Tested Studies for Laboratory Teaching
Proceedings of the Association for Biology Laboratory Education
Volume 40, Article 13, 2019

Comparative Vertebrate Anatomy and Phylogeny

Joslyn Mills[1], Melissa LaBonty[2], Nafis Hasan[3], and Angela Seliga[4]

[1]Brown University, Molecular Biology, Cell Biology, and Biochemistry Department, 185 Meeting St., Providence RI 02912 USA
[2]University of Alabama at Birmingham, Cell, Developmental, and Integrative Biology, 1900 University Blvd, Birmingham AL 35294 USA
[3]Tufts University, Sackler School of Graduate Biomedical Studies, 136 Harrison Ave, Boston, MA 02111 USA
[4]Boston University, Department of Biology, 590 Commonwealth Ave, Boston, MA 02215 USA
(**JoslynMillsBonal@gmail.com; Labonty@uab.edu; Nafis.Hasan@tufts.edu; AMSeliga@BU.edu**)

Comparative vertebrate anatomy is typically taught over a full semester, but this lab condenses this learning experience into a 3 to 6-hour lab that exposes students to numerous vertebrates and touches on evolution. This lab is designed to explore various body systems that differentiate the six common groups of vertebrates. Students will hypothesize the evolution of these groups from their common ancestor by drawing a phylogenetic tree. This lab has flexibility so that it can be condensed to fit into a shorter time frame, expanded upon to lengthen the lab, or to divide each module as a free-standing activity.

Keywords: Vertebrate, comparative, bone structure, internal anatomy, dissection

Introduction

Comparative vertebrate anatomy is typically taught over a full semester, but this lab condenses this learning experience into a 3-6-hour lab that exposes students to six groups of vertebrates and touches on evolution. This lab is designed to explore the physical characteristics that differentiate the six common groups of vertebrates: mammals, birds, reptiles, amphibians, and bony and cartilaginous fish. There are three modules, with two of them consisting of various stations that students will rotate through, and the final module will be a culmination of all the data and observations the students gathered in the previous modules. Module one focuses on the skeletal system of a number of vertebrates, with stations focusing on using skulls to predict dominant sense(s) of the animal, bone structure similarities and the concept of convergent evolution, bone shapes and sizes to predict important muscles, and overall skeletal structure differences and diseases that affect bones. Module two delves into the internal anatomy of these groups using dissected preserved specimen to explore the integument, digestive, respiratory, and circulatory systems, as well as identifying a number of accessory organs and comparing modifications specific to each group. The final module allows the students to hypothesize the evolution of these groups from their common ancestor by drawing a phylogenetic tree, placing each group along a branch depending on the presence (or absence) of a trait they identified in the previous modules. This lab has flexibility in its components that can be condensed or excised to fit into a shorter time frame, expanded upon to lengthen the lab, or to divide each module as a free-standing activity.

This lab was presented as a three-hour lab where the participants looked at bones and six different groups of pre-dissected vertebrates. For the first hour, we described the goals of the entire lab and then presented the stations from the Bone Module. After a short break, we discussed the stations used for the exploration of the internal anatomy, which consisted of a pre-dissected cat, pigeon, snake, mudpuppy, perch, and dogfish shark. The students rotated through each station in the first two modules, allowing them the opportunity to interact with each exercise and specimen within the same lab period. Finally, using what we learned from the anatomy of these vertebrates, we designed a phylogenetic tree. Table 1 describes the goals and activities of the stations within each module.

Table 1. Module descriptions, components, and goals for CVA&P.

