary based on the level.

## Time

The activity should take about 30-45 minutes for the introduction and time for students to map the race. An additional 15 minutes of discussion time around the maps allows students to explore the evolutionary concepts behind the map and practice their tree reading skills.

**Materials**

* One copy of the student directions per student or per team.
* One set of markers on rings and one set of runners’ rings.

Per set:

* 14 rings
* 14 badge clips
* 1 alligator clip
* Contrasting yarn (six pieces approximately 18 inches long each)
* Dark square of felt (approximately 3X3)
* 2 pieces of sponge
* 2 rubber gaskets
* 2 die
* 3 buttons
* 6 wooden beads
* 6 wingnuts
* 4 pieces of pipe

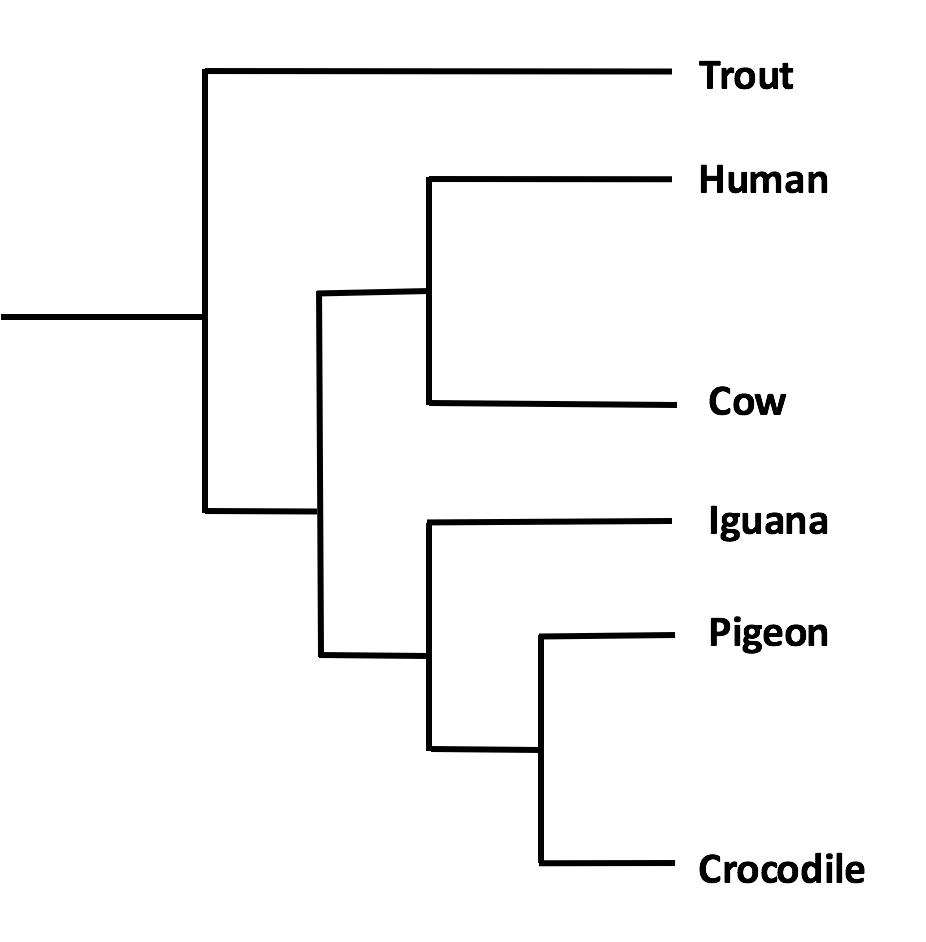
Or use the 3D printing code file to print tokens

## Procedure

### Race in the Woods

First, distribute the sheet “Reconstructing Evolutionary History” and give each team of students one set of tokens and one set of runners’ rings. You may wish to guide students through the introduction to the mapping activity, or have students read the directions to one another. Have students become familiar with the tokens before exploring the runners’ rings. Do not provide any guidance regarding shape of the paths, location of the check in stations or runner exit sites except to remind students of the rules. Make sure that they understand that each runner finishes the race at a unique finishing point , and that all runners complete the race.

