Shape of Life
The Story of the Animal Kingdom

Constructing the Tree of Life

Explore evolution with playful phylogenetic trees

Overview

Students explore the evolution of life on Earth by constructing a "Tree of Life"—metaphorical art that arranges groups of organisms by characteristics and when scientists think they first evolved. First, they organize a small group of organism cards by shared traits. Then they work together to construct more complete trees of evolutionary relationships with additional cards and/or an online interactive game. They share completed trees with the class and the teacher facilitates discussion. Students then revise their trees and record observations/ideas in science notebooks. Enrichments and extensions are listed towards the end of the lesson to help engage all students.

Objectives

- Students will explore a model of the evolutionary Tree of Life. They will attempt to group related organisms based on anatomical similarities and which organisms evolved first in relation to other organisms.
- Students will explain how trees are used to model evolutionary relationships, orally and in writing.
- Students will demonstrate understanding that all living things can trace their existence to the beginning of life on Earth about 3.7 billion years ago. They will communicate scientific information orally and in writing that common ancestry and biological evolution are supported by multiple lines of empirical evidence.

Subjects

Science, Art, Writing, Reading, and Environmental Education

Grades 6–16

Time

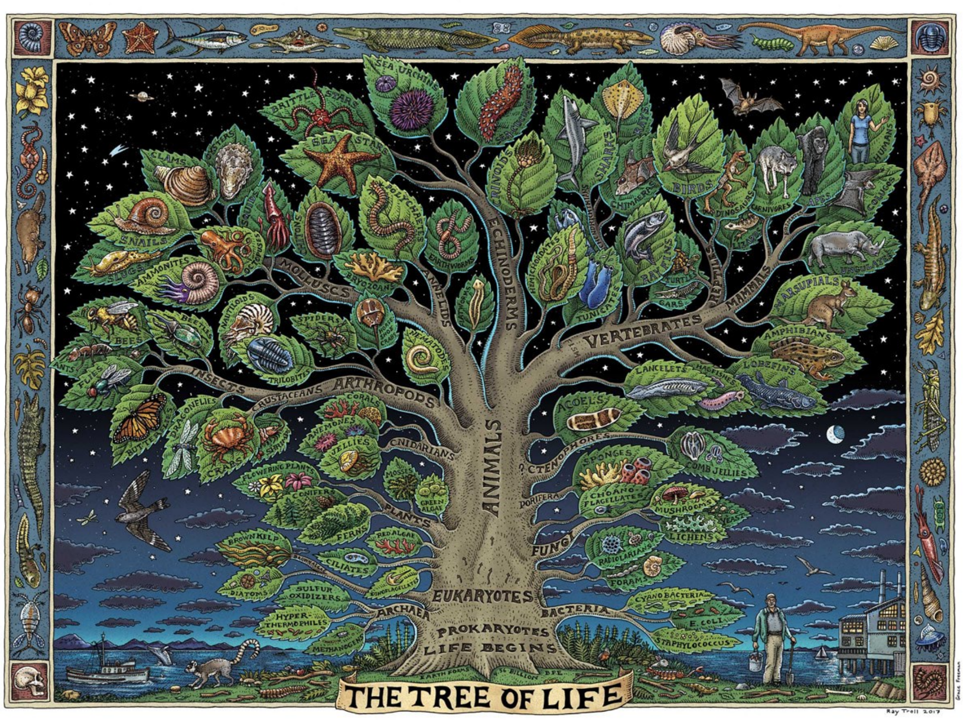
45–90 minutes

Vocabulary

Adaptations, common ancestry, biological evolution, phylogenetic tree

Standards

MS-LS4-2; HS-LS4-10
See details and more standards met in the table at the end of the lesson.



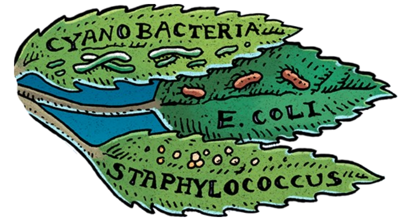
Ray Troll's painting "The Tree of Life" that he created for Shape of Life. Learn more and see a larger version at shapeoflife.org/blog/making-new-tree-life-shape-life.

Teacher Background

First Life Forms

Life on Earth began approximately 3.7 billion years ago as single-celled organisms. Since the first cells arose, they have adapted to their environments through genetic mutations and natural selection (survival of the fittest) – the process of evolution. Over millions of years, new groups of organisms evolved and split from one another to create the six kingdoms of life on Earth. All life on Earth evolved from a universal common ancestor.