Module	Goals	Stations	Description
Bones	Students learn what clues we can get from an animal's skeleton about diet, dominant sense(s), muscle design, and evolution. Compare and contrast the structural design of various vertebrates.	Skulls 1 & 2	Observe teeth shape, position of orbit, and size of nasal passage and auditory bullae
		Fusion Power	Compare pectoral and pelvic girdles in various animals and discuss increased surface area for muscle attachment
		First in Flight	Compare bat versus bird wings and discuss convergent and divergent evolution
		Pet Cemetery & Human Skeleton	Compare skeletons from common animals and humans
Dissections	Students will dissect (or view pre-dissected) specimens and explore various body systems and identify important organs. Compare the anatomy across all taxa to appreciate specialized modifications and evolution of these systems.	Integument	Students at each station will identify what covers the skin of their specimen.
		Digestive System	Students at each station will explore the digestive tract of their specimen and identify the important organs of this system.
		Respiratory & Circulatory Systems	Students at each station will explore the respiratory tract and circulatory system of their specimen and identify the important organs of these systems.
		Organ Identification & Comparison	Students at each station will identify organs in their specimen from a provided list. Then the groups will rotate through each station and identify and compare the same list of organs in all of the specimens.
Phylogeny	Students apply what they have learned from inspecting the animals' anatomy to predict the evolutionary progression of these taxa	No stations, work in groups	Working together in small groups, each participant will draw a phylogenetic tree describing how they believe each of these taxa evolved from a shared ancestor.

Student Outline

Objectives

- Identify what clues we can get from an animal's skeleton about diet, dominant sense(s), muscle design, and evolution
- Recognize and describe organs of various body systems in different groups of vertebrates
- Compare and contrast the structural design and internal anatomy of various vertebrates
- Apply collected knowledge to design a phylogenetic tree

Introduction

Think for a moment, what physical characteristics do you have in common with the person next to you? How about what is common between you and a cat or dog? A bird? A shark? While it isn't surprising to have most things in common with another human, or even other closely-related mammals, you may be surprised there are a lot of shared characteristics between you and a shark! Using *comparative anatomy* to study body systems and structures can help us determine the relatedness of species. We can also examine how organs and other body parts may have evolved from a common ancestor through adaptation due to selective pressures in different environments. Using evidence, such as the presence or absence of the same organs and whether they have the same functions can help us determine these connections. Besides being able to determine which species is the most primitive and the most evolved, we can also use this information to help us decide if the species is a good animal model to study human disease based on its similarities to humans.

In this exercise, we will be exploring *vertebrate zoology*, the "study of vertebrates" and their body systems and applying the concepts of comparative biology. We will be examining six groups of vertebrates: Chondrichthyes (cartilaginous fish), Osteichthyes (bony fish), Amphibians, Reptiles, Birds, and Mammals.

Finally, the practice of organizing animals based on the evolution of their characteristics is called phylogeny. Our goal today is to compare and contrast the major body systems of the six groups of vertebrates, including the skeletal system, digestive and excretory systems, respiratory system, and circulatory system. Using the information you collect through observation, you will be able to determine how closely related these groups are and demonstrate this by drawing a phylogenetic tree.

Methods and Data Collection

Part A: Bone Stations

Using your worksheet as a guide, explore the skulls and skeletons of common vertebrates and discuss the questions with your group leader. Fill in the homology table (Table 2) based on your observations; 1 means the characteristic is present in the animal, 0 means it is absent.

Part B: Internal Anatomy

Diving deeper into the anatomy of these animals, you will next be investigating the various organ systems and comparing them between the specimen. Using your worksheet as a guide, explore the various systems and discuss the questions with your group leader. Remember to fill in the remainder of your homology table (Table 2).

Part C: Designing a Phylogenetic Tree

To apply your knowledge that you collected by observation, you will predict the evolution of the six taxa of vertebrates by designing a phylogenetic tree. Start by adding the numbers for each specimen to give you a hint of how evolved it is. Use each characteristic as a node in evolving order, where the animal with only that characteristic branches off from. For example, all the specimen are vertebrates; however, the dogfish shark does not have calcified bones. Therefore, the dogfish shark would branch from the node "vertebrate", and the next node would be "calcified bones," and so on.

General Rules and Guidelines

- Follow lab safety rules, including no food or drinks in lab.
- Animal specimen are preserved with chemicals. Please use cation to not contaminate yourself, others, and materials not intended for use with the animals, including cell phones.
- Please keep your cell phone put away. Contamination with dangerous chemicals may occur.
- Please do not touch the specimen without gloves.
- Be sure to follow the instructions of the group leader at each station.
- When time is up, you must move to the next station even if you were not able to complete all tasks.
- Stay with your group.

