Shape of Life
The Story of the Animal Kingdom

Our Chordate Family Tree

How did we evolve with the rest of the animal kingdom?

Overview

Students explore the evolution of the phylum Chordata by constructing a "family tree"—a diagram of evolutionary traits and animals. First, they use cards showing traits to create a diagram of evolutionary relationships. Then they watch a Shape of Life video to observe chordates and their distinguishing traits. The teacher facilitates discussion and then they revise their diagrams and add information, including examples of modern animals that exhibit the traits. Many possible adaptations and extensions are listed at the end of the lesson to help engage all students.

Objectives

- Students will create evolutionary family trees.
- Students will understand and discuss key characteristics of chordate species orally and in writing.
- Students will explain how common ancestry and biological evolution are supported by multiple lines of empirical evidence.

Subjects

Science, Environmental Education, Writing, Reading, Art, and Social Studies

Grades 6–16

Time

45–90 minutes

Vocabulary

Adaptations, ancestry, biological evolution, chordate, notochord, nerve cord (tube), pharyngeal (gill) slits, plankton

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. MS-LS1-3. Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells.
	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

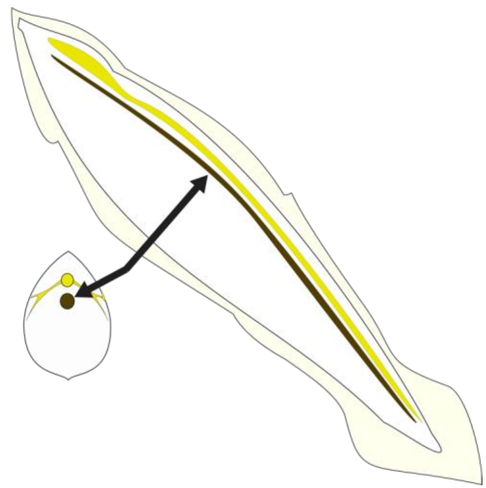
Teacher Background

Although there are tremendous variations among species, chordates all have four distinguishing structures in common at some stage in their life:

- ## Notochords

  These flexible, rod-like structures made of cartilage are found in all chordates in at least one stage of their development. Notochords provide support for the rest of the skeletal structure. **Amphioxus**, a **lancelet**, is an animal highlighted in the Shape of Life video "Chordates: We're All Family" that retains the notochord throughout its life cycle; the 25 – 35 known species of lancelets provide insight into the evolution of all chordates.

  In **vertebrates** (fishes, reptiles, birds, mammals, and amphibians), the embryotic notochord becomes the discs in the spinal column. See the Shape of Life video "Chordate Animation: Amphioxus to Vertebrate Body Plan" (1:31): shapeoflife.org/video/chordate-animation-amphioxus-vertebrate-body-plan.



Notochord shown as dark-colored line inside model of simple marine animal, and the nerve cord as a light line above it.

Diagram adapted from Piotr Michał Jaworski. Wikimedia Commons: commons.wikimedia.org/wiki/File:BranchiostomaLanceolatum_PioM.svg

- ## Dorsal Nerve Cord (Tube) *(shown as light-colored line inside model of lancelet to the right)*

  Referred to by zoologists as the **dorsal hollow nerve tube**, it runs above the notochord and "sends branches of nerve tissue into muscles and other organs. As the nerve cord grows, its walls thicken, almost eliminating the central hollow space." ("Phylum Chordata," Exploring Our Fluid Earth). Nerve cords relay signals from the brain and are found in all chordates at each stage of their lives; in vertebrates, they are protected by the spine and therefore often called the **spinal cord**.

- ## Pharyngeal (Gill) Slits

  These are a series of openings between the **pharynx** (throat) and the outside. Primitive chordates use the slits to filter food, while fishes and amphibians use them as gills to exchange gases. They are only present in the embryonic stages of most land-based chordates. The skeleton and muscles of the gill slits become various parts of the jaw, face, ear, pharynx, and tongue in humans.

- ## Post-Anal Tail

  All chordates have a tail located further back from the anus, although in some species (such as humans and frogs) it is barely present in mature stages.

There are Three Chordate Subphyla:

1. ### Subphylum Cephalochordata (Lancelets)

   Animals classified as **Cephalochordata** are commonly called lancelets. Amphioxus is a lancelet. They are small, narrow creatures which contain roughly 100 pharyngeal (gill) slits, which are used to filter the water for food. While lancelets have all four of the key characteristics of chordates listed above, they only have a very small brain and poorly developed sensory organs.

2. Subphylum Tunicata (Urochordata)

The Chordata subphylum **Tunicata** contains fascinating invertebrate groups of marine species that also use their gill slits to filter water to feed, including:

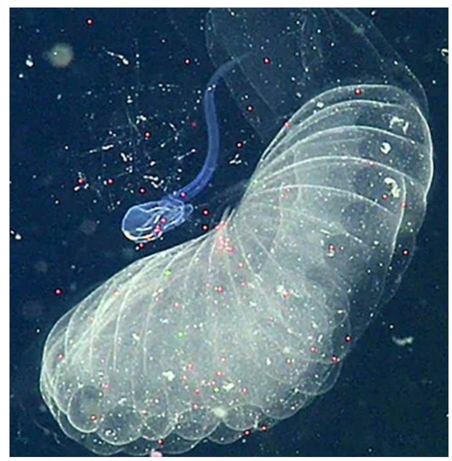
• Ascidians (Sea Squirts)

Sac-like organisms found around the world, most commonly in shallow water, ascidinans are **sessile** (fixed in place) as adults and they filter water to extract nutrients. However, most species can swim freely during their larval stage using a long tail, with a body form similar to that of a tadpole. During this stage of their life cycle they exhibit the key identifying characteristics of chordates, including a notochord, dorsal nerve cord, gill slits, and post-anal tail. They use sensory receptors to identify a good location to attach in place and metamorphose into their sessile adult forms.

Purple Sea Squirt
Image by Nhobgood, Creative Commons license:
commons.wikimedia.org/wiki/File:Triphyllozoon_inornatum_(Bryozoan)_and_Polycarpa_aurata_(Sea_quirt).jpg

• Larvaceans (Appendicularia)

These marine organisms swim freely throughout their lives and filter plankton. Most species can extract more of this nutritious food by creating "houses" of mesh-like mucous around their bodies that can be a meter in diameter in some cases. When their houses become clogged, the animal leaves the house and creates a new one. The old house then sinks, providing food for other deeper animals. See featured scientist "Dr. Kakani Katija, Principal Engineer, Monterey Bay Aquarium Research Institute (MBARI)." Shape of Life: shapeoflife.org/news/featured-scientist/2017/08/26/dr-kakani-katija-principal-engineer-monterey-bay-aquarium.