A map/phylogeny key is provided below. Remember that branches can rotate around nodes, so the order of the tips can change. Check in stations may be placed anywhere along a branch.



Second, have students share their maps with the class. Ask a volunteer group to guide the class through their map. Ask the class if the map is correct, and if not, correct any errors. Select a second map that looks different (check in sites are in different locations on branches, the runners do not emerge in the same order reading left to right across the finish line, etc). Point out the differences and ask the class if this map is also correct. Allow some class discussion and repeat with another map if desired. Students can often see that the solutions are “correct” and “equivalent” even when they are drawn quite differently. This is worth complimenting them on, as it is a major stumbling block in reading phylogenies. If students are unsure if a map is correct, ask them to consider each runner in turn and confirm that the tokens correspond to the check-in stations that they passed on their way from the starting line.

Important ideas to highlight include:

* The check in point can be anywhere along the path between branch points.
* The order of runners (reading left to right) across the finish line can vary.
* The map does not have to be in a particular orientation (bottom to top is most common, probably because of the introductory prompts).
* The shape of the paths does not change the overall map pattern (eg whether nodes are on short vs. long branches).
* All the runners completed the race. All extant organisms (all living organisms) are at the same point in the evolutionary race. No species is more or less evolved than any other.

These points are important because students often read phylogenies “across the tips.” This is incorrect because branches can rotate around nodes similar to a hanging mobile. Students are often confused if the shape of the phylogeny changes. There are many styles of drawing phylogenies which are typically driven by space constraints or aesthetics. The check in stations represent traits that have evolved over time somewhere along an ancestral branch between forks. You can say that either is valid, but given how little of the race course is exactly at the branching points (nodes), it is probably more likely that check in stations are between nodes. We usually cannot pinpoint the exact time of trait evolution, so students will need to see that trait (or traits) as appearing sometime during the evolution of that group rather than the marker of a speciation event. It is a very common misconception that “simpler” organisms are less evolved than others. This is an example of thinking of evolution as a progressive process, leading to a more desirable endpoint (like humans!). Evolution is not progressive, and it is not directional.

Another important point is that we could reconstruct the race course even though none of us were there to see the race. This is an illustration of the nature of science. Scientists are often able to study things or events that we cannot directly see, whether because they are too small, too big, or too far away (in space or time).

### Converting runners to modern animals

Give each team the clothes pins with organisms and traits listed. Give them a few minutes to match the runners and the animals. You may want to have them re-label their maps with the animals and traits replacing the runners and tokens.

### Reading the tree

Relationships between organisms on a tree are determined by the most recent common ancestor. To identify the most recent common ancestor between any two organisms, start at the tip and trace back through the phylogeny until you reach a shared node. That node represents the most recent common ancestor. Note that the ancestor did not necessarily look like either of the extant organisms, or a blend of them. It simply represents an (often unknown) organism that had all the traits shared by the two species of interest.

Have students trace the evolutionary pathway of humans back through the tree. They should notice that we share traits with many other organisms, we are related more or less closely to various organisms based on the number of shared traits (not the number of nodes – node counting is another common mistake students make, see Gregory, 2008).

## Activity Guide with Teacher Notes

### Reconstructing the Evolutionary History of Biological Diversity

All species on Earth are related by common ancestry. This means that we can learn a lot about one species by knowing which other species are closely related. For example, we know that ungulates - animals who walk on their toes (usually on hooves such as cows) - are always herbivores and all species in the cat family are carnivores. Why is this? Because of the evolutionary history of these species.

Scientists study the evolutionary history of species many different ways. One way to determine relationships is to study the traits or characteristics of different species. Informative traits can be anatomical, genetic comparisons, behavioral patterns, geographic distribution, and fossil comparisons. Scientists use these traits to group species together and infer historical relationships. These relationships are represented in phylogenetic trees, which map the evolution of different species. It is important to remember that phylogenies show our best understanding of species relationships today. In the future, new information may lead us to redraw parts of a phylogeny, but many phylogenies are well understood and unlikely to change much. These activities are designed to give you a feel for how scientists make a phylogeny.