Student Worksheet
Comparative Vertebrate Anatomy and Phylogeny[1]

Your Name ________________ Date: ________________________

Station 1 & 2: Examination of skulls from a carnivore, herbivore, and omnivore (Station 1) and two micro-skulls (Station 2)

Skulls from a coyote, deer, and bear (Station 1) and skulls from a bat and a shrew (Station 2) are examined for the location of the eyes, the size and shape of the olfactory bulla, the length of the nasal cavity, and type of teeth. The micro-skulls are examined under a dissecting microscope and are intended to be more challenging. The characteristics of the sensory organs are used to determine the dominant sense of the animal, and the dentition is used to determine the diet of the animal and where it fits into the food web.

Station 3: Comparison of limbs adapted for flight

The articulated skeletons of a bird and bat are at this station. Comparison of two different skeletal modification for flight were examined, and convergent and divergent evolution are discussed.

Station 4: Comparison of the anatomy and physiology of the girdles and their attachment points

This station emphasizes the adaptations in skeletons of animals that need extra force of muscles, such as in the hind legs of frogs and the wings of birds. The pectoral and pelvic girdles and the axial skeleton of a frog and a pigeon will be compared to the skeleton of a salamander, and the increased surface area for muscle attachment in the frog pelvis and vertebrae and the pigeon keel of the sternum will be discussed.

Station 5: Pet Cemetery

You may have seen each of these animals as pets or at a zoo. Take this opportunity to look at how many similarities they share in their skeletal anatomy and also how many differences they have!

Make the following observations on the perch, snake, and cat skeleton and enter them as 1 (present) or 0 (absent) on Table 2, Homology Data. Vertebrae, calcified bone, dorsal process on vertebrae, 4 limbs, beak, shell.

Station 6: My Bones

Take this opportunity to check out what your skeleton looks like! What makes humans different from other vertebrates?

---

[1] This lab was developed for use in a BIOBUG education outreach project at Boston University (Crandall et al.). In the ensuing 12 years, it has been modified and expanded. The current version is the culmination of these efforts by the current authors. For the earlier version, please see https://www.bu.edu/lernet/biobugs/anatomy/anatomy_worksheet.pdf

Table 2. Homology Data Table
1 = Present, 0 = Absent

	Dogfish ***Squalus acanthias***	**Perch** ***Perca flavescens***	**Mudpuppy** ***Necturus maculosus***	**Snake** ***Thamnophis sirtalis***	**Pigeon** ***Columba livia***	**Cat** ***Felis domesticus***
1. Vertebrae						
2. Calcified bone						
3. Four walking limbs						
4. Egg with amniotic membrane	0	0	0	1	1	1
5. Pronounced large intestine						
6. Skin covering (describe)						
7. Pronounced dorsal process on vertebrae						
8. Egg with mineralized shell						
9. Lower Jaw Bones fused into beak (no teeth)						
10. Keeled breastbone						
11. Diaphragm						
12. Number of chambers in heart						

Vertebrate Dissections: Internal Anatomy

Round 1: Integument

Circle the species at your station:

Dogfish Perch Salamander Snake Pigeon Cat

1. What covers the skin of your specimen?

fur dermal denticles scales shell mucus feathers

2. How does the skin covering differ from the other groups?

Cat:_________________ Snake:______________ Pigeon:_____________

Salamander:__________ Perch:______________ Dogfish:________________

3. Why has each group evolved different skin covering?

Rotate to next station

Round 2: Lower Digestive Tract

Circle the species at your station:

Dogfish Perch Salamander Snake Pigeon Cat

Locate the stomach, small intestine, large intestine, liver, pancreas, kidneys, and bladder

Rotate to next station

Round 3: Respiratory Tract

Circle the species at your station:

Dogfish Perch Salamander Snake Pigeon Cat

Identify the air exchange organ on your specimen: lungs gills skin

1. What about the other groups?

Cat:_________________ Snake:______________ Pigeon:_____________

Salamander:__________ Perch:______________ Dogfish:________________

Identify the heart.
What other system does the heart connect to the respiratory system?

Identify the aorta and pulmonary vein and artery and the spleen

Rotate to next station

Round 4: Organ Identification

Circle the species at your station:

Dogfish Perch Salamander Snake Pigeon Cat

Write the number from the pin that corresponds to the organs of your specimen in the Organ Identification Table.

Once you have completed identification of all the organs of your species, you will rotate to examine the other specimen and identify each organ as before.