Giant larvacean (tadpole-like animal) with "house"
Image © 2016 MBARI: shapeoflife.org/news/featured-creature/2017/08/26/giant-larvacean-bathochordaeus

• Salps

Shaped like small barrels, salps can pump water through their bodies by contracting their muscles, a simple and efficient form of jet propulsion. Like other tunicates, they filter plankton, and are found throughout the world, most commonly in the plankton-rich waters of the Southern Ocean. While they are solitary during one part of their complex life cycle, they reproduce asexually by forming colonies called **aggregates** of many individuals linked in long chains. These chains can range in size from 10's to 100's of individuals. Salps can be the dominant component of the diet of many marine animals, from tuna to turtles.

Salp aggregate
Image by Peter Southwood, Creative Commons license:
commons.wikimedia.org/wiki/File:Salp_colony,_Aorangaia_PA171899.JPG

3. Subphylum Vertebrata: The Genes Make the Difference

- Vertebrates became bigger and more complex because they evolved four times the number of genes of simple chordates.
- The evolution of flexible jaws in vertebrates allowed them to become powerful predators and increase their body size.
- Fish were the first animals with bony jaws.
- Skulls protect soft brains as they became larger.
- The evolution of stronger limbs (legs) helped vertebrates to spread over the land.
- Reptiles evolved to reproduce on land by developing eggs with hard shells.
- Mammals came to be the dominant animals on land after the dinosaurs were wiped out by an asteroid 65 million years ago.
- The great apes (chimpanzees, orangutans, etc.) are our closest ancestors.

Coho salmon (a vertebrate)
Image from BLM, Creative Commons license:
www.flickr.com/photos/blmoregon/16335492972

Komodo dragon
(vertebrate with walking legs)
Image by TLSPAMG from Pixabay:
pixabay.com/photos/reptile-komodo-dragon-wildlife-1984970

List of Chordate Traits from "Trait + Animal Cards" in Order of Appearance

Approximate dates for the evolution of the traits based on the fossil record are listed below. See the "Evolutionary Chronology" sources in the "Expand Knowledge + Skills" section for more details and resources you can share with students.

0. **Cells**: 3.5 billion years ago
1. **Bilateral symmetry**: 630 million years ago (mya)
2. **Segmented bodies**: 540 million years ago (mya) (during Cambrian Period)
3. **Notochord**: 530 mya (during Cambrian Period)
   Nerve cord: 530 mya (during Cambrian)
   Post-anal tail: 530 mya (during Cambrian)
   Pharyngeal (gill) slits: 530 mya (during Cambrian)
4. **Head with sensory organs** (hagfish): 520 mya (during Cambrian)
5. **Cartilaginous backbone** (lamprey): 485mya
6. **Flexible jaw made of cartilage & teeth** (sharks, etc.): 460 mya
7. **More genes:** Gene duplication happened more than once.
8. **Bony skeleton** (bony fish): 460 mya
   Scales (bony fish): 460 mya
9. **Lobed fins with bones**: 440 mya (during lower Devonian Period)
   Bony jaws: 440 mya
   Bony vertebral column (spine / backbone): 438 mya
10. **Skull (large bony head plates)**: 415 mya
11. **Four limbs**: 397 mya (during Devonian)

12. **Stronger limbs (legs)**: 375 mya (during Devonian)
13. **Amniotic eggs**: 340 mya (during Carboniferous Period)
14. **Large canine teeth:** 220 mya
15. **Fur / Hair**: 200 mya

    Mammary glands: 200 mya
16. **Long-lasting placenta:** 140 mya
17. **Grasping feet** (primates): 63 mya
19. **Flat nails** (primates): 55 mya

Non-Chordate Trait Included in Cards to Highlight a Key Difference

Exoskeleton: 543 mya (around start of Paleozoic Era / Cambrian Period)

Materials + Preparation

This is one of three pages of evolutionary traits; decide if you will share all of them with students or start with just two. There are also two pages of animals which can be incorporated into "Chordate Family Tree" diagrams later in the lesson.

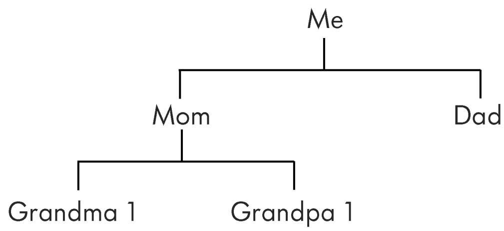
- Sets of the "Trait & Animal Cards" for student groups to share (found at the end of the lesson); cut them on a paper cutter or provide scissors or cutters for students.
- Be ready to show (or have students view) these Shape of Life videos:
  - "Chordates: We're All Family" (15:42): shapeoflife.org/video/chordates-we're-all-family
  - "Chordate Animation: Amphioxus to Vertebrate Body Plan" (1:31): shapeoflife.org/video/chordate-animation-amphioxus-vertebrate-body-plan
- Decide if you will:
  - Show the video(s) to the whole class during the "Explain" phase of the lesson and/or
  - Have partners view the video while creating a Tree of Life with the "Trait & Animal Cards."
- Make copies of "The Tree of Life" evolutionary tree or prepare for students to access it online: shapeoflife.org/sites/default/files/global/treeoflife.pdf.
- Science notebook and pencil or pen for each student
- 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)
- Whiteboard or chart paper and markers
- *Optional:* Be ready to refer to the "Tree of Life" poster shown at shapeoflife.org/sites/default/files/global/treeoflife.pdf.
- *Optional:* Computer with Internet connection and data projector if you plan to show all or part of the videos to the whole class
- *Optional:* Colored pencils and/or markers for students to share

Teaching Suggestions in the 5E Model

Engage

1. "Hook" students and introduce the lesson. (2–3 min.)

- Ask students to think about their personal family trees. How far back can they trace their personal ancestry? To their grandparents, great-grandparents, or further back than that? Or perhaps they were adopted and are unsure about their biological ancestors. Show the students an example of a simple human family tree diagram, with a living person at the top and their known ancestors below. You can use yourself or a well-known scientist, such as Jane Goodall or Neil deGrasse Tyson, as an example.



- Give the students a minute to turn to a neighbor and discuss, creating simple sketch family trees on a sheet of paper or in their science notebooks.
- Then ask students to think about who their ancestors might have been hundreds of millions of years ago. What might some of these ancestors have looked like? What similarities and differences might we have with them?
- To see what they already know about the phylum and prime them for the lesson, ask the students to complete the "Chordata Trivia" activity or discuss the following questions as a class:
  - What are chordates? (Animals in the phylum Chordata, such as all mammals, fish, birds, amphibians, and reptiles)
  - True or false? All chordates have a backbone. (False: Some only have a notochord made of cartilage for one part of their life cycle.)
  - True or false? All chordates have a nerve cord (nerve tube). (True)

Explore

2. Students try to construct a chordate tree of traits. (10 min.)

- Pass out sets of the "Trait Cards" to groups of 2 – 4 students. You can ask them to use all three pages of trait cards (27 total), or simplify the activity by using just the first two pages of cards (18 total).
- Ask them to try to arrange the trait cards on a desk or table according to which evolved the earliest, with the oldest at the bottom of the diagram. Tell the students that this can be thought of as another type of family tree—of evolved traits of the animal kingdom.

