Evolutionary Biology Team Investigation

Lesson Topic
Evidence of evolution, classification, cladograms

RIEL Biology Element
Affirming Identities

Time Required
One to two class periods

Standards Addressed

- SC.912.L.15.1 Explain how the scientific theory of evolution is supported by the fossil record, morphology, embryology, biogeography, molecular biology, and observed evolutionary change.
- SC.912.L.15.4 Describe how and why organisms are hierarchically classified and based on evolutionary relationships.
- SC.912.L.15.7 Discuss distinguishing characteristics of vertebrate and representative invertebrate phyla, and chordate classes using typical examples.

Lesson Summary

Students are introduced to evidence supporting the theory of evolution and take on the role of evolutionary biologists in order to complete a cladogram of 9 chordates based on provided morphological, genetic, embryological, and fossil evidence. The lesson concludes with a reflective class discussion on how student's ideas about their cladograms changed over the course of the lesson and why. Students are encouraged to share how this lesson may have influenced their perspective about how scientists work collaboratively, and the skills needed to succeed in a global community faced with multifaceted questions.

This lesson helps students explore and enact their choice of scientific identity within the broader category of 'evolutionary biologist' by allowing them to choose the type of evidence they would like to engage with. Learners may gravitate towards roles that allow them to explore visual aspects of morphology or discrete numerical aspects like comparing the number of mutations. Students iteratively converse, collaborate, explain, and revise, just as scientists do, such that at the end of the lesson these activities cultivate a sense of ownership and contribution to the final explanation that meets the learning objectives. The reflective discussion at the end of the lesson prompts students to reflect on their experience of practicing science, while they learn about the theory of evolution.

Students develop and revise cladograms (model) based on evidence to illustrate the evolutionary relationships between chordates. Analysis of evidence includes visual comparisons of anatomical structures, analytical comparisons of text descriptions, numerical analysis of mutation counts, and inferential interpretation of spatial relationships. Students compare and contrast these types of data and evaluate the impact of new data on their initial cladograms. Throughout this process, students ask and evaluate questions that challenge each other's interpretations as they compare cladogram models to develop draft and final models.

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Materials

- Draft Cladogram
- Evidence Handouts: Embryological, Molecular, Morphological, Fossil Record
- Evidence of Evolution & Classification ADI Handout
- PowerPoint w/ video thinking tools (optional)

Before the Activity

- Print Draft Cladograms (2 per student)
- Print Evidence Handouts (class set - 1 line of evidence per student)
- Print Evidence of Evolution & Classification ADI Handout - 1 per student
- Read through PowerPoint and watch videos; decide if the ADI handout OR video thinking tools work best for your students. Using both may take up too much time.
- Think about student groups of 4 for Part 2 (Morphologists only, Geneticists only, Paleontologists only, Embryologists only). Are students going to choose their evidence type or be given their type?
- Think about student groups of 4 for Part 3 (one of each from Part 2 groups).

Lesson Activities

1. **Unpacking.**
   Teacher: Provides handouts; questions students "What does an Evolutionary Biologist do?"; introduces Mercedes Burns PhD; introduces Essential Question; reviews unknown words, supports with thinking tools videos; and introduces task.
   Student: Thinks about and responds to "What does an Evolutionary Biologist do?"; questions about Mercedes Burns PhD; skims handout, circles unknown words; considers and clarifies essential question; builds vocabulary via discussion about circled words, thinking tools, annotations; and explores task.

Standards continued

- SC.912.L.15.19 Recognize that the strength or usefulness of a scientific claim is evaluated through scientific argumentation, which depends on critical and logical thinking, and the active consideration of alternative scientific explanations to explain the data presented.

Science and Engineering Practice

- Asking questions and defining problems
- Developing and using models
- Analyzing and interpreting data
- Constructing explanations and designing solutions

Content Learning Objectives

- Identify and describe ancestral and derived characteristics that differentiate 9 types of chordates (turtle, fish, frog, chicken, horse, bat, monkey, rabbit, human).
- Diagram evolutionary relationships of 9 chordates using cladograms.
- Explain how evolution is supported by multiple lines of evidence.

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Lesson Activities

2. **Single Evidence Teams.**
   Teacher: Prompts students to choose their scientist title & evidence type; provides evidence; supports and explains use; facilitates group work; asks probing questions; prompts class discussion at end of part 2 to discuss and compare models.
   Student: Chooses scientist title & evidence type; asks clarifying questions, redefines problems; interprets evidence and revises model; collaborates with peers to build cladograms; discusses model differences at the end of Part 2.

3. **Multiple Evidence Teams.**
   Teacher: Prompts students into groups with each scientist type and evidence represented; provides a second copy of the cladogram; facilitates group work; asks probing questions; prompts class discussion at end of part 2 to discuss and compare models.
   Student: Asks clarifying questions, redefines problems; interprets evidence, revises model; collaborates with peers to build cladograms; submits final cladogram; discusses model differences at the end of Part 3.

4. **Reflection Discussion.**
   Teacher: Facilitate discussion and listens to students; consider using talking chips/think pair share or other methods to ensure *all* students have the opportunity to voice their opinion.
   Student: Reflect and share for the following –

   a. Did your cladograms change over time?
   b. How did working in each group compare?
   c. Did your evidence conflict with someone else's?
   d. How did you resolve these issues?
   e. How does this activity compare with your ideas about science and what scientists do?
   f. Was this "practicing science" or "learning about science"? Why do you think so?

Teacher Notes

- Lesson resources can be found below, or [here]

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Evidence of Evolution & Classification ADI Handout

Essential Question: What ancestral and derived characteristics differentiate the members of the Phylum Chordata and how are they related?