Round 4 continued: Organ Comparison

You will have 5 minutes to identify the organs pinned with numbers at each station.

Write the numbers of the pins that correspond to the organs for all of the stations in the Organ Identification Table.

Table 3. Organ Identification Table.

	Dogfish	Perch	Salamander	Snake	Pigeon	Cat
Esophagus						
Stomach						
Pancreas						
Spleen						
Small Intestine						
Large Intestine						
Liver						
Gall bladder						
Heart						
Kidney						
Bladder						
Air exchange						
Gonads (M or F?)						

Figure 1. Vertebrate Phylogenetic Tree Hypothesis.
(Draw the phylogenetic tree that your class creates here)

Materials

A computer and projector for presentation purpose is required. Each group of students can work together on one worksheet, or each student may have their own. Additionally, space for six stations is needed; however, this may be modified down to four stations as mentioned in "Notes for the instructor."

The following materials are necessary for the complete demonstration of this course:

- (2x) Dissecting microscopes
- Bones/skeletons (Pictures can be used instead if any are not available):
- Full skulls with all teeth from coyote, bear, deer, bat, shrew
- Full skeletons of pigeon (2x), bat, salamander, frog, turtle, fish (perch), snake, cat, human, dogfish "skeleton"
- Human arm and human pelvis
- Preserved specimen for dissection, plain injection (BioCorporation catalog #): cat (#CT1014P), snake (#SN1418P), pigeon (#PG0002P), mudpuppy (#NT1014P), perch (#YP0709P), dogfish shark (#SK1822P)
- (6x) dissecting trays
- (78x) Pins: 6 sets with numbers 1-13 (pre-dissected) or 6 sets with the names of the 13 organs from the worksheet (students dissecting)
- (6x) Magnifying glasses
- Gloves
- Biohazard waste disposal for fixed specimen

Finally, depending on the presentation of the course, the need for dissecting tools may differ. If the instructor dissects the animals beforehand, only one set is required; otherwise, each station will require a set of scissors, blunt probe, needle tipped probe, and forceps.

Notes for the Instructor

This lab was originally designed as a six-hour lab in which the students were responsible for dissecting the animals in rotations, in addition to making all of the observations. In the interest of time for the presentation of this workshop, we worked with pre-dissected animals with numbered pins stuck into each organ, which is a secondary format of this lab designed to fit into a three-hour period.

The outline of the set up and timing for the two optional structures is described. The three-hour option will include six bone stations, with six minutes per station for the students to fill out their worksheet. Next, there will be six pre-dissected specimen stations, with two rounds of observation and organ identification. The Digestive System and Respiratory & Circulatory systems each get 15 minutes and four additional rounds of organ identification get 10 minutes each. For the phylogeny exercise, groups draw or fill in a phylogenetic tree in 20 minutes with a short lecture. Alternatively, the six-hour format will have six or four bone stations, with six or ten minutes per station. Then there will be six specimens to be dissected in four rounds as follows: Integument 5 minutes, Digestive System 30 minutes, Respiratory and Circulatory Systems 30 minutes, Organ Identification first round 20 minutes, five additional rounds of 10 minutes each. Finally, for the phylogeny exercise, groups will draw or fill in a phylogenetic tree in 20 minutes with a short lecture.

This lab is designed to have a supervisor at each station to guide the students through the tasks, and then individually discuss with each group before coming back together as a class to share what they found.

There is some flexibility in how you would like to present this lab. First of all, if you don't have the advantage of recruiting volunteers to lead each station, you may consider having the students self-lead, in which you will likely need to extend the amount of time they spend at each station. This may require the students to prepare for this lab beforehand by reading a pre-lab description outlining expectations. You may opt to have one student per group be the "expert" for an individual station and lead the discussion when their group rotates through. This spreads the responsibility, still allows small groups, and encourages deeper learning when they are required to teach their fellow classmates. Alternatively, you may remove the concept of stations and go through each of the tasks as a class. The advantage of working in small groups is that students get more one-on-one interaction with an educator, and they are more likely to ask questions because there are fewer people to feel intimidated by.