3. Students watch "Chordates: We're All Family" and consider their key characteristics. (20 min.)

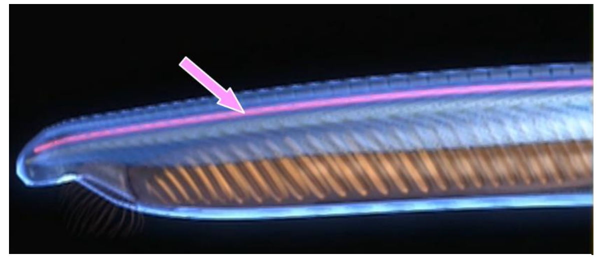
- Depending on how many computers and/or other devices your students have access to, consider asking groups to watch the video together while thinking about the **traits** that the chordate animals possess. On a second viewing, they can rearrange their diagrams and/or record notes about the physical adaptations (body structures) and behavioral adaptations (things the organisms do) that help the chordate species to survive, including simple sketches of the organisms and their important structures. They also might add arrows or other symbols to indicate movements and other processes. Consider giving them a choice between recording notes in science notebooks and a digital format.

- Encourage students to turn on closed captioning using the CC button so they can read along with the video. Students can also use headphones, if available, to better hear the narration and minimize distractions to other groups.
- Circulate through student groups, answering questions and providing feedback, as necessary.

Explain

4. Discuss important concepts and terms with students. (4 – 10 min.)

- Discuss important evolved traits of chordates (adaptations), writing them on the board and asking students to take notes on them in science notebooks. If desired, watch the "Chordates: We're All Family" video again and/or "Chordate Animation: Amphioxus to Vertebrate Body Plan" for visual aids to emphasize key concepts during the discussion. For example, discuss:
  - **Amphioxus** and how it shares traits common to all members of phylum Chordata:
    - **Nerve cord (tube):** Referred to by zoologists as the **dorsal hollow nerve tube**, it runs above the notochord and "sends branches of nerve tissue into muscles and other organs. As the nerve cord grows, its walls thicken, almost eliminating the central hollow space." ("Phylum Chordata," Exploring Our Fluid Earth). Nerve cords relay signals from the brain and are found in all chordates at each stage of their lives; in vertebrates, they are protected by the spine and therefore often called the **spinal cord.**



Amphioxus with the nerve cord shown in pink

    - **Gill slits**: a series of openings between the **pharynx** (throat) and outside of chordate animals. Primitive chordates use the slits to filter food, while fishes and amphibians use them as gills to exchange gases. They are only present in the embryonic stages of most dry land-based chordates.
    - **Notochord** (precursor of backbone/spine): These flexible, rod-like structures made of cartilage are found in all chordates in at least one stage of their development. Notochords provide support for the rest of the body. **Amphioxus** is an animal highlighted in the Shape of Life video "Chordates: We're All Family." In **vertebrates** (fishes, reptiles, birds, mammals, and amphibians), the embryotic notochord remains as the discs between the vertebrae spine or backbone).
  - **Cephalization** (sensory organs clustered in head at anterior end of animal)
  - **Cartilaginous backbone** (like lamprey): advantages of cartilage for animals (strong, light, flexible, buoyant)
  - **Flexible jaws and teeth**: more feeding opportunities; how the development of flexible jaws in a wide mouth allowed fish to move to the top of the food chain
  - Fish were the first animals with **bony jaws** that were even stronger than cartilage.
  - **Bones:** stronger body structures; more success as predators
  - **Tetrapods**: four limbs with bones; helped animals colonize the land
  - **Amniotic eggs:** Membrane (the amnion) surrounds embryo to retain water; allowed animals to reproduce on land
  - **Mammary glands** and **fur / hair:** Helped mammals come to dominate after dinosaurs went extinct
  - The addition of **4 times more genes** allowed vertebrates to become bigger and more complex.
  - **Skulls** protected the soft brains of fish and allowed them to grow larger.

- **Tunicates** continued as simple animals down their own branch of the chordate family tree, as did **salps** and **larvaceans**. If you have time, you may want to discuss these fascinating organisms more fully. For example:
    - **Ascidians (sea squirts)** are sac-like organisms found around the world, most commonly in shallow saltwater. They are **sessile** (fixed in place) as adults and filter water to extract nutrients. However, most species can swim freely during their larval stage using a long tail, with a body form like that of a tadpole. During this stage of their life cycle they exhibit the key identifying characteristics of chordates, including a notochord and nerve tube controlling muscles. They use sensory receptors to identify a good location to attach in place and metamorphose into their simpler adult forms.
    - **Larvaceans (appendicularia)** are marine organisms that swim freely throughout their lives and filter plankton. Most species can extract more of this nutritious food by creating "houses" of mesh-like mucous around their bodies, that can be a meter in diameter in some cases. When their houses become clogged, the animal leaves the "house" and creates a new one.
    - **Salps** are small, barrel-shaped animals that can pump water through their bodies by contracting their muscles, a simple and efficient form of jet propulsion. Like other tunicates, they filter plankton, and are found through the world, most commonly in the plankton-rich waters of the Southern Ocean. While they are solitary during one part of their complex life cycle, they reproduce asexually by forming colonies called **aggregates** of many individuals linked in long chains. These chains can range in size from 10s to 100s of individuals, which begin life as tiny clones that feed and grow together. Salps can be a dominant component of the diet of many marine animals, from tuna to turtles.
- Use guided questions during or after the video(s) to enhance learning, such as:
    - How might hard skulls have been an evolutionary advantage? (Protected soft brains, which could grow larger, leading to higher intelligence)
    - What traits of mammals might have helped them to thrive after the dinosaurs went extinct? (Fur/hair to stay warm, mammary glands to feed their young, and other traits inherited from earlier ancestors, such as hard bones and skulls, four limbs, etc.)