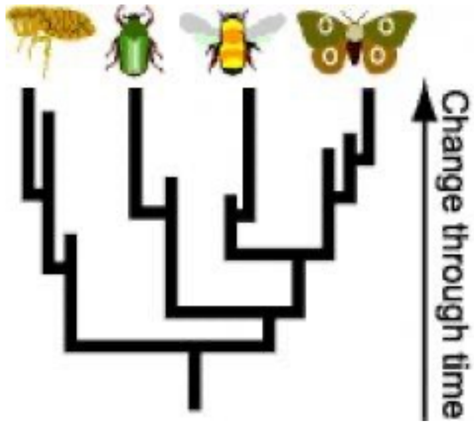

Figure 1. Descent with modification

Introduction

The central idea of biological evolution is that through a process of descent with modification, the common ancestor of all life on Earth gave rise to all the biodiversity we see today (see Figure 1). Simply put, descent with modification means that traits are passed down from generation to generation and sometimes undergo changes or modifications over time. These changes may be caused by natural selection or even a mutation of DNA. This idea is important in biology because it enables scientists to study the evolutionary history of life on Earth.

Scientists use a variety of evidence to support biological evolution, including: (a) morphology, (b) embryology, (c) the fossil record, and (d) molecular genetics.

Morphology

There are many different species alive on Earth but they all have some physical features in common. The study of the physical features and structure of an organism is called morphology. Structures in two or more species are termed homologous if they can be traced back to a common origin. Clues to homology usually lie in the skeletal structure and its connections to surrounding parts, rather than to a similar function. For instance, the forelimbs of a human, a seal, and a bird are all used for different types of locomotion, so one should not expect them to be identical. However, if one searches beyond the superficial structure of wings, fins, and arms and looks at the structural relationships of each bone, one will see that they are very similar. Each humerus is connected to a radius and ulna, which are in turn connected to the bones of the hand. So, even though organs and bones may look drastically different and may serve very different functions, the fact that they can be identified as the same organ with modification supports evolution.

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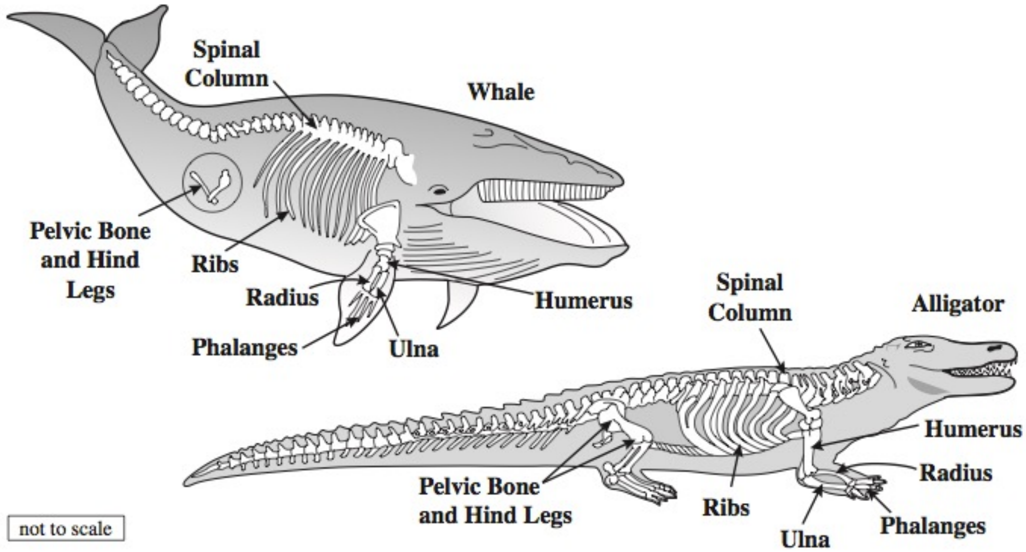
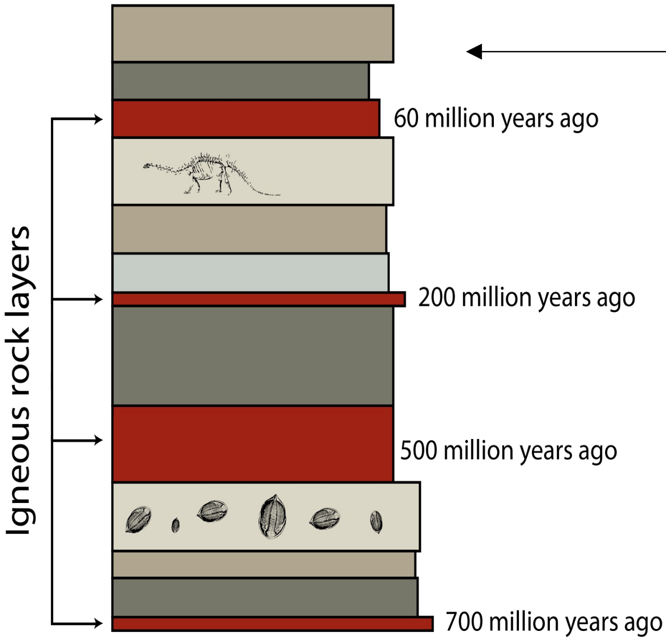
Finally, vestigial organs provide an indication of biological modification and change, in that they remain even when their original function is lost. For instance, whales are now fully marine organisms, but they evolved from terrestrial carnivores tens of millions of years ago. Whales retain remnants of pelvic elements situated near their "hips" that no longer have any clear function in hindlimb activity



Additional evidence for evolution comes from the study of living populations. Some scientists take a macroscopic approach by documenting morphological and behavioral changes in natural laboratories. A good example of this type of work can be found in Jonathan Weiner's The Beak of the Finch (1994). In this account of evolution in action, scientists visit island populations where they measure morphological attributes of animals and plants (for example, the beak size of finches in the Galapagos) and correlate those changes to environmental changes. They can follow the breeding patterns of populations over many generations and record changes that are passed along, thus developing a hypothesis of adaptation and natural selection.

Embryology

The study of one type of evidence of evolution is called embryology, the study of embryos. An embryo is an unborn (or unhatched) animal or human young in its earliest phases. Embryos of many different kinds of animals: mammals, birds, reptiles, fish, etc. look very similar and it is often difficult to tell them apart. Many traits of one type of animal appear in the embryo of another type of animal. For example, fish embryos and human embryos both have gill slits. In fish they develop into gills, but in humans they disappear before birth. This shows that the animals are similar and that they develop similarly, implying that they are related, have common ancestors and that they started out the same, gradually evolving different traits, but that the basic plan for a creature's beginning remains the same.