Other options would be to have fewer stations if you condense some of the stations together, or you may demonstrate a dissection on one of the animals before having the students dissect theirs. Furthermore, the time you spend on the phylogeny can be greatly expanded depending on the complexity of evolution you would like to get into.

The "Cheat sheet" in Appendix D has answers to the worksheet as well as talking points for each station and animal. Each station is outlined in detail below.

Module 1: Bones

The goal of this module is to teach students what clues we can get from an animal's skeleton about diet, dominant sense(s), muscle design, and evolution. Additionally, this is an opportunity for students to compare and contrast the structural design of various vertebrates, particularly their own skeletons. There will be six stations, and students will rotate through each of these stations. While having the physical bones for the students to interact with is more engaging, photos of the sets of bones is an alternative if you do not have access to the samples.

Skulls instruction and discussion questions

The skulls from a deer, bear, and coyote will be at station one, and skulls from a bat and a shrew will be at station two. The latter are pretty tiny, so you will need to use dissecting microscopes to look at the details. The students are asked to identify the incisors, canines, premolars, molars, nasal passage, orbit, and auditory bulla (all features are labeled in Figures 2 and 3), and then fill in the table of their worksheet. The group should split duties in order to complete all the skulls in the time allotted. They should then predict what the animal's best sense(s) is and what kind of diet it has and explain their answers.

First in Flight Instruction and Discussion Questions

There will be pigeon and bat skeletons at this station, as well as a human arm. The purpose of this station is to discuss convergent and divergent evolution. Pigeon and bat wings are an example of convergent evolution, meaning they have independently evolved similar traits as a result of adaptation even though they are not closely related. Divergent evolution is the accumulation of different adaptations in the same species that could eventually lead to them becoming different species (i.e.- polar bear versus brown bear, goat versus buffalo versus giraffe (all hoofed animals), cheetah versus lion versus tiger.) Both the pigeon and the bat have wings, the students will discuss the differences by answering the following questions:

1. Which bones probably support most of the wing muscles and flight surfaces in the pigeon? Are these different from the bat?

Answer: In the pigeon, the keel (breastbone) and humerus support most of the wing muscles while the ulna and radius support most of the flight surfaces (proportionally bigger compared to human arm).

Conversely, the bat's clavicle (collar bone), scapula (shoulder blade), and humerus support most of the wing muscles while the elongated metacarpals and phalanges support most of the flight surfaces (much longer "fingers" than human.)

2. Based on your evidence, do you think that bat wings and bird wings are closely related? In other words, did they get their wings from the same ancestor? Is this an example of convergent or divergent evolution?

Answer: Not likely, their most recent common ancestor probably didn't have wings, so they evolved separately (analogous/convergent, not homologous/divergent)

3. Based on your evidence, do you think that the bat radius + ulna and the bird radius + ulna are closely related? Did they get their arm bones from the same ancestor?

Answer: Yes, shapes and positions are similar, even when compared to humans. The most recent common ancestor may not have had wings, but it is likely the bone positions and shapes were shared in this common ancestor. They evolved from the same ancestor; therefore, this is a homologous trait with divergent characteristics.

4. What are some other examples of convergent evolution?

Answer: Fins of shark versus dolphin versus penguin, skin flaps of flying squirrel versus sugar glider

Fusion Power Instruction and Discussion Questions

At this station there will be skeletons from a salamander, frog, and pigeon. The purpose of this station is to stress the importance of surface area on the bone surface to allow for muscle attachment. Depending on the animal, different bones have fused together to allow for more surface area for muscle to attach, thus indicating increased strength of that muscle. The students will identify the pelvic girdle and pectoral girdle on each skeleton, and then address these discussion points:

1. Compare the pelvic girdle in the salamander to the pelvic girdle in the frog. Which one has more bones?

Answer: Salamander, frog has fused girdle

2. Compare the pectoral girdle in the salamander to the pectoral girdle in the pigeon. Which one has more bones?

Answer: Salamander, bird has fused pectoral bones

3. The flat bone in centered in the frog's pelvis that is formed from fused vertebrae is called the urostyle, and the flat bone centered in the pigeon's pectorals that is formed by fusion and enlargement of sternum is called the keel. Both are formed by the fusion of several bones into a single, large, flat bone that serves a common purpose in both animals. What is this purpose? (hint: think about specialized forms of locomotion in both animals, and all that tasty meat in chicken breasts and frog legs)

Answer: Increase surface area for muscle attachment

Full Skeletons Instruction and Discussion Questions

At these stations, there will be skeletons of a fish, snake, turtle, cat, and human. The full skeleton stations can be combined, or the human skeleton can be a free-standing station that can deviate from the comparative anatomy and discuss human bone diseases. A number of students in the past expressed interest in going to medical school, so these can be fun topics to discuss. The purpose of this station is to compare and contrast skeletons of familiar animals and, to make observations of our skeleton and compare it to what they have or will see at the other stations.