5. Discuss how understanding chordate structures and their functions helps us understand their evolution. (2–10 min.)

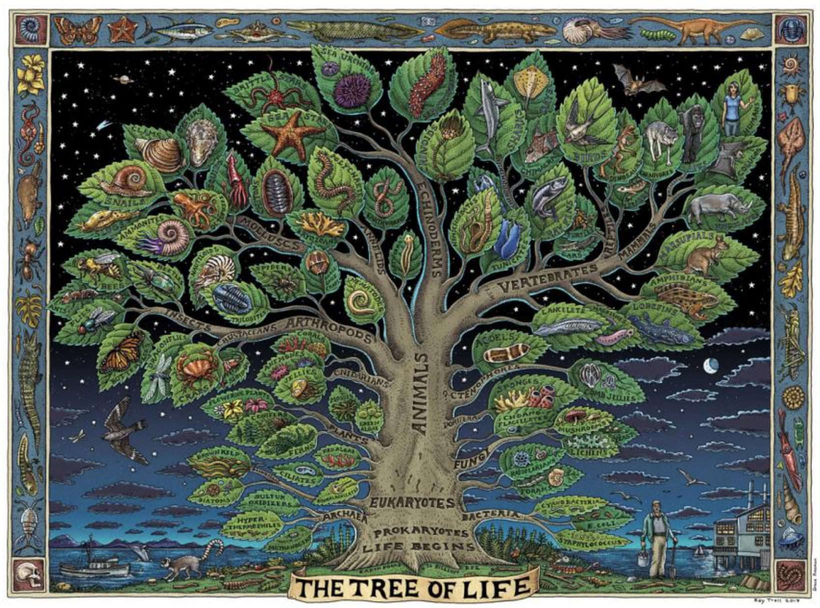
- Ask students to reflect on how chordate characteristics help to explain their evolution. For example:
    - How **stronger limbs** helped animals to move out of the water onto land.
    - How **amniotic eggs** evolved with a water-tight membrane (the amnion) that surrounded the embryo to retain water; this allowed animals like **reptiles** to reproduce on land.
    - How warm-blooded mammals have high metabolisms that require lots of energy (food).
    - How the **great apes** (such as chimpanzees) are our closest living relatives and possess many of our physical and behavioral characteristics.
    - How sometimes environmental events drive evolution, for example the huge asteroid that struck Earth 65 milli

Amniotic eggs were a key evolutionary development that allowed animals to colonize the land.
Creative commons image by Mayer Richard: commons.wikimedia.org/wiki/File:Tortoise-Hatchling.jpg

    dinosaurs, which gave **mammals** the chance to evolve into the largest and most powerful animals on the planet.
    - This can first be done as a think-pair-share activity before discussing it as a class.

- What traits evolved in animals before the chordates evolved? (i.e. cells, nerves, bilateral symmetry, etc.) Ask what organisms we are related to, beginning at the start of the fossil record billions of years ago. What characteristics do we have in common with different branches of the tree of animal life? You can refer to the "Tree of Life" poster shown at shapeoflife.org/sites/default/files/global/treeoflife.pdf.
- 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 them to grow much larger in some species (like primates, whales, and elephants), helping them to become extremely intelligent. On the other hand, you might also discuss how bony skulls in fish did not necessarily lead to a direct cause and effect (like fish brains getting larger and larger); when the increase in size stopped improving their chances of survival and passing on their genes, they stopped growing larger.
- *Optional:* You might also discuss how **natural selection** of species through competitive pressures can result in the long-term effects of evolutionary changes over time. What might have caused the further evolution of chordate structures into those found in modern chordates, including the great apes and humans? (For example, predator pressure in forests and open grasslands selected for primates that had grasping feet to climb trees, and flat nails (instead of claws) because they were an advantage when holding tree limbs and objects, picking up things, etc.)

6. Ask students to correct their first diagram of traits and then add the animal cards. They can include additional information, more evolutionary traits and organisms, etc. (20 – 25 min.)



Ray Troll's gorgeous, illuminating painting "The Tree of Life." View a larger version and the story of its creation at shapeoflife.org/blog/making-new-tree-life-shape-life.

- Pass out poster board or butcher paper (one sheet per group) and ask students to make a more accurate and detailed tree of life which includes the "Trait + Animal Cards" and additional traits and organisms, as well as lines connecting them. Consider sharing an exemplar that you or a student created, as well as "The Tree of Life" evolutionary tree from Shape of Life: shapeoflife.org/sites/default/files/global/treeoflife.pdf. Students can also create a graphical outline of a tree on the paper to help organize the traits and animals.
- Students should be encouraged to add at least five more traits or organisms to their diagrams (potentially more than are in the cards), as well as labels and annotations (more detailed explanations of the features of the diagrams). They can also color their diagrams and explain them in writing, including the evolutionary traits that helped the animals to survive over long periods of time.
- Diagrams can be completed with the support of additional reference materials such as books and those on the Internet, such as those listed in the "Expand Knowledge + Skills" section at the end of the lesson.

A "Chordate Family Tree" diagram of trait and animal cards arranged after viewing the Shape of Life videos and discussing the evolutionary traits

Extend / Enrich

- Students each choose a specific chordate species and create a family tree for it. (20 – 30 min.)
- Students create persuasive presentations about a chordate species and why it is important in its ecosystem and/or how it evolved. (30 min. or more)
    - Students should cite scientific evidence. A rubric, such as the one at the end of the lesson, can be used to help guide students and for evaluation.
    - Students could also create public service announcements about their organisms and how to protect them; video can be used or other communication methods, such as live acting.
- Students can engineer a 3-D model of a new chordate species adapted to survive in a hotter climate or more acidic ocean. (30 min. or more)
    - Discuss with students how species might adapt in the future over millions of years through the process of evolution if rapid climate change is not reversed.
    - Clay and/or other natural and human-made materials can be provided for students to select from when constructing their models.
    - Students can label the adaptations on their models and create oral presentations to explain their new species and its adaptations to the class.

New organisms created by students with clay and natural materials; offering scrap materials to use in the engineering designs is another great option

- Students research the life cycle of a chordate species and create an illustrated, annotated diagram for it. (20 – 30 min.)
- Discuss the tremendous diversity and ecological challenges facing chordate species around the world. (5 – 8 min.)
    - Discuss how there are about 44,000 known species of chordates. What factors explain this tremendous biodiversity?
    - What factors threaten the biodiversity of chordates and other 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.
- Students compare a chordate species to another organism. (10 – 20 min.)
    - Ask the students to compare a chordate with a non-chordate organism—either a modern one or an ancient ancestor. For example, a Venn diagram or another type of graphic organizer could be used. Then students could explain their graphic organizers in writing.
    - Students can compare physical traits, what it eats, what eats it, etc. They can also compare the life cycles of the organisms.
    - Oral presentations can be given to the class which explain the analytical comparisons.

- Conduct a field study so students can observe and compare living chordates. (Will vary)
    - Take students on a field trip to a tidepool, wetland, aquarium, or other area where students can observe chordates and their ecosystems firsthand.
    - Be sure students are prepared with appropriate clothing, safety rules, ways to avoid damaging the ecosystem, etc.
- Students choose one or more chordate species and create an educational game to teach other students about them and their evolution, habitats, etc. (30 min. or more)
    - It can be a board game, or use cards, technology, a simulation, scavenger hunt with outdoor exploration, etc.
    - Provide a rubric such as the one at the end of the lesson so students know how they will be assessed.
- Observe chordates under magnification. (1 – 20 min.)
    - If you have access to live chordate specimens, either in the wild or at an aquarium or in the classroom, students can view parts of the them (such as skin, scales, hair, organs, etc.) under magnification via a microscope, hand lens, and/or macro lens to better see their unique adaptations.
    - You can also use a microscope or macro lens connected to a computer and/or data projector to show them to the whole class.
- Dissect simple chordates. (10 – 20 min.)
    - You can prepare to lead students in a dissection—or they can lead themselves—with the support of resources listed at the end of the lesson.
- Discuss current events related to one or more chordate species. (1 – 20 min.)
    - Find some local news highlighting issues related to chordates, such as salmonids or whales. This will make the activities and discussions more relevant and personal to the students.
    - Other important news related to chordates, such as the impacts of climate change on coral reefs, would also stimulate thinking and discussion.
- Students can conduct in-depth research projects about a chordate species and its adaptations. (60 min. or more)
    - Students can also create detailed scientific illustrations of the chordates.
    - They can add annotated labels to the illustrations for the species' key adaptations / evolutionary traits.
- Students can write fictional stories or poems that involve chordates. (15 min. or more)
    - Stories can include one or more chordate species.
    - For example, they could be imaginative pieces about a day in the life of an endangered sea turtle, overcoming the challenges of plastic and light pollution. Or the setting could be a coral reef in which fish and other chordates are struggling to survive in the habitat impacted by ocean acidification.