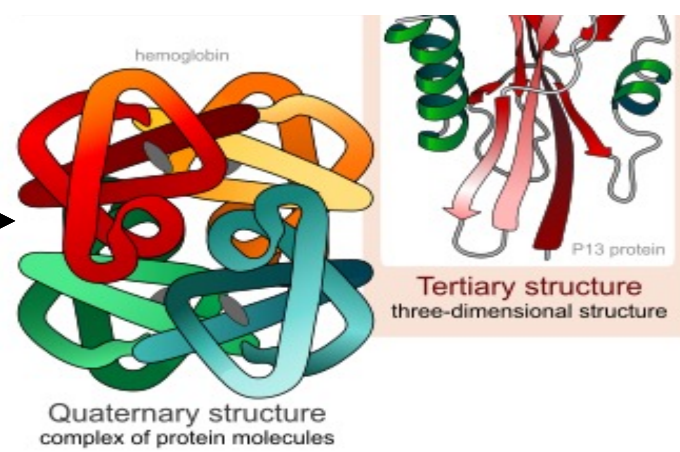
Fossil Record

Fossils are found in layers of sedimentary rock. The oldest layers are on the bottom, and the youngest layers are on the top. Because sediments sometimes include once-living organisms, sedimentary rock often contains a lot of fossils. Fossils are once-living organisms that have been turned into rock, in which the shape or form of the organism can still be seen. One thing that Darwin noticed on his travels, and that people continue to notice today, is that fossils in the bottom layers are very different from the organisms alive today; Darwin didn't even recognize them. As one looks farther up, at younger and younger rock layers, the fossilized plants and animals become more and more familiar until they are a lot like organisms that are around now. The organisms also tend to become more and more complex. From this, Darwin concluded that organisms have not remained the same since earth's beginning, and that they have changed a lot, gradually becoming more and more complex. He also realized that as new species arise, other ones become extinct. People look at fossils to discover which life forms evolved first and which later on. Today scientists also have ways of dating the rocks, figuring out about how long ago each layer was deposited. This also helps us piece together the time scale of evolution and when certain events occurred.

Molecular Genetics

You have learned about the different macromolecules (carbohydrates, lipids, proteins, and nucleic acids) that play important roles in living things. Recall, proteins are made up of a chain of amino acids and a specific gene determines the sequence of amino acids in the chain. Scientists often want to identify the amino acid sequence of protein because the amino acid sequence determines the structure of a protein (see Figure 2). Scientists can also use amino acid sequences to examine evolutionary relationships because all life on earth shares a common ancestor.

The process of descent with modification suggests that two species that diverged from one another relatively recently in the history of life on Earth will share more genetic similarities than two species that diverged from one another further back in time. Species that share many genetic similarities are considered to be more closely related than two species that have many differences. Hence, scientists can compare an amino acid sequence for a specific protein to determine the evolutionary history of a group of organisms.



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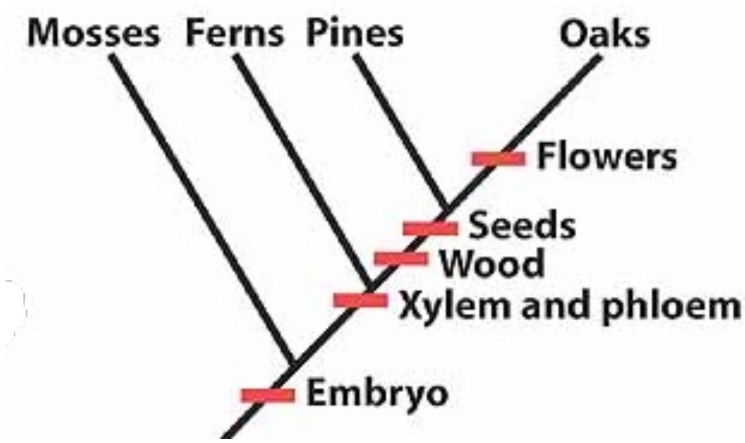
Cladograms

One way to determine how groups of organisms are related to one another is to compare certain features such as embryologic development, morphology (physical appearance, body organs, and parts), the fossil record, or their genetic makeup (DNA structure) in order to determine how similar these features are in each type of organism. When different organisms share a large number of features, they are described as being closely related. In order to capture the evolutionary history of a group of organisms, biologists often create a diagram of branching lines that connect those groups called a cladogram. You will need to develop a cladogram in order to answer the research question. In order to construct a cladogram (Figure 3), it is important to identify the characteristics of the ancestral population and those of the descendants. Characteristics shared by most or all members of related taxa are referred to as ancestral traits. These ancestral traits link the members of related branches to a common ancestor. On the other hand, characteristics that are found in various evolutionary branches that differ from those of the ancestors are considered derived. In many cases, a derived characteristic is a unique modification of a shared ancestral characteristic. Derived characteristics or traits distinguish the members of one evolutionary branch from the members of another branch

A cladogram is constructed based on the presence of derived traits in two or more related taxa. Ideally, a cladogram should be based on branches that are defined by a unique derived trait that emerged only once and are shared by all subsequent descendants. Because living organisms are a complex combination of traits, however, sometimes it is possible to draw more than one cladogram that might reflect the evolutionary history of a group of organisms.



Your Task

In this investigation you will determine how to use morphological evidence, embryological evidence, the fossil record, and molecular genetics evidence to construct and defend a cladogram showing the evolutionary relationship of chordates.

The classification scheme of chordates you will analyze in this investigation is:

Domain	Eukarya
Kingdom	Animalia
Phylum	Chordata
Class	Osteichthyes, Amphibia, Reptilia, Aves, Mammalia

The guiding question of this investigation is: ***What ancestral and derived characteristics differentiate the members of the Phylum Chordata and how are they related?***

Materials

You may use any of the following materials during your investigation:

- Morphological Evidence
- Embryological Evidence
- Fossil Record
- Molecular Evidence
- Cladogram Template

Getting Started

Evidence: Analyze each piece of evidence following the directions provided.