These first single-celled organisms were the **prokaryotes**, simple cells lacking cell nuclei containing their DNA. They have been the dominant form of life on Earth throughout its history. The evolution of the first **eukaryotic** cells with cell nuclei was a critical development that led to the evolution of multicellular life forms. From eukaryotic cells came plants, fungi, and animals, and sexual reproduction. See the start of the video "Tree of Life" (5:31) on the Shape of Life website and Vimeo: vimeo.com/934690484/fa958016ed. We suggest you show it during the "Animated Tree of Life" lesson which follows this lesson.



Bacteria are prokaryotes. These metaphorical leaves are shown near the base of Ray Troll's "The Tree of Life."

(R)evolutionary Concepts

A core concept of evolution is that groups of organisms share **adaptations** and a **common ancestry**. For example, mammals (animals that have hair or fur and milk-producing mammary glands), shared a common ancestor with reptiles. Mammals diverged from those ancestors during the Carboniferous Period over 300 million years ago. The lineage of any two species can be traced back to a point of common ancestry.

Misconceptions about evolution abound. One might think evolution is a linear, progressive march toward perfection. However, this is not the case. Populations of organisms are simply responding to changes in their environments and genetic mutations. It is also not true that a particular species is "better," "more advanced," or "more evolved." Any two living taxa—whether two living individuals, two living species, or two living groups of species—have identically long evolutionary histories.

A sea otter's dense fur—up to 1,000,000 hair follicles per square inch! – is an incredible adaptation for survival in cold ocean waters.
Photo by Peter Kraayvanger: pixabay.com/photos/riesen-otter-mammal-swim-fur-90026

Evidence of Evolution

Evolution is supported by multiple lines of evidence, including:

- **Anatomy**. Naturalists observed that different species share structures that have the same basic form. For example, bones in bat wings, whale flippers, and human hands are constructed similarly. Scientists call similar structures between species homologies and believe they are the result of common descent.
- **Fossils**. Around 1800 English geologist William Smith observed rocks layered in predictable patterns. These layers could be identified by the fossils they contained, and he observed the same succession of fossil groups from older to younger rocks. Since then, hundreds of thousands of fossil organisms, dated by radiocarbon dating, have been discovered. They show successions of life forms through time and reveal evolutionary transitions. New fossil discoveries around the world continue to reveal relationships between different species as lineages of organisms evolved.
- **Genetics and biochemistry**. Similarities and differences in DNA also reveal shared ancestry between species and groups of organisms. The more closely related organisms are, the more similar is the code in their DNA. Because of mutations, the sequence of nucleotides (basic units of

A cast of the fossilized bony jaws of Livyatan mellvillei*, an extinct species of sperm whale.*
Photo by Hectonichus CC BY-SA 3.0: commons.wikimedia.org/wiki/File:Physeteroidea_-_Livyatan_melvillei.JPG

DNA) in a gene gradually changes over time. Scientists can create a family tree by comparing the number of changes in the code. In addition, the same set of 20 amino acids makes up all proteins in every organism on Earth, which again, supports the idea of common descent.

See "Evidence Supporting Biological Evolution" from National Library of Medicine for more information: ncbi.nlm.nih.gov/books/NBK230201. Additional sources are listed in the Expand Knowledge + Skills section at the end of the lesson.

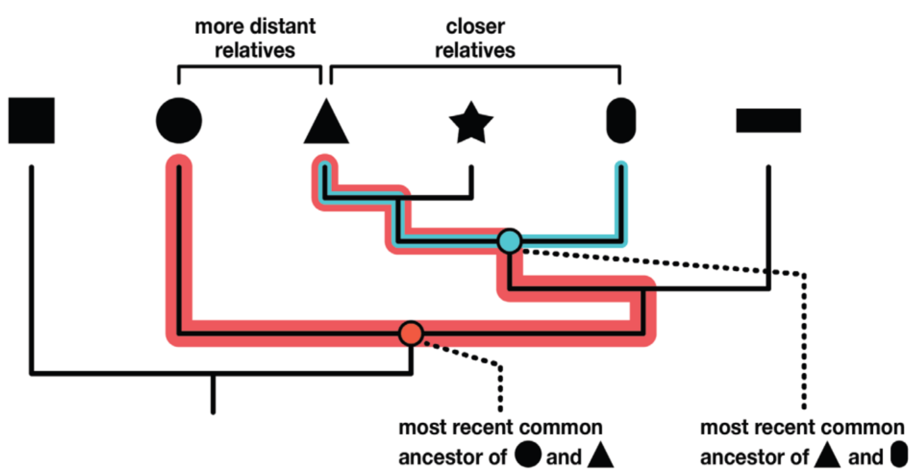
Phylogenetic Trees

Visual representations of the evolutionary history of groups of organisms are called **phylogenetic trees**. Phylogenetic trees can take many forms, with curved or straight lines, some angled and some branched. Darwin chose the tree of life as a metaphor for relatedness of living things. People have been modeling relationships between organisms at least as far back as Aristotle (4th century BCE).