- Setup learning/exploration centers and offer students a choice of activities.

  Classroom centers can be setup with other activities related to chordates and their adaptations, such as those listed above. This would provide more opportunity for student choice and differentiated learning experiences to maximize intrinsic motivation, engagement, and learning.

Evaluate

7. Students can present their tree of life diagrams and/or other projects to the class.

   - Students should be encouraged to explain "how common ancestry and biological evolution are supported by multiple lines of empirical evidence" (NGSS), such as the common characteristics of simple and complex chordates.
   - Provide a rubric such as the one at the end of the lesson so students know how they will be assessed.
   - Students could also be asked to explain how every living thing is related.
   - Completed projects can also be displayed on classroom and/or school walls.

8. Review completed student diagrams and science notebooks.

   - Review student diagrams and/or other projects.
   - Fill out rubrics and return to students.

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

   - Close with a discussion of how the legacy of chordate evolution is present with us humans to this day, including traits that we have in common with other modern chordates. For example, our nerve cord, gill slits (which we have as embryos), spinal discs (evolved from the notochord, which we also have as embryos), and our post-anal tail (barely present at the end of our spine) help reveal our connections to all chordates.
   - Students can be asked to reflect on what they learned in the lesson, including about chordate evolution and traits, orally and/or in writing. They can also be asked to reflect on what you, as the teacher, might do to improve the lesson next time.
   - Ask how the traits of simple chordate species, such as amphioxus, help to explain the evolution of the incredibly diverse and successful phylum Chordata.
   - Discuss "how common ancestry and biological evolution are supported by multiple lines of empirical evidence" (NGSS).

Expand Knowledge + Skills

Chordata Background

- "About Chordates." Shape of Life: shapeoflife.org/resource/about-chordates
- "Phylum Chordata – Advanced." Shape of Life: shapeoflife.org/phylum-chordata-advanced and Fact Sheet: shapeoflife.org/sites/default/files/global/Phylum-Chordata-Factsheet.pdf
- "Phylum Chordata." Exploring Our Fluid Earth: Teaching Science as Inquiry (TSI). Univ. of Hawai'i: hmanoa.hawaii.edu/exploringourfluidearth/biological/invertebrates/phylum-chordata
    - Generalized diagram of chordate features: manoa.hawaii.edu/exploringourfluidearth/media_colorbox/3344/media_original/en
- "Biology: Chapter 29.1 Chordates." OpenStax CNX. Rice University: cnx.org/contents/GFy_h8cu@11.10:rZudN6XP@2
- "Chordata: More on Morphology. Univ. of California Museum of Paleontology: ucmp.berkeley.edu/chordata/chordatamm.html
- "Chordate." Wikipedia (also references many other excellent sources): en.wikipedia.org/wiki/Chordate
- "Invertebrate Chordates." CK-12: ck12.org/biology/Invertebrate-Chordates/lesson/Invertebrate-Chordates-BIO
- Lundberg, J.D. "Chordata." Tree of Life web project: tolweb.org/Chordata/2499
- Morris, J. "Get a Backbone." Science Whys: blogs.brandeis.edu/sciencewhys/2016/11/26/get-a-backbone
- Pallardy, R. "All the better to eat you with, my dear: The evolution of jaws." Earth.com: earth.com/news/jaws-evolution
- "Vertebrate Diversity." CK-12: ck12.org/biology/vertebrate-diversity/lesson/Vertebrate-Characteristics-BIO
- "Your Bony Jaw Origins Revealed by Early, Armored Fish." Society of Vertebrate Paleontology: vertpaleo.org/Society-News/Blog/Old-Bones-SVP-s-Blog/December-2016/Your-Bony-Jaw-Origins-Revealed-by-Early,-Armored-F.aspx

Evolutionary 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
- Dryden, G. (2008). Animal Nutrition Science. CABI. In print or preview online at: books.google.com/books?id=OG6qrtVKwTEC&dq
- 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

- "Timeline of Human Evolution." Wikipedia (and sources referenced in article): en.wikipedia.org/wiki/Timeline_of_human_evolution

Related Videos + Articles

- "Chordates." Khan Academy: khanacademy.org/science/biology/crash-course-bio-ecology/crash-course-biology-science/v/crash-course-biology-123
- "Jenny Clack, Paleontologist." Shape of Life: shapeoflife.org/scientist/jenny-clack-paleontologist
- "Dr. Kakani Katija, Principal Engineer, Monterey Bay Aquarium Research Institute (MBARI)." Shape of Life: shapeoflife.org/news/featured-scientist/2017/08/26/dr-kakani-katija-principal-engineer-monterey-bay-aquarium
- "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

- "Phylum Chordata – Questions." Shape of Life: shapeoflife.org/sites/default/files/global/phylum-chordata-questions.pdf
- "A Paleontologist Searches for Bilateral Ancestors." Shape of Life: shapeoflife.org/lesson-plan/sol/paleontologist-searches-bilateral-ancestors
- "Free Collection of 30+ Animal evolution worksheets." Free Worksheets Library & World of Puzzles: tonobanquetes.com/animal-evolution-worksheet.html
- "The Secrets of Fossils." Shape of Life: shapeoflife.org/lesson-plan/sol/secrets-fossils

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
- Examples of what NGSS looks like for California students can be found in the 2016 Science Framework for California Public Schools: cde.ca.gov/ci/sc/cf/documents/scifwchapter4.pdf
- 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 also appreciate biologists Chuck Baxter and Nancy Burnett for their help with the chronology of evolutionary traits.

We welcome your questions or comments.