Claim: Construct the cladogram on the paper template provided.

Label each node with the name of the chordate it represents.

Label each clade with the ancestral and derived characteristics.

Justification: Note how each line of evidence supports your constructed cladogram and how the concept descent with modification applies to chordates.

Day 1: Draft (paper) Cladogram:

After researching and analyzing lines of evidence (morphological, molecular, embryological and the fossil record), create an annotated cladogram (paper draft) of chordates with nodes that indicate the shared/derived characteristics that support your decision-making process. Be sure to support your decision with as many lines of evidence as possible. Be specific! You will be reviewed by your peers based on the accuracy of your cladogram, and the strength of your evidence.

Day 2: Final Cladogram:

Reproduce your cladogram on a dry-erase board. Follow the instructions given and conduct peer review. After you have received feedback from your peers, make any necessary changes to your board, and then submit a photo of your final board for grading.

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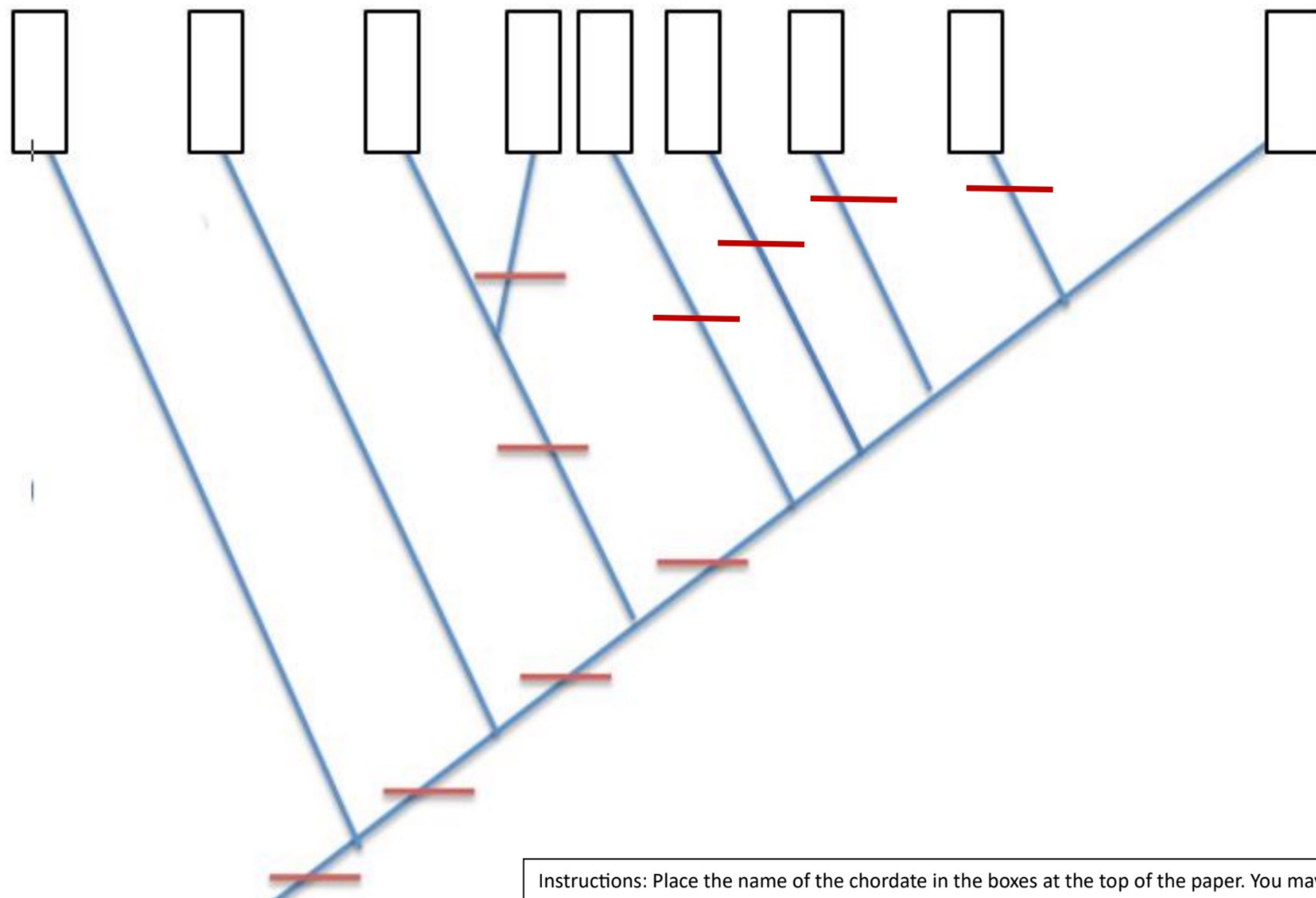
Draft Cladogram



Instructions: Place the name of the chordate in the boxes at the top of the paper. You may write ancestral/derived characteristics on this sheet OR label and explain on a separate sheet of paper.