Some scientists today refer to a more-complicated, branched shrub. Artist Ray Troll created his own Tree of Life for Shape of Life based on thorough research. New discoveries will continue to remodel how scientists view relationships between organisms.

While phylogenetic trees appear conceptually simple, there are misconceptions about how they are read. These problems arise because we read from left to right, and because we tend to think that "up" is better than "down." Trees should be read with the following principles in mind:

- The bottom of the tree represents the beginning of life.
- Moving up represents the passage of time.
- Branch points (nodes) represent where groups split from a common ancestor.

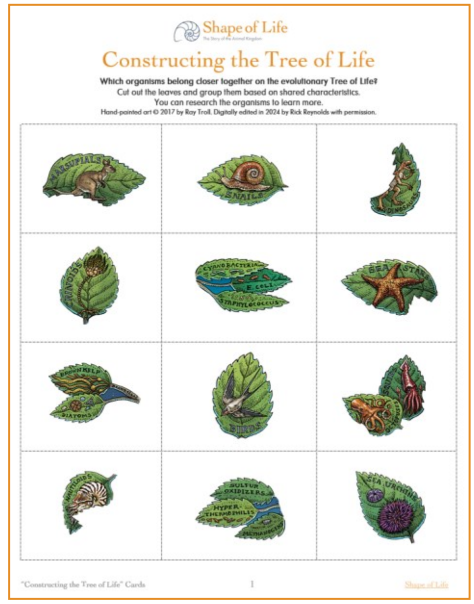


Source: Adapted from UCMP's Understanding Evolution site: evolution.berkeley.edu

- Branches represent the evolution of new groups of organisms.
- Evolution happens anywhere along the branch, not just at nodes.
- Leaves (on Ray Troll's tree) represent groups of organisms, not single species.
- Closeness on the tree **does not** represent how closely related two groups of organisms are. Rather, the nodes show where groups diverged.

Materials + Preparation

- Print page 1 of the "Constructing the Tree of Life" cards for groups of 2–3 students. The cards and other resources listed below are at shapeoflife.org/lesson-plan/constructing-tree-life.
    - You could print page 2 on the back of the page 1 cards and/or use a different brightly-colored paper for this first set of 12 cards. The different backs with shell graphics and/or colored paper will make it easier to separate them from the other cards for the next class.
    - You could cut the cards apart and/or pass them out with scissors for students to cut out.
    - Use card stock and/or laminated cards to make them easier to use and reuse.
- Print pages 3–5 of the cards (with blank backs) for each group of 2–3 students. Prepare to pass these out to the groups after they have had time to work with the first set of 12 cards.
- Print copies of the "Tree of Life Game Board" (with blank leaves) as two separate pages. Tape them together with clear tape to be ready to pass them out to student groups.
- Print copies of the "Tree of Life Answer Key" for groups and/or prepare to show the "Tree of Life" poster with a data projector or have students view it on their devices.
- Science notebook and pencil or pen for each student
- Whiteboard or chart paper and markers
- Prepare for students to use the online version of the puzzle individually or in pairs if time allows: engagingeverystudent.com/tree-of-life-game.
- *Optional:* Scissors and/or clear tape for groups of students to share
- *Optional:* Poster board or butcher paper for student groups to share (consider using the back sides of used sheets as a more eco-friendly and cost-effective option; educator colleagues often have them that they can share)
- *Optional:* Computer with Internet connection and data projector
- *Optional:* Colored pencils and/or markers for students to share