Lesson plan written, designed, and produced by
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Edited by Nancy Burnett and Natasha Fraley
Shape of Life

Shape of Life
The Story of the Animal Kingdom

Chordata Trivia

1. Which of these groups of animals are classified as chordates? (Check all that apply)

    ____ Amphibians
    ____ Mammals
    ____ Reptiles
    ____ Fish
    ____ Birds
    ____ Invertebrates that have a notochord
    ____ All of the above

2. Phylum Chordata is named for their cord-like muscles.

    ____ True
    ____ False

3. Put an "X" or checkmark in front of all the animals below that are classified as chordates.

    ____ Hydras
    ____ Corals
    ____ Jellyfish
    ____ Sea anemones
    ____ Humans
    ____ Crows

4. Chordates are:

    ____ Carnivores
    ____ Herbivores
    ____ Omnivores

5. Mark all the things below that chordates eat.

    ____ Algae
    ____ Fish
    ____ Plankton
    ____ Sea turtles
    ____ Large mammals
    ____ Detritus (dead organic matter)

6. All chordates have gill slits for at least one part of their live cycle.

    ____ True
    ____ False

7. All chordates have a nerve cord (tube).

    ____ True
    ____ False

8. All chordates have a tail for at least one part of their live cycle.

    ____ True
    ____ False

Chordata Trivia Answer Key

1. Which of these groups of animals are classified as chordates? (Check all that apply)

   ____ Amphibians
   ____ Mammals
   ____ Reptiles
   ____ Fish
   ____ Birds
   ____ Invertebrates that have a notochord
   __X_ All of the above

2. Phylum Chordata is named for their cord-like muscles.

   ____ True
   __X_ False (it is named for the notochord)

3. Put an "X" or checkmark in front of all the animals below that are classified as chordates.

   ____ Hydras
   ____ Corals
   ____ Jellyfish
   ____ Sea anemones
   __X_ Humans
   __X_ Crows

4. Chordates are:

   __X_ Carnivores
   __X_ Herbivores
   __X_ Omnivores

5. Mark all the things below that chordates eat.

   __X_ Algae
   __X_ Fish
   __X_ Plankton
   __X_ Sea turtles
   __X_ Large mammals
   __X_ Detritus (dead organic matter)

6. All chordates have gill slits for at least one part of their live cycle.

   __X_ True
   ____ False

7. All chordates have a nerve cord (tube).

   __X_ True
   ____ False

8. All chordates have a tail for at least one part of their live cycle.

   __X_ True
   ____ False

Name(s): ____ Date: ________________

Presentation Rubric

Title: ____

Presentation Component	Maximum Points Possible	Self-Score (fill out before presentation)	Teacher Score
Part 1: Content			
Subject and purpose of presentation clearly introduced	10		
Key concepts identified and clearly explained in well-organized way	10		
Ideas supported by examples, data, graphs, etc.; All information accurate and obtained from reliable sources	10		
Conclusion summarizes key points in persuasive way; Questions answered thoroughly and accurately	10		
Part 2: Delivery / Audience Engagement			
Speech delivered clearly at appropriate volume and speed (not too fast, slow, loud, or soft)	10		
Speed, volume, and voice inflection are varied to engage audience and emphasize key points	10		
Speaker connects with audience through eye contact and does not spend too much time looking at notes or screen	10		
Speaker demonstrates enthusiasm for topic throughout presentation; audience is persuaded by speaker	10		
Part 3: Visuals			
Visuals help to clearly explain concepts	10		
Part 4: Writing Conventions			
Grammatical and spelling conventions followed	10		
TOTALS:	**100**		

Comments:

Notochord

Evolved trait: A flexible, rod-like structure made of cartilage

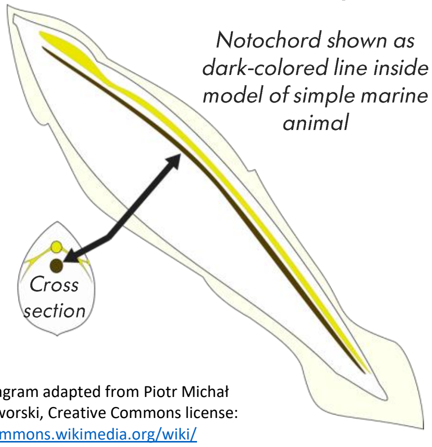


Diagram adapted from Piotr Michał Jaworski, Creative Commons license: commons.wikimedia.org/wiki/File:BranchiostomaLanceolatum_PioM.svg

Nerve Cord (Tube)

Evolved trait: Nerve tissue that runs above the notochord and sends branches of nerves into muscles and organs

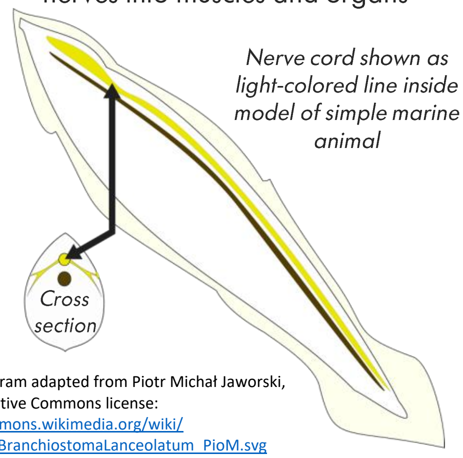


Diagram adapted from Piotr Michał Jaworski, Creative Commons license: commons.wikimedia.org/wiki/File:BranchiostomaLanceolatum_PioM.svg

Pharyngeal (Gill) Slits

Evolved trait: A series of openings between the pharynx (throat) and outside of chordate animals

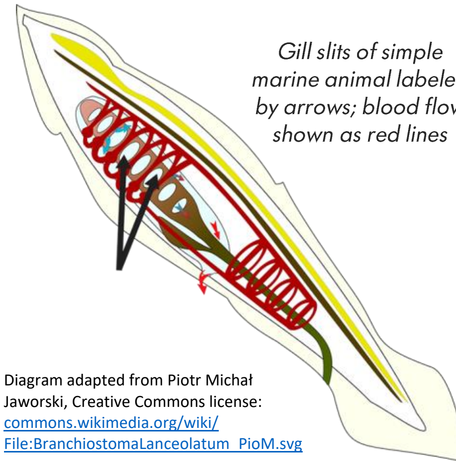


Diagram adapted from Piotr Michał Jaworski, Creative Commons license: commons.wikimedia.org/wiki/File:BranchiostomaLanceolatum_PioM.svg

Post-Anal Tail

Evolved trait: Tail located further back from the anus

Image by Chris Wolf from Pixabay: pixabay.com/photos/howler-monkey-monkey-tail-tree-1183053

More Genes

Evolved trait: More genes allowed animals to become more complex.