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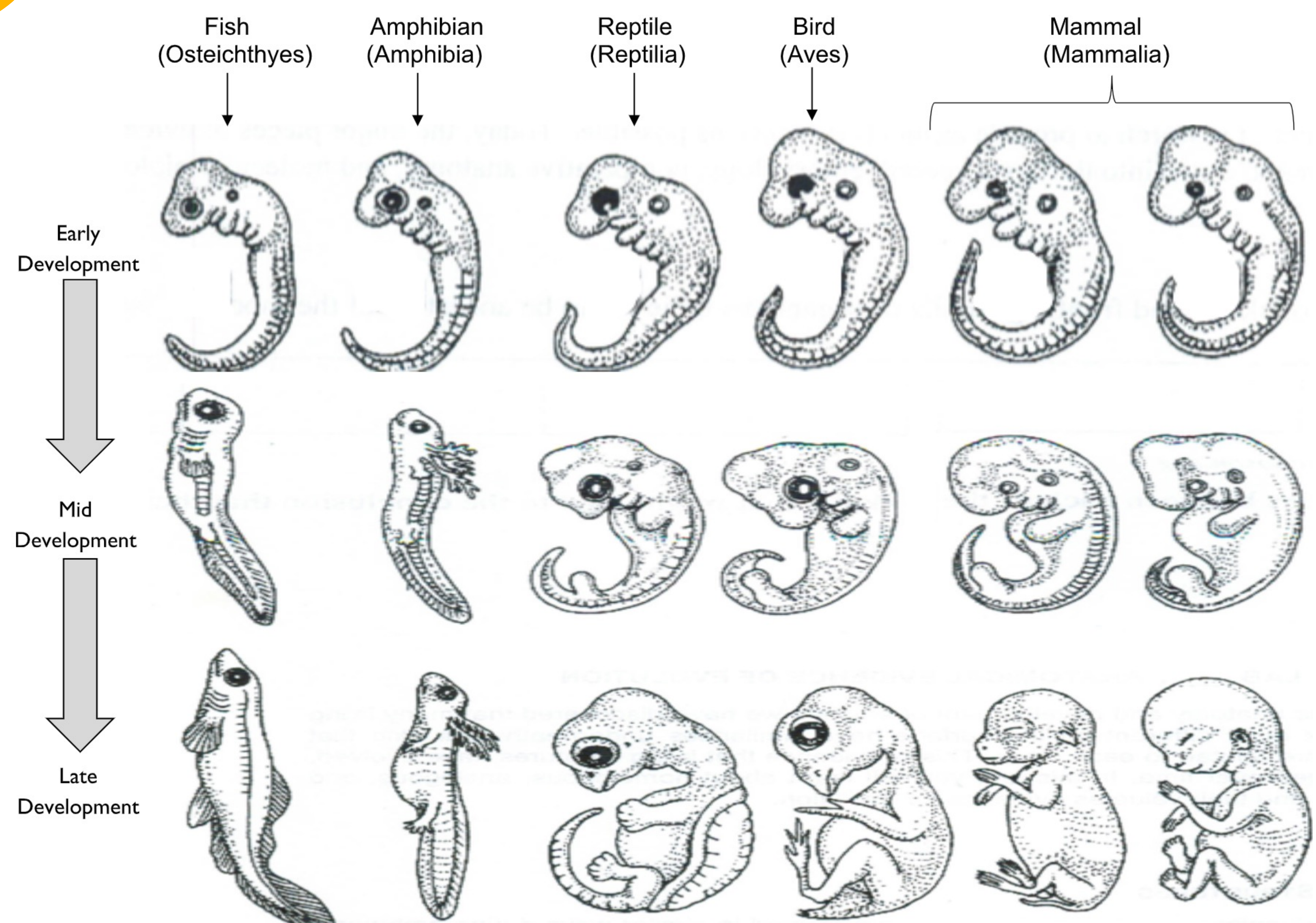
Evidence Handout: Embryological



Adapted from Lab 27- Argument Driven Inquiry in Biology by Victor Sampso

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Evidence Handout: Molecular

Molecular Genetics Evidence: Cytochrome C Amino Acid Sequences for Common Animal Chordates

Instructions: Compare the amino acids at each location ***to that of the human*** and circle any differences. Add up the number of changes for each organism and record in the column provided (at the far right of the page).

Organism	Loci 42	43	44	46	47	49	50	53	54	55	56	57	58	60	61	62	63	64	65	66	100	101	102	103	104	Total mutations
Human	Q	A	P	Y	S	T	A	K	N	K	G	I	I	G	E	D	T	L	M	E	K	A	T	N	E	0
Chicken	Q	A	E	F	S	T	D	K	N	K	G	I	T	G	E	D	T	L	M	E	D	A	T	S	K	7
Horse	Q	A	P	F	T	T	D	K	N	K	G	I	T	K	E	E	T	L	M	E	K	A	T	N	E	
Fish	Q	A	E	Y	S	T	D	K	S	K	G	I	V	N	N	D	T	L	M	E	S	A	T	S	---	
Frog	Q	A	A	F	S	T	D	K	N	K	G	I	T	G	E	D	T	L	M	E	S	A	C	S	K	
Turtle	Q	A	E	F	S	T	E	K	N	K	G	I	T	G	E	E	T	L	M	E	D	A	T	S	K	
Monkey	A	A	P	Y	S	T	A	K	N	K	G	I	T	G	E	D	T	L	M	E	K	A	T	N	E	
Rabbit	Q	A	V	F	S	T	D	K	N	K	G	I	T	G	E	D	T	L	M	E	K	A	T	N	E	
Bat	Q	A	P	F	S	T	D	K	N	K	G	I	T	G	E	A	T	L	M	E	K	A	T	K	E	

Note: Each letter stands for the amino acid produced by the codon in the mRNA sequence. Ex: A = Alanine

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Evidence Handout: Morphological

Instructions: Place an “x” in the bottom table for each organism that exhibits the trait listed. Use this information to help determine who is most closely related to who when building your cladogram.

Bony Fishes	Birds	Reptiles	Mammals	Amphibians
•Internal bony skeleton with jaws. •Skin covered with scales. •Release unshelled eggs into the water.	•Internal bony skeleton with jaws and four limbs. •Fossil members have two extra openings on each side of skull behind eyes. •Skin covered with feathers. •Members lay amniotic eggs.	•Internal bony skeleton with jaws and four limbs. •Fossil members have two openings on each side of skull behind eyes. •Skin covered with scales •Members lay amniotic eggs.	•Internal bony skeleton with jaws and four limbs. •Skin covered with hair. •Two members still produce amniotic eggs (platypus and anteater) and are placental mammals. •All others bear live young, and the placenta is a modified amniotic egg.	•Internal bony skeleton with jaws and four limbs. •Thin, smooth skin. •Release unshelled eggs in water.