Page 1 of the "Constructing the Tree of Life" cards handout

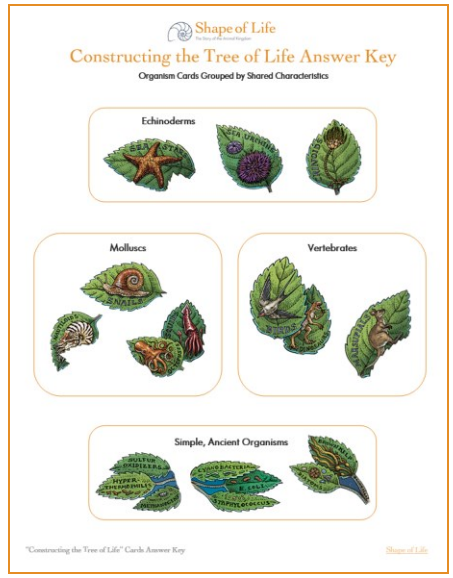
Teaching Suggestions in the 5E Model

Engage

1. Students discuss similarities and differences between organisms and which may have evolved earlier. (5 min.)

    - Pass out the following 12 "leaves" on page 1 of the cards to pairs or groups of three students:
        - Nautiloids, octopuses/squids, snails (all molluscs)
        - Crinoids, sea stars, sea urchins (all echinoderms)
        - Dinosaurs, birds, marsupials (all vertebrates)
        - Bacteria and sulfur oxidizers, hyperthermophiles, and methanogens (beginnings of life on Earth)

- Ask the partners or groups to arrange the leaves how they think the organisms are related, and which are the most ancient in the evolutionary tree of life. See the answer key here, but do not share it with the students yet: shapeoflife.org/lesson-plan/constructing-tree-life.
    - Ask students to think about the adaptations and/or physical characteristics of each organism and make notes about why they think these organisms are related in science notebooks.
    - Ask: Which organisms do you think are the most ancient? Why do you think so?
- Circulate through student groups, answering questions and providing feedback, as necessary. Tell students when they have another minute to work. Ask them to be ready to share their ideas with the class.
- Briefly discuss student ideas as a class.



Answer key for the first leaves activity

Explore

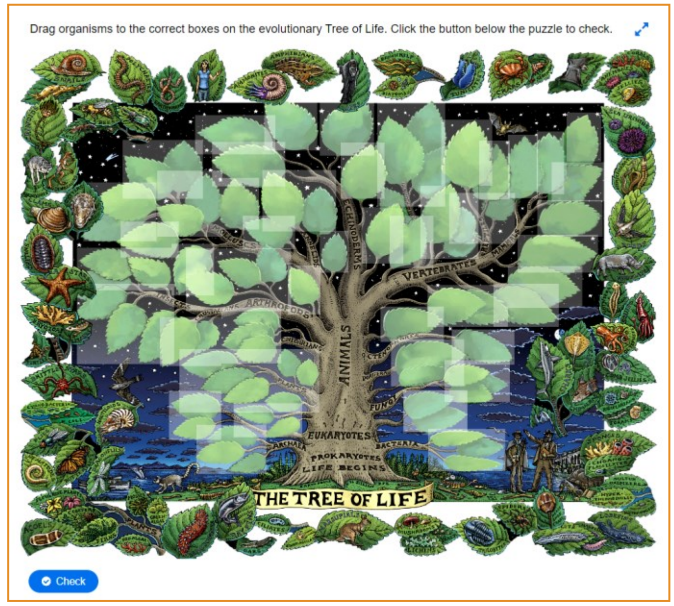
2. Students construct a tree representing life on Earth. (10–20 min.)

- Pass out Tree of Life Game Boards to groups, along with more organisms from pages 3–5 of the cards. If necessary, ask them to finish cutting out the leaves with organisms using scissors. Then they can work together to try to correctly arrange the leaves on the game board.

The Tree of Life Game Board with blank leaves. Please note that the science itself is evolving and subject to change as more fossil and DNA evidence is revealed.

- More advanced students could be given the complete set of organism cards, or groups could ask for more of them after they worked through a set of them.
- Ask students to discuss why they think organisms were placed in certain locations by the artist, Ray Troll, in collaboration with scientists. Ask them to record their ideas in science notebooks.
- Circulate through the groups, answering questions and providing feedback, as necessary. Tell students when they have another minute to work.

- If students finish adding all the leaves to the board, they can play the online version of the puzzle game individually or in pairs at engagingeverystudent.com/tree-of-life-game.



Explain

3. Discuss the Tree of Life and important concepts and terms with students. (4–10 min.)

    - Ask students to share their attempts at completed puzzles (with a document camera, if available) and their experience with the activities.
    - Share the complete Tree of Life illustration with a data projector and/or printed images taped together. Ask them to use it to finish constructing the Tree of Life, if necessary. When students complete the puzzle, they can take a picture of it or tape down the leaves in the correct locations with clear tape.
    - Ask students what they know about how evolution occurs. Ask them what evidence exists to support the idea of evolution. Why do scientists believe what they do about evolution?
    - Tell students that the Tree of Life painting is an example of a **phylogenetic tree**. Ask them to write the term in science notebooks. Tell them it was Charles Darwin who chose the tree of life as a metaphor for relatedness of living things. People have been modeling relationships between organisms at least as far back as the Ancient Greek scientist/philosopher Aristotle.