#### Step 1: Race in the woods

Last year, race organizers held a very successful race in a local park and they want to run the race again this year. Unfortunately, they lost the course map. In this race, runners all started at one point on the west side of the park. As they ran through the park, the paths branched repeatedly and each runner took different routes. Throughout the course there were check-in stations where the runners collected tokens. In this race, runners could finish anywhere on the east side of the park, rather than at a single finish point. Although all the runners crossed the finish line (the far side of the park), they did so at different places depending on the route they followed through the woods. 

Your task is to help the race organizers reconstruct the route each runner took by referring to the tokens each runner collected at check in stations.

(Teacher note: emphasize that all runners must reach the far side of the park.)

The following rules apply:

* Runners begin with no tokens. (Teacher note: the badge clips and rings are not tokens. Use the alligator clip to hold the knotted yarn at the starting line. Have students clip individual pathways to the far side of the board.)
* Runners must collect a token from each check-in station they pass.
* Each check-in station hands out only one token and no two check-in stations use the same token.
* The path always forks in two, and paths never cross or rejoin.
* Runners cannot backtrack.

##### Reconstructing the race route

The yarn represents the runners’ pathways. Clip the yarn to a single starting point on the felt board, twisting all the yarn together to reflect a single starting path. Show the location of check-in stations by clipping the appropriate token where the station was. Clip the runners’ rings on the far side of the felt board to represent where they emerged on the far side of the park. Remember that all the runners finished in a unique location, so on your final map you should see one start and six finishes.

(Teacher Note:

* Have students start by becoming familiar with the tokens, and then have students look at the runners’ rings.
* The color of the tokens is not important, but it does act as a distractor for students. This reflects biological reality. In a similar way a general trait, such as fur or feathers, might come in different colors.
* As the paths branch, students should twist the yarn together to indicate a single, shared pathway.)