Organism	**Internal Skeleton w/ Jaws**	**Four Limbs**	**Amniotic Eggs**	**Skin Covered by Hair**	**Two Extra Skull Openings**	**Skin Covered by Feathers**
Human						
Chicken						
Horse						
Fish						
Frog						
Turtle						
Monkey						
Rabbit						
Bat						
Total						

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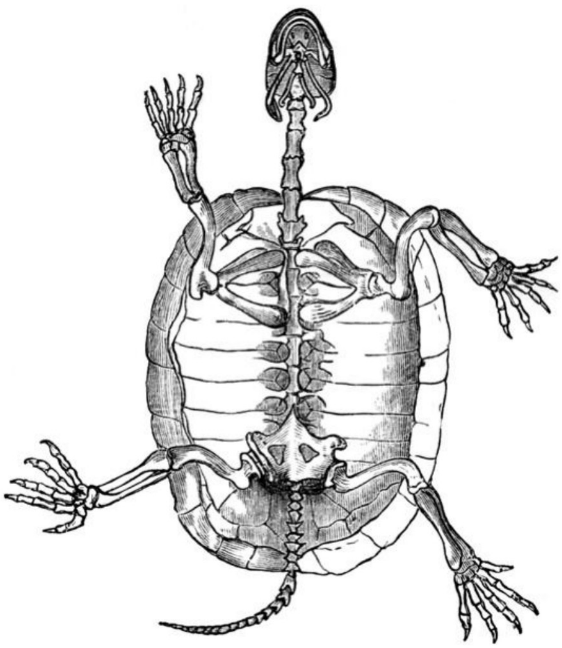
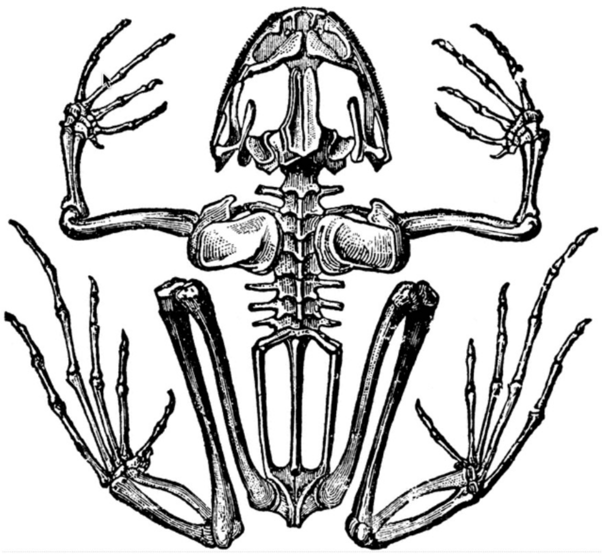
Evidence Handout: Morphological