4. Discuss how understanding an organism's structures and functions helps us understand its evolution. (2–10 min.)

    - Ask students to reflect on how an organism's characteristics / anatomy help to explain its evolution. This can first be done as a think-pair-share activity before discussing it as a class. You could prime the discussion with examples such as:
        - How the evolution of **stronger limbs** helped animals to move out of the water onto land.
        - How **the evolution of amniotic eggs** with a water-tight membrane (the amnion) that surrounded the embryo to retain water allowed animals like **reptiles** to reproduce on land.
        - How the **great apes** (such as chimpanzees) are our closest living relatives and possess many of our physical and behavioral characteristics.

Amniotic eggs were a key evolutionary development. *Photo by Richard Mayer CC BY-SA 3.0: commons.wikimedia.org/wiki/File:Tortoise-Hatchling.jpg*

- How sometimes major environmental events drive evolution. For example, the asteroid that struck Earth 65 million years ago wiped out the **dinosaurs**, which gave **mammals** the chance to evolve into the largest and most powerful animals on the planet.

- Relate the important NGSS concept of cause and effect to your discussion. For example, talk about how the evolution of skulls protected the brains of vertebrates and allowed brains to grow much larger in some species (like primates, whales, and elephants).

5. Students think about and discuss other lines of evidence that support the theory of evolution. (5 min.)

   Ask students to discuss other lines of evolutionary evidence with their partner or group. Ask them to record their ideas in science notebooks. After a few minutes, ask them to share their ideas with the class, which may include fossils and genetics/biochemistry. See the Teacher Background section at the beginning of the lesson and sources at the end of the lesson for more information.

Evaluate

6. Closing discussion / reflection (2–5 min.)

   - Discuss these questions:
     - What evidence supports scientific beliefs in the common ancestry of living things and biological evolution? (NGSS HS-LS4-1)
     - What scientific ideas explain the similarities and differences among modern organisms and between modern and fossil organisms? What are some shared traits of different organisms that help show the evolutionary relationships between them? (NGSS MS-LS4-2)
   - Students should be encouraged to explain "how common ancestry and biological evolution are supported by multiple lines of empirical evidence" (NGSS), such as common characteristics of simple and complex organisms.

7. Ask students to record written answers to the questions above and notes about their experience. (3–5 min.)

   Ask students to record written thoughts about the questions and their experience with the activities in science notebooks.

8. Review completed student trees and science notebooks.

   Review student diagrams and/or other projects. Provide feedback.

Enrich / Extend

- Show students the animated Tree of Life video.
  - The video that incorporates Ray Troll's art is available on the Shape of Life website and Vimeo: vimeo.com/934690484/fa958016ed.
  - Discuss the animated tree as a class. Remind students that even though evolution is not linear and it's not directed, it might appear so in the animated tree.

Screenshot from the "Tree of Life" video.

    - See the "Animating the Tree of Life" lesson from Shape of Life for details: shapeoflife.org/lesson-plan/animating-tree-life.

- Ask students to choose an organism group from the Tree of Life and create a family tree for it. (20–30 min.)

  See the "Our Chordate Family Tree" lesson for details and ideas: shapeoflife.org/lesson-plan/sol/our-chordate-family-tree

- Students create presentations about an organism group from the Tree of Life and how scientists believe it evolved. (30 min. or more)

    - Ask students to choose an organism group from the Tree of Life or a specific species to prepare short presentations to the class about. Ask them to cite scientific evidence for how it evolved, such as fossils with shared characteristics to the modern organism.
    - Provide a rubric, such as the one on the lesson page, so students know how they will be assessed.
    - Students could also create public service announcements about their organisms, why they are important, and how to protect them. Students can use video and/or other communication methods, such as live acting.

- Discuss the tremendous diversity of species around the world and ecological challenges they are facing. (5–8 min.)

    - For instance, discuss how there are about 44,000 known species of chordates alone. What factors explain this tremendous biodiversity?
    - What factors threaten the biodiversity of species, which is so important for the health of ecosystems and life on Earth?
    - Students can participate in service projects to identify a threatened local species and take action to protect it and its habitat. For example, trash (including dangerous plastic) can be picked up, invasive species could be removed, or signs could be created for storm drains that warn the public that they connect to our rivers.