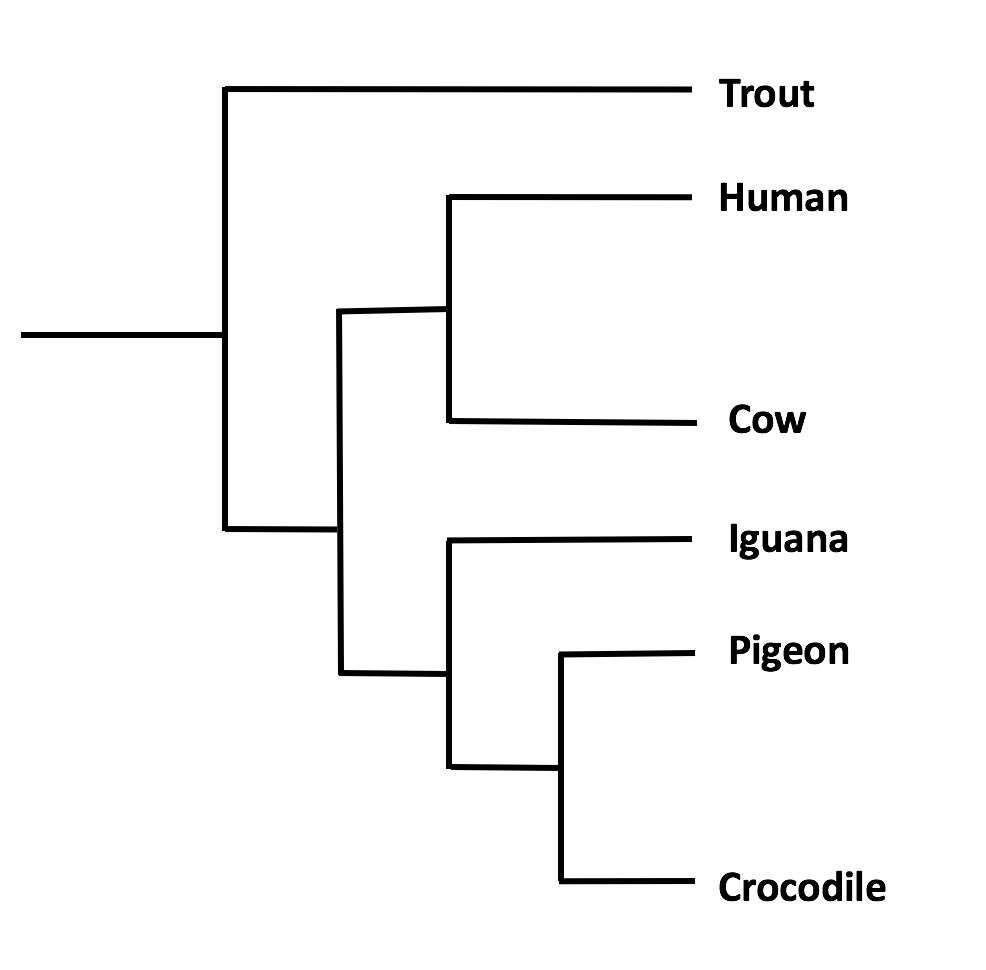
**Questions**

1. Can you tell if you got the map right? How?
2. Compare your map to those generated by other groups. How are they similar? How do they differ?
3. Can you tell which should come first: the wing nut or the wooden bead? Why or why not?

#### Step 2: Converting “runners” to modern animals

The problem of determining the evolution of species is very similar to the race map. As species evolve over time they acquire new traits – like the tokens that the runners pick up. Also, sometimes an ancestral species splits into two evolutionary lineages – like the branching of the racecourse.

The racecourse the students built reflects living animals and their traits. Have the students add the clothespin labels to the appropriate rings. (See the phylogenetic tree below for the key)



(Teacher note: In general, it is easier for students to read this “bracket” style phylogenetic tree, rather than a “V” shaped tree. Trees with the root and tips horizontal, instead of vertical also avoid confusion about the direction of time.)

##### Characters

| Trait | Token | Comments |
| --- | --- | --- |
| Swim bladder | Rubber gasket | The swim bladder in bony fishes serves several purposes. It can be used to control buoyancy, stabilizer and a resonating chamber. The swim bladder is highlighted by the red box in this diagram. Diagram of the internal organs of a fish. Below the top fin, a long cylindrical organ, the swim bladder is highlighted. |
| Lungs | Wingnut | Lungs are used for respiration by vertebrates. Lungs allow organisms to bring in oxygen and remove CO2 from the blood to support energy production through cellular respiration and maintain homeostasis. |
| Four limbs/tetrapod | Wooden bead | Tetrapods evolved from the lobe finned fishes and can be aquatic, semi-aquatic or land based. |
| Hair | Button | Hair is an identifying characteristic of mammals. |
| Rumen | Sponge | The rumen is a gut adaptation that allows cows to support bacteria to digest cellulose to a molecular form that the cow can metabolize. |
| Diapsid Skull | Pipe | A distinguishing characteristic of Sauria. Diapsid skulls have two holes behind the eye socket. Diagram of the diapsid skull showing two smaller holes behind the larger eye socket. |
| Non-overlapping scales | Hose clamp | Archosauria (birds and crocodiles) have non-overlapping scales. Lepidosauria (lizards and snakes) have overlapping scales.  Overlapping scales of a snakeClose up of snake scales showing how they overlap on one another.  Non-overlapping scales of a crocodile  Close up of crocodile scales showing how they fit together like pieces rather than overlap. |
| Feathers | Die | Only aves (birds) have feathers. Avian ancestors also had similar structures. |

Scientists often use a matrix to mark traits for each organism in conjunction with a phylogenetic tree.