Public domain image from Pixabay: pixabay.com/illustrations/dna-biology-science-dna-helix-163710

Flexible Jaws Made of Cartilage + Teeth

Evolved trait: Animals could become powerful predators and increase their body size

Image by Sharkcrew, Creative Commons license: commons.wikimedia.org/wiki/File:Guadalupe_Island_Great_White_Shark_Underwater.jpg

Head with Sensory Organs

Evolved trait: Organs for seeing, hearing, taste, and smell concentrated in head near brain

Hagfish image by C. Ortlepp, Creative Commons license: flickr.com/photos/justinlindsay/242633975

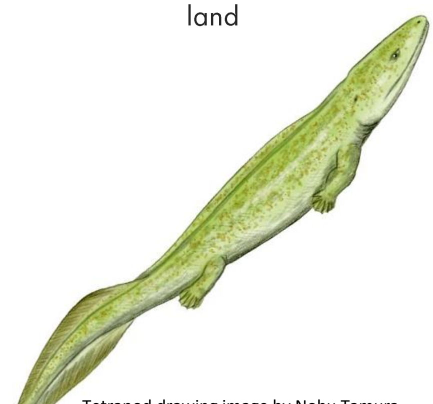
Lobed Fins with Bones

Evolved trait: Stronger limbs; more controlled movement

African coelacanth image from NOAA: fisheries.noaa.gov/species/african-coelacanth

Four Limbs

Evolved trait: Stronger limbs; tetrapods (4-footed animals) able to climb onto land



Tetrapod drawing image by Nobu Tamura, Creative Commons license: commons.wikimedia.org/wiki/File:Elginerpeton_BW.jpg

Amniotic Eggs

Evolved trait: Membrane (the amnion) surrounds embryo to retain water; allowed animals to reproduce on land

Image by Mayer Richard, Creative Commons license: commons.wikimedia.org/wiki/File:Tortoise-Hatchling.jpg

Fur / Hair

Evolved trait: Retains body heat, protects skin, etc.

Sea otter image by Peter Kraayvanger from Pixabay: pixabay.com/photos/riesen-otter-mammal-swim-fur-90026

Cartilaginous Backbone

Evolved trait: Cartilage is light, strong, flexible, and buoyant

Sea lamprey painting by Ellen Edmonson: en.wikipedia.org/wiki/Lamprey#/media/File:Petromyzon_marinus.jpg

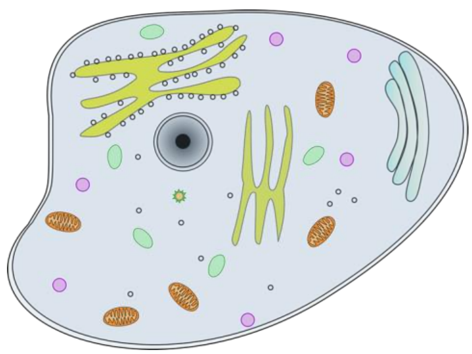
Scales

Evolved trait: Protect skin from predators and infection; help with water retention (in reptiles) and hydrodynamics (in fish and aquatic reptiles)

Goldfish Image from Pixabay: pixabay.com/photos/goldfish-freshwater-fish-365082

Cells

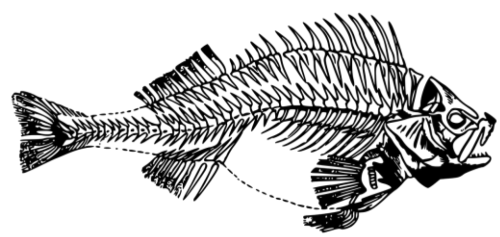
Evolved trait: Basic "building blocks" of all living things that provide structure, take in nutrients, create energy, etc.



Animal cell image from Pixabay: pixabay.com/vectors/view-cell-information-close-48543

Bony Skeleton

Evolved trait: Hard bones include the **vertebral column (spine / backbone)**, a series of flexible bones (vertebrae) that protect the spinal cord (nerve tube) and provide structural support



Perch skeleton image from Pixabay: pixabay.com/vectors/fish-perch-skeleton-1296618/

Mammary Glands

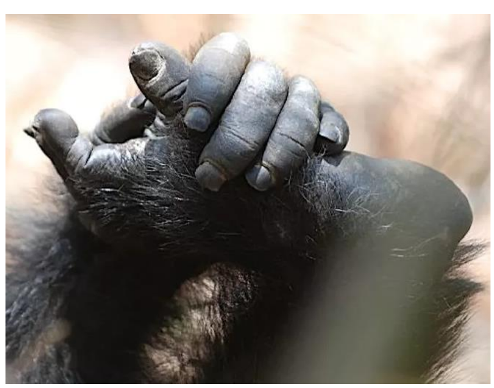
Evolved trait: Organs of mammals used to produce milk for young

Cow udder image by Muhammad Mahdi Karim, Creative Commons license: en.wikipedia.org/wiki/Udder#/media/File:Cow_udders02.jpg

Flat Nails

(instead of claws)

Evolved trait: Helped to grasp trees, pick up objects, pick off things (like bugs), etc.



Chimpanzee image by Nils Rinaldi, Creative Commons license: pixabay.com/photos/riesen-otter-mammal-swim-fur-90026

Grasping Feet

Evolved trait: Helped primates climb trees

Image from Pixabay: pixabay.com/photos/wildlife-nature-tree-animal-wood-3188071

Bony Jaws

Evolved trait: Stronger mouth parts allow more opportunities to feed

Image by Hectonicus, Creative Commons license: en.wikipedia.org/wiki/Megalodon#/media/File:Physeteroidea_-_Livyatan_melvillei.JPG

Bilateral Symmetry

Evolved trait: Organisms balanced by one of each type of limb or major organ on both the left and right sides

Image by Torban Stroem from Pixabay: pixabay.com/photos/eagle-bird-bird-of-prey-natural-1753002

Vertebral Column (Spine / Backbone)

Evolved trait: A series of flexible bones (vertebrae) that protect the spinal cord (nerve tube) and provide structural support

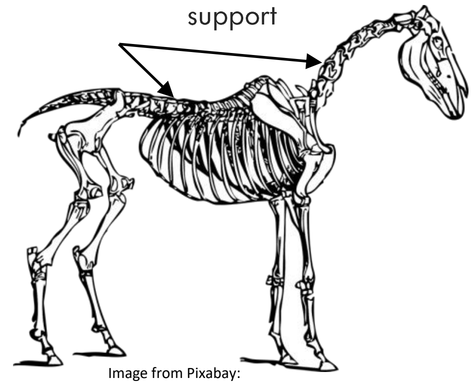


Image from Pixabay: pixabay.com/vectors/horse-anatomy-skeleton-bones-torso-30760

Skull

Evolved trait: Bone protects soft brains as they became larger

Image adapted from Pixabay: pixabay.com/illustrations/anatomical-anatomy-body-gut-health-2261006

Segmented Body

Evolved trait: Allows animals better movement and protection of organs

Image of bee on flower by Magnus Ohlin from Pixabay: pixabay.com/photos/bee-wasp-spring-flower-yellow-210731

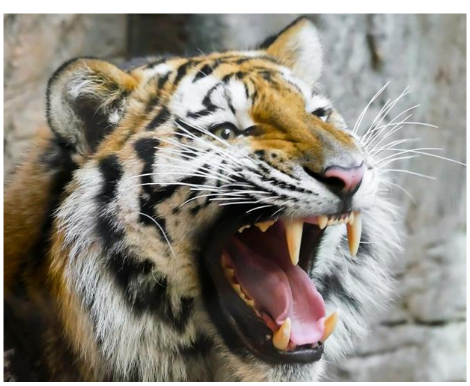
Stronger Limbs (legs)