- Conduct a field study so students can observe and compare groups of living organisms. (Will vary)

    - Take students on a field trip to a tidepool, wetland, aquarium, or other area where students can observe different types of living organisms from the tree firsthand.
    - Be sure students are prepared with appropriate clothing, safety rules, ways to avoid damaging the ecosystem, etc.

Standards		Middle School / High School
Next Generation Science Standards	Performance Expectations	HS-LS4-1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence. MS-LS4-2: Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships.
	Disciplinary Core Ideas	LS4: Biological Evolution: Unity and Diversity LS4.A: Evidence of Common Ancestry and Diversity LS4.C: Adaptation LS1: From Molecules to Organisms: Structures and Processes LS1.A: Structure and Function LS1.B: Growth and Development of Organisms
	Crosscutting Concepts	• Patterns • Cause and effect • Structure and function • Systems and system models
	Science & Engineering Practices	• Developing and Using Models • Engaging in Argument from Evidence • Obtaining, Evaluating, and Communicating Information

Common Core ELA	Writing	7
	Speaking & Listening	4, 6
	Language Standards	1, 2, 3, 6

Expand Knowledge + Skills

Evolution Background / Chronology

- Bell, G. (2015). *The Evolution of Life*. Oxford University Press. In print or preview online: books.google.com/books?id=80aPBQAAQBAJ
- "Big History: Examines Our Past, Explains Our Present, Imagines Our Future." DK – Penguin. In print or preview online: books.google.com/books?id=wCcCDQAAQBAJ
- Evans, L. (1999). *Nature's Holism.* iUniverse. In print or preview online at: books.google.com/books?id=k1_wEXk8WtcC
- "Evolution: Deep Time." PBS: pbs.org/wgbh/evolution/change/deeptime/paleoz.html
- "Evolution of Mammals." Wikipedia (and sources referenced in article): en.wikipedia.org/wiki/Evolution_of_mammals
- Gore, R. "The Rise of Mammals." National Geographic: nationalgeographic.com/science/prehistoric-world/rise-mammals

- Marshall, M. "Timeline: The Evolution of Life." New Scientist: newscientist.com/article/dn17453-timeline-the-evolution-of-life
- National Academy of Sciences. (1999). "Evidence Supporting Biological Evolution." National Academies Press: ncbi.nlm.nih.gov/books/NBK230201
- "Timeline of Human Evolution." Wikipedia (and sources referenced in article): en.wikipedia.org/wiki/Timeline_of_human_evolution

Related Videos + Articles

- "Tree of Life." Shape of Life: vimeo.com/934690484/fa958016ed
- "Jenny Clack, Paleontologist." Shape of Life: shapeoflife.org/scientist/jenny-clack-paleontologist
- "Kristi Curry Rogers, Paleontologist." Shape of Life: shapeoflife.org/scientist/kristi-curry-rogers-paleontologist
- "Discovering the tree of life." Khan Academy: khanacademy.org/science/high-school-biology/hs-evolution/hs-phylogeny/v/discovering-the-tree-of-life

Related Lesson Plans / Activities

- "Animating the Tree of Life." Shape of Life: shapeoflife.org/lesson-plan/animating-tree-life
- "Modeling Evolutionary Relationships with Trees." Shape of Life: shapeoflife.org/lesson-plan/modeling-evolutionary-relationships-trees
- "Our Chordate Family Tree." Shape of Life: shapeoflife.org/lesson-plan/sol/our-chordate-family-tree
- "The Secrets of Fossils." Shape of Life: shapeoflife.org/lesson-plan/sol/secrets-fossils
- "A Paleontologist Searches for Bilateral Ancestors." Shape of Life: shapeoflife.org/lesson-plan/sol/paleontologist-searches-bilateral-ancestors
- "Teach Evolution." Understanding Evolution: evolution.berkeley.edu/teach-evolution
- "Evolution Lab." Game and Educator Guide from NOVA: pbs.org/wgbh/nova/labs/lab/evolution

Standards

- Next Generation Science Standards, including a link to the *Framework for K-12 Science Education* to which this lesson was aligned: nextgenscience.org/framework-k%E2%80%9312-science-education
- Common Core State Standards and links to the complete documents: corestandards.org

Appreciation + Thanks

Thank you for using Shape of Life resources and helping
to inspire the next generation of thinkers and scientists!

We welcome your questions or comments.

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Shape of Life