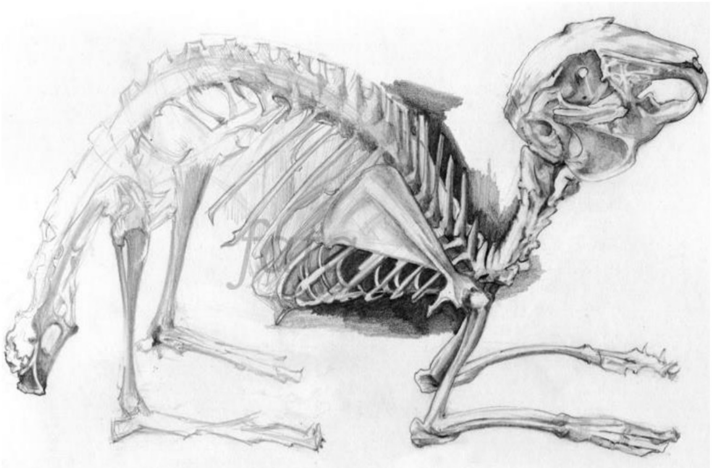
Turtle



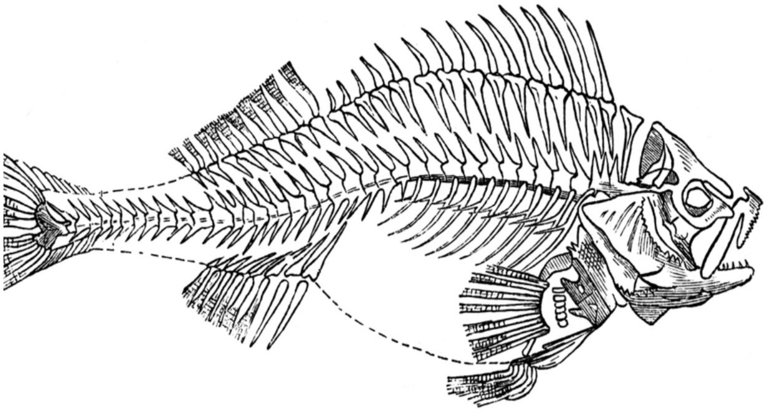
Frog



Rabbit



Fish



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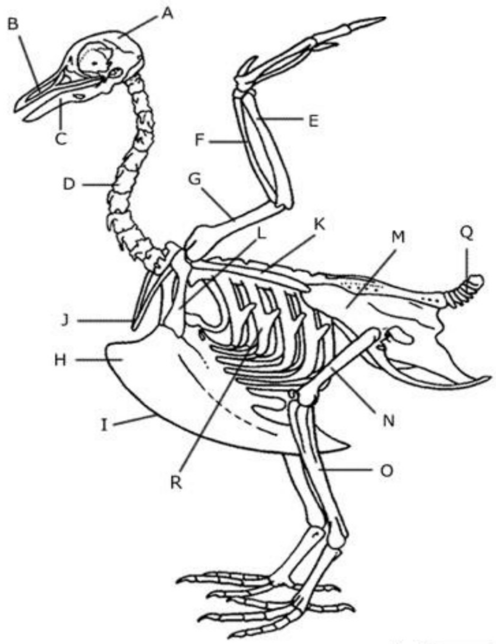
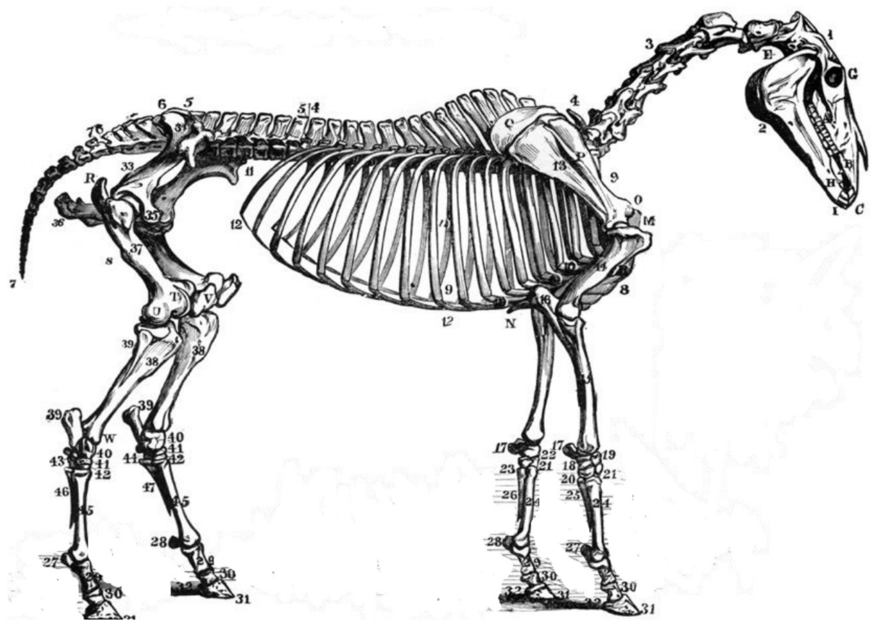
Evidence Handout: Morphological

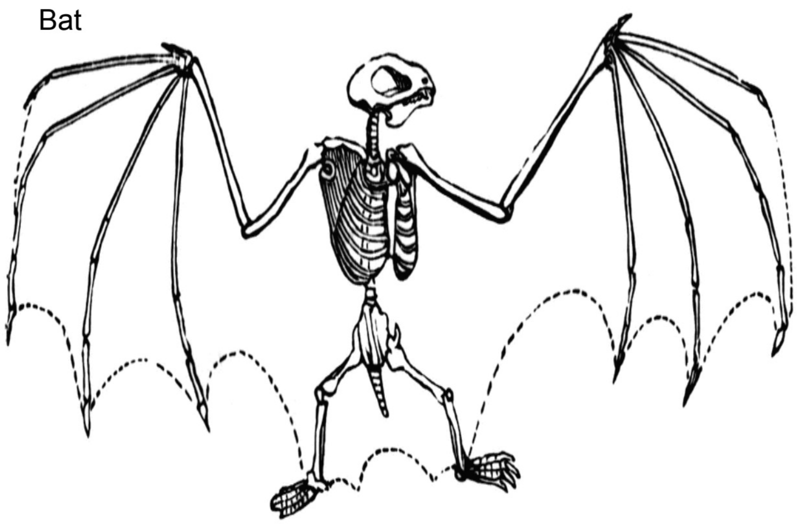
Chicken



Horse



Bat



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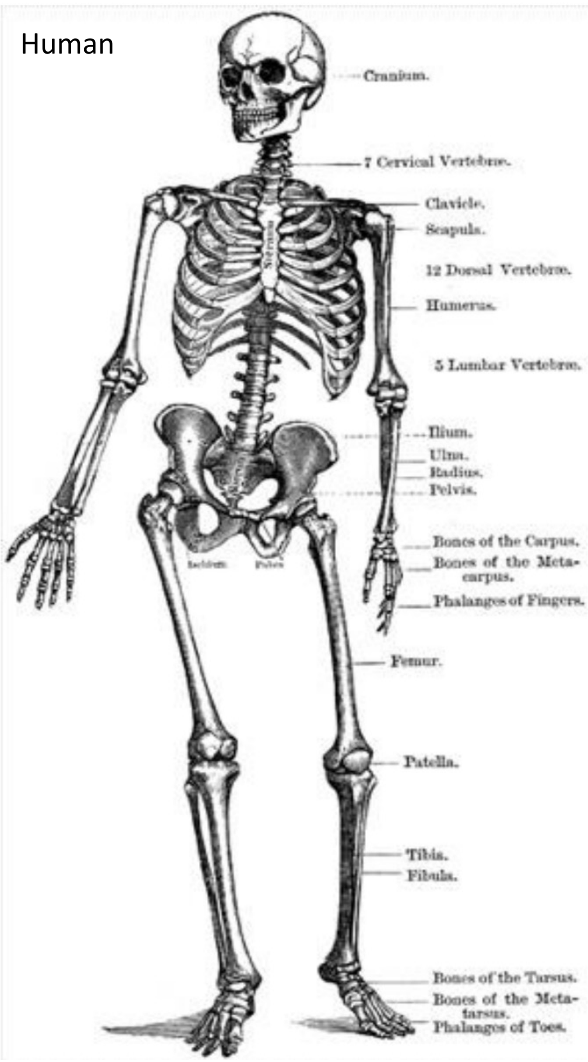
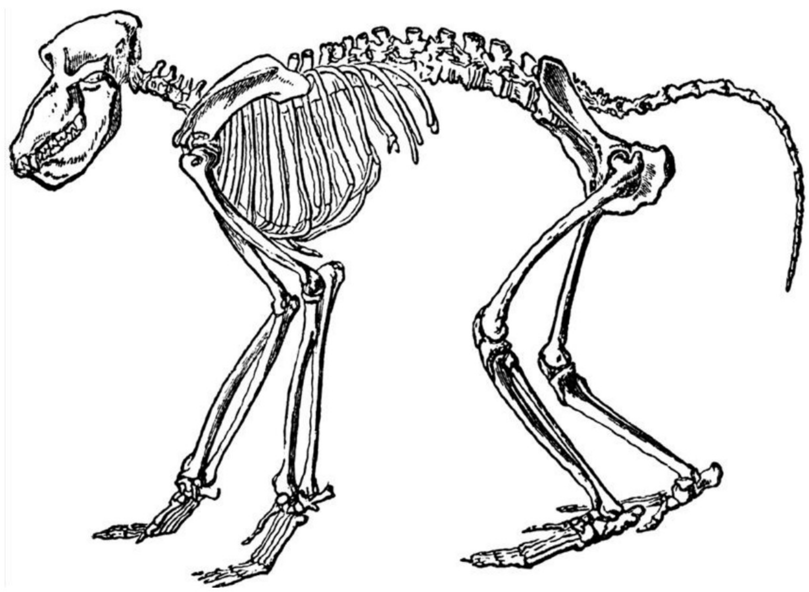
Evidence Handout: Morphological