Evolved trait: Helped animals spread over the land

Komodo dragon image by TLSPAMG from Pixabay: pixabay.com/photos/reptile-komodo-dragon-wildlife-1984970

Large Canine Teeth

Evolved trait: Helps carnivores and omnivores catch, kill, and hold prey



Tiger image by Gellinger from Pixabay: pixabay.com/photos/animal-tiger-big-cat-predator-1994500

Long-lasting Placenta

Evolved trait: Helps females bear offspring and protect them longer internally

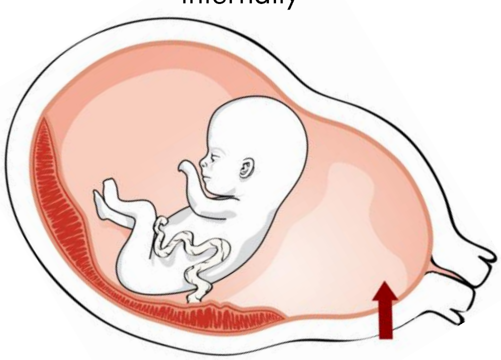


Image adapted from Wikimedia Commons, CC license: upload.wikimedia.org/wikipedia/commons/2/23/2906_Placenta_Previa-02.jpg

Exoskeleton

Evolved trait: Protective outside layer that provides protection and retains water

Image from National Park Service: flickr.com/photos/santamonicamtns/11954193476

Tyrannosaurus rex
Phylum: Chordata
Class: Reptilia

Image by Jill White from Pixabay:
pixabay.com/photos/tyrannosaurus-prehistoric-skeleton-447801

American Bullfrog
Lithobates catesbeianus
Phylum: Chordata
Class: Amphibia

Image by Carl D. Howe, Creative Commons license:
commons.wikimedia.org/w/index.php?curid=528421

King Cobra
Ophiophagus hannah
Phylum: Chordata
Class: Reptilia

Image by Antriksh Kumar from Pixabay:
pixabay.com/photos/king-cobra-cobra-snake-reptile-405623

Salp (Tunicate)
Phylum: Chordata
Subphylum: Tunicata

Salp colony image by Peter Southwood,
Creative Commons license:
commons.wikimedia.org/
wiki/File:Salp_colony,_Aorangaia_PA171899.JPG

Red King Crab
Paralithodes camtschaticus
Phylum: Arthropoda, Class: Crustacea

Public domain image from NOAA:
afsc.noaa.gov/race/media/photo_gallery/photos/Crabs/redkingcrab.jpg

Human
Homo sapiens
Phylum: Chordata, Class: Mammalia

Image from Pixabay:
pixabay.com/photos/basketball-game-competition-dribble-582384

Ladybug
(Ladybird beetle)
Coccinella magnifica shown below
Phylum: Arthropoda, Class: Insecta

Image by Gilles San Martin, Creative Commons license:
commons.wikimedia.org/wiki/File:Coccinella_magnifica01.jpg

Coho Salmon
Oncorhynchus kisutch
Phylum: Chordata, Class: Osteichthyes

Image from BLM, Creative Commons license:
flickr.com/photos/blmoregon/16335492972

Great White Shark
Carcharodon carcharias
Phylum: Chordata
Class: Chondrichthyes

Image from Wikimedia Commons:
commons.wikimedia.org/wiki/File:
Guadalupe_Island_Great_White_Shark_Underwater.jpg

Anna's Hummingbird

Calypte anna
Phylum: Chordata, Class: Aves

Public domain image by Robert McMorran:
hcommons.wikimedia.org/wiki/File:Anna%27s_hummingbird.jpg

Amphioxus (Lancelet)

Phylum: Chordata
Subphylum: Cephalochordata
Class: Leptocardii

Adapted from Giovanni Maki, Creative Commons license:
commons.wikimedia.org/wiki/File:Amphioxus.png

Stomphia

Stomphia coccinea
Phylum: Cnidaria, Class: Anthoza

Image from Shape of Life video "Cnidarians: Anemone Swims Away from Sea Star":
shapeoflife.org/video/cnidarians-anemone-swims-away-sea-star

Red Fox

Vulpes vulpes
Phylum: Chordata, Subphylum: Vertebrata, Class: Mammalia

Image by Karen Arnold from Pixabay:
pixabay.com/photos/fox-animal-wild-wildlife-red-220492

Largetooth Sawfish

Pristis pristis
Phylum: Chordata
Class: Chondrichthyes

Image by David Iliff, Creative Commons license:
commons.wikimedia.org/wiki/File:Pristis_pristis_-_Georgia_Aquarium_Jan_2006.jpg

Crocodile

Crocodylus spp.
Phylum: Chordata, Subphylum: Vertebrata, Class: Reptilia

Image by Ridia from Pixabay:
pixabay.com/photos/crocodile-mouth-lunch-thailand-1999427

Sea Squirt

Polycarpa aurata
Phylum: Chordata, Subphylum: Tunicata, Class: Ascidiacea

Image by Nhobgood, Creative Commons license:
commons.wikimedia.org/wiki/File:Triphyllozoon_inornatum_(Bryozoan)_and_Polycarpa_aurata_(Sea_quirt).jpg

Giant Larvacean

Bathochordaeus charon
Phylum: Chordata, Subphylum: Tunicata, Class: Appendicularia

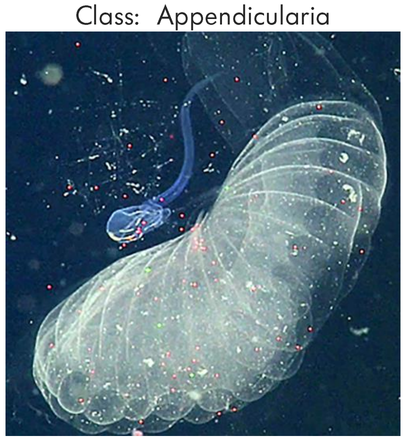


Image © 2016 MBARI: shapeoflife.org/news/featured-creature/2017/08/26/giant-larvacean-bathochordaeus

Sea Lamprey

Petromyzon marinus
Phylum: Chordata
Class: Hyperoartia

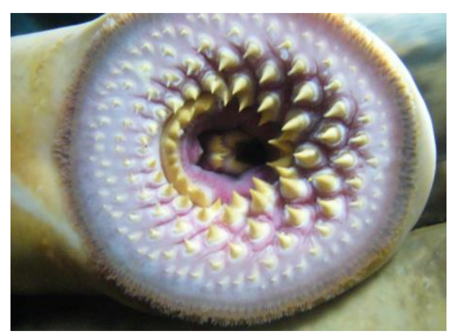


Image by Drow Male, Creative Commons license:
commons.wikimedia.org/wiki/File:Boca_de_lamprea.1_-_Aquarium_Finisterrae.JPG