Discussion points:

1. Why do you think you haven't seen a shark skeleton yet?

Answer: Sharks are cartilaginous fish; therefore, they don't have calcified bones

2. How are the bodies of cats specialized for their predatory habits?

Answer: Nimble, flexible backbone, tail for balance, claws for climbing and holding prey, teeth for eating meat, eyes positioned for hunting (forward)

Points of discussion for human skeleton:

1. What is different about a human that allows them to walk on 2 legs rather than 4?
Answer: Pelvic girdle positioning, longer connection of femur and hip, stronger knees, no tail but instead a curve to the lower back to absorb shock, neck and head adaptations so head sits on top of spine instead of tilted forward, larger gluteus (butt) muscle
2. You can discuss some diseases of bone and how they may change the shape of the skeleton.
Fractures or breaks
Bone loss: Osteoporosis, Osteopenia, Osteitis deformans, makes bones weak
Osteopetrosis- too much mineralization makes bones brittle
Leukemia- bone marrow cancer
Spinal curve disorders: Scoliosis (curve in middle of spine), Kyphosis (curve in spine to produce hunchback), and Lordosis (curve in spine to produce protruding lumbar/butt)

Module 2. Internal Anatomy of Dissected Specimens

The goal of this module is to allow students to dissect, or view pre-dissected, vertebrates and explore various body systems and identify important organs. At the end, they will compare and contrast the anatomy across all groups to appreciate the development or loss (evolution) of organs or specialized modifications in each group. One animal will be at each of the six stations. Students will spend one rotation at each animal to discuss the integument (round 1), digestive system (round 2), and respiratory and circulatory system (round 3). Organ identification and comparison can be treated as a competition or a basic quiz to see if the students can identify organs from the provided list. They will have the chance to identify organs in each animal by rotating six times (they will be revisiting the animals they saw for the body system discussions.)

One way to expand on this module is to include histological samples of the various organs at each station. For example, hematoxylin and eosin stained intestine and colon can be set up on a compound light microscope; this will allow the students to observe at the microscopic level how the lumen of each of these is different from one another, based on their function in the digestive tract. Of note, some students may be unenthusiastic to interact with the preserved animals, so this may be a good alternative to still have them participate without forcing them to do something they are against.

Integument Instruction and Discussion Questions

This is a very quick round. After a brief introduction to what the integument is and why it is important, each group will identify what covers the skin of each of their animals. A short discussion of why these animals may have different coverings will conclude this section, and the students will rotate to the next station.
Notes for each animal:
Cat: Fur insulates the animal and is needed because mammals are endothermic.
Pigeon: Feathers with scales on feet
Snake: Two different kinds of scales: the bottom (ventral) scales correspond to the number of ribs the snake has and allows greater flexibility of movement
Mudpuppy: Mucus prevents dehydration and also helps with respiration
Perch: Scales reduce drag in water and protect the animal.
Dogfish shark: Dermal denticles cover the shark. These reduce drag in the water. When you run your hand from the head to tail, it is really smooth, but if you go in the opposite direction, it's rough.