|  | **Cow** | **Crocodile** | **Trout** | **Human** | **Pigeon** | **Iguana** |
| --- | --- | --- | --- | --- | --- | --- |
| **Four limbs (bead)** | X | X |  | X | X | X |
| **Lungs (wing nut)** | X | X |  | X | X | X |
| **Swim Bladder (rubber gasket)** |  |  | X |  |  |  |
| **Hair (button)** | X |  |  | X |  |  |
| **Rumen (sponge)** | X |  |  |  |  |  |
| **Non-overlapping scales (hose clamp)** |  | X |  |  | X |  |
| **Diapsid skull (pipe)** |  | X |  |  | X |  |
| **Feathers (die)** |  |  |  |  | X |  |

### Reading the Tree

Looking at the map, you see that all living species are all the same distance from the “root” – this shows us that all living species have been evolving for the same amount of time. No species is more or less “advanced” than any other. Even species such as sharks or coelacanths that have not changed physically for a long time are evolving. Because their physical form is well suited to their environment selection maintains their physical form. However, if you look at their DNA, you will see that changes have accumulated over time. Another thing to notice is that although living species share traits with their ancestors, no living species is ancestral to another living species. Similarly, although you and your cousins may share some of your grandparents’ physical traits, such as curly hair or eye color, you and your cousins are not ancestral to one another.

We can also use a tree to determine how closely related two species are. Identify the most recent common ancestor of two species by starting at the tips for the two species of interest and tracing the branches back through the tree until you reach a shared node. This is the most recent common ancestor for those two species. Two species that share a more recent common ancestor (one closer to the tips) are more closely related than are two species that share a more distant common ancestor (one that is located deeper in the tree).

#### Questions

1. Is an iguana more closely related to a trout or a cow? Why?
2. Is a crocodile more closely related to a human or a cow? Why?
3. If you add salamanders to the tree using the following traits: four limbs, lungs and four toes on the front feet, where would it be placed on your tree? Would adding this new species change the relationships of the other species?

**Teacher Notes: Additional questions not included in student handout**

* In thinking about the analogy to evolution, what would the following represent?
  1. The runners
  2. The check-in stations
  3. The race course
* Can you determine relationships between runners by looking at their relative positions on the finish line? In other words, if you go from left to right, do the runners always emerge in the same order? Why or why not?
* In the biological case, is it valid to assume that the “runners” receive an empty ring at the start and that they always gain, but never lose, tokens?

(Teacher Note: As a case in point, archosaurs (represented by crocodiles and pigeons in this activity) are characterized by “socket teeth” or thecodont teeth, but birds have lost this trait.)

* There was no token for the trait of a vertebral column. All these organisms have this trait. If the trait is added to the tree, where would it be added and would it change the structure of the tree? (Teacher Note: It would be added anywhere between the root and the first branch of the tree, and it would not change the structure of the tree.
* Which organism has the most traits in this tree? (Pigeon) By comparison, how many traits do humans have? Does this indicate that “Birds are more evolved” than other organisms on the tree? (Teacher Note: No. All organisms are equally distant in time from the “start” of the evolutionary “race” and all are at the same time point in their evolutionary pathways. In this phylogeny, more traits were required to distinguish birds from other organisms.)
* When West Nile virus first arrived in the USA, it was observed in birds, horses and occasionally people. The normal host for West Nile virus is birds, and it is easily transmitted between birds. It is much rarer and less deadly in horses and humans. However West Nile virus had a big impact on crocodile farms. Why do you think that might be? (Teacher note: Crocodiles are more closely related to birds, the natural host of West Nile, than mammals are. As such, they are susceptible to the virus).

## References and additional resources:

This activity was developed by David Baum, University of Wisconsin, and Kristin Jenkins, National Evolutionary Synthesis Center, and is based on D. Goldsmith’s “The Great Clade Race.” The tactile variation was developed by Andrew Hasley, University of Wisconsin, J. Phil Gibson, University of Oklahoma, and Kristin Jenkins, BioQUEST.

### Resources and References

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Tree Thinking Assessment from Baum, et al. 2005 Science Vol 310 p979

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