Human



Monkey



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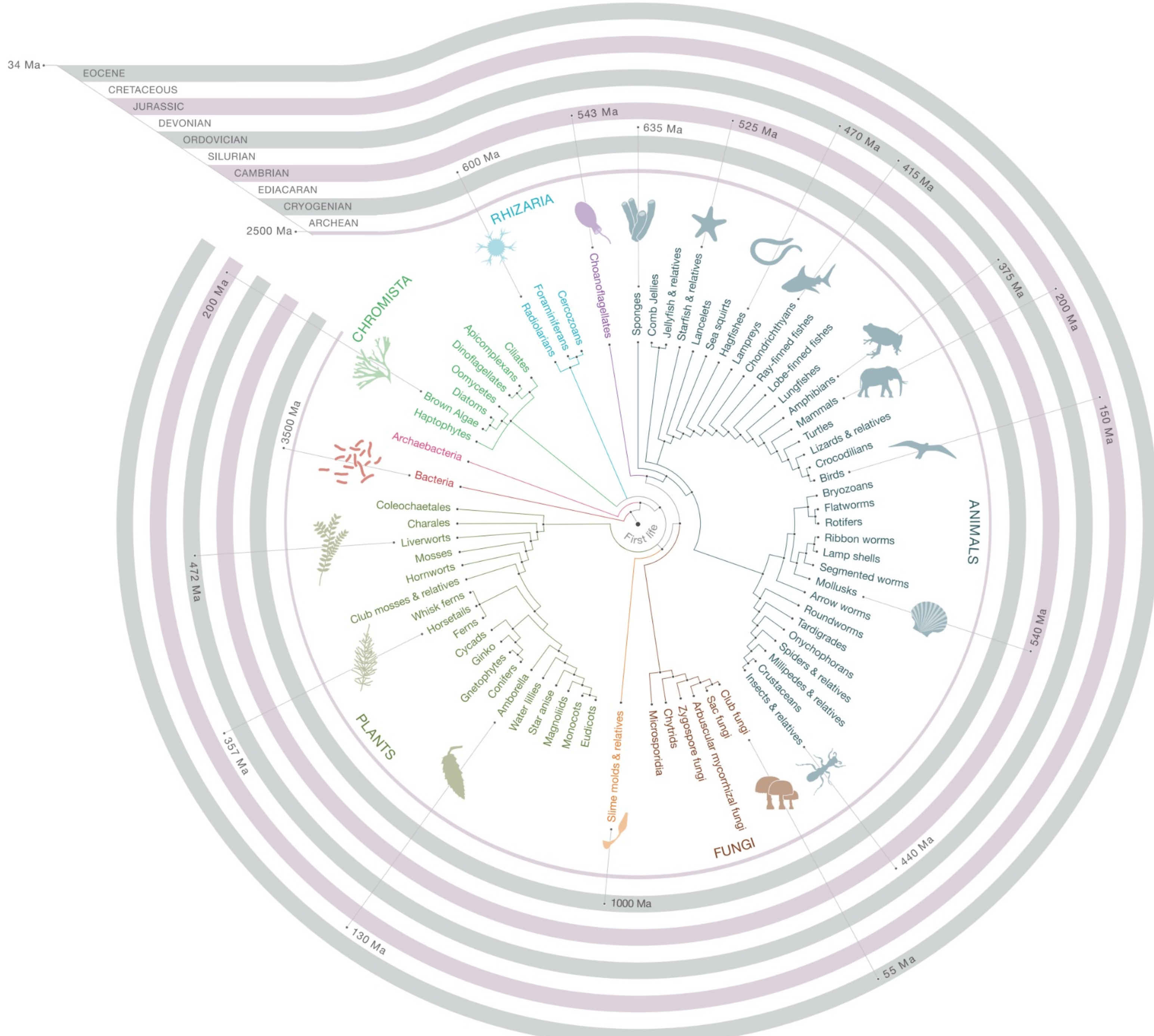
Evidence Handout: Fossil Record



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Evidence Handout: Fossil Record

With the publication of 'On the Origin of Species by means of Natural Selection' on the 24th November 1859, Charles Darwin not only explained how and why we have the diversity of life we see all around us, but also showed how all life is connected.

Since then we have continued to gather evidence from a range of different disciplines including physiology, biochemistry and DNA analysis. The evidence indicates that all organisms on Earth are genetically related, a genealogical relationship that can be represented as an evolutionary tree known as the Tree of Life.

The Tree of Life illustrates how different species arise from previous species via descent with modification, and that all of life is connected. The diagram above shows the relationship between the major biological groups. The centre represents the last universal ancestor of all life on Earth and the outer branches represent the major biological groups.

We now know that life on Earth began about 3.8 billion years ago, initially with single-celled prokaryotic cells. Multicellular life evolved over a billion years later and it's only in the last 570 million years that the kind of life forms we are familiar with began to evolve. The diagram above picks out some of the key dates for the major biological groups.

The tree is based on research carried out by: David Hillis, Derrick Zwickl and Robin Gutell from the University of Texas. It is based on analysis of small sub-unit rRNA sequences sampled from about 3,000 species from throughout the Tree of Life.

The dates are from a variety of sources.

Ma (Mega-annum), a unit of time equal to **one million years.**

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