Digestive System Instruction and Discussion Questions

After a short introduction to the digestive tract and excretory system and its related organs, students will be asked to identify the organs in their animal at their station. Afterwards, there will be a discussion about what each group found, such as the lack of a defined large intestine in the shark, perch, and mudpuppy, the lack of a bladder in the shark and pigeon, and the modifications in the pigeon (the presence of a crop in the esophagus and 2 stomachs- the gizzard is full of pebbles to help crush seeds). If they have the chance to cut open the stomach, you can discuss the wrinkles or ridges in the lining of the stomach. These are called rugae and allow the stomach to pack nicely in the body cavity when empty but allows expansion of the stomach when a meal is eaten. And if we were to cut down the length of the intestines, we would notice the lining of the small intestine that is closest to the stomach has a very different texture when compared to the large intestine. The small intestine lining is covered in tiny finger-like structures call villi - these increase the surface area to allow greater nutrient absorption without the intestine being so much longer. The villi become shorter and shorter as you approach the large intestine and colon, which is the site of water absorption.
Notes for each animal:
Cat: Cats, like most predators, have a short small intestine because meat breaks down faster than plant material, and the intestine doesn't need all the length for absorption. This is in contrast to cows, which have long intestines and multiple-chambered stomachs to break down and absorb nutrients from grass and other plants. Cats also have an anus, rather than cloaca as seen in the non-mammalian vertebrate groups, this is the intestinal opening for excretion. All organs of the digestive tract are well-defined.
Pigeon: Pigeons have two stomachs: the proventriculus (1st stomach) is where digestive enzymes are secreted and

the gizzard (2nd stomach) is where food is crushed (seeds), and it usually contains small rocks or pebbles. Birds also have a crop, which is an outcropping of the esophagus, and is used for storage of food to digest later. Finally, birds do not have a bladder; first, this is less weight to carry while flying, and furthermore, the waste from the kidney is mostly uric acid (not high in urea like in mammals), which is less toxic and does not need to be diluted with water in the bladder. The uric acid mixes with the feces from the digestive tract all waste leaves through cloaca.
Snake: The organs in a snake are elongated to fit in its long, narrow body. The esophagus is very elastic, which allows the snake to fit big food that is slowly digested. A snake's gall bladder is not associated with the liver; instead it is closer to the stomach to assist in digestion.
Mudpuppy: Amphibians don't need a long large intestine because its main function is to reabsorb water into body to prevent dehydration and to solidify waste; its habitat is always moist. Additionally, mudpuppies have a short and poorly defined esophagus, leading to a short trip for food to get from mouth to stomach.
Perch: Bony fish have a tiny vestigial bladder and an undefined large intestine. In addition to kidneys and bladder, fish can use their gills to remove nitrogen waste from the blood. All other waste (and reproductive material!) leave from the cloaca, like the shark.
Dogfish shark: The dogfish shark has a very short small intestine and does not have a large intestine; instead it has a lot of internal spirals to increase surface area for nutrient absorption. They don't need a large intestine because its main function is to reabsorb water into body to solidify waste, which is not important for fish. Also, sharks do not have a bladder; all waste (and reproductive material!) leaves from the cloaca. A large amount of the body cavity is taken up by its huge liver which also assists with buoyancy because they lack a swim bladder.

Respiratory and Circulatory Systems Instruction and Discussion Questions

After a short introduction to the respiratory and circulatory systems and their related organs, students will be asked to identify the organs in their animal at their station. Afterwards, there will be a discussion about what each group found, including the diaphragm in the cat, the single lung in the snake, air sacs in the pigeon lungs, and gills and lungs in the mudpuppy. The spleen is considered an accessory organ for the circulatory system because it filters out old and deformed red blood cells from the circulation. This will be a deep red or dark gray oblong organ.
Notes for each animal:
Cat: Cats have lungs and a diaphragm, which is unique to mammals. They have a four-chamber heart and a two-loop circulatory system.
Pigeon: Pigeons have lungs with air sacs; air sacs store air so there is oxygen rich air in lungs during inhale AND exhale, which leads to a very efficient respiratory system needed to meet high oxygen demand of flight. Birds have a four-chamber heart and a two-loop circulatory system
Snake: Snakes have lungs, but usually only one of them is functional. To breathe, snakes use muscles to expand and contract rib cage to bring air in and push air out (no diaphragm). Snakes have a three-chamber heart and a two-loop circulatory system.
Mudpuppy: Mudpuppies have gills as a juvenile, which are retain as an adult (neotenic) but are not the main organ for gas exchange because they develop lungs as adult. They can also "breath" through their skin. Mudpuppies have a three-chamber heart and a two-loop circulatory system.
Perch: Fish have gills, which allow a counter current flow where oxygenated water moves away from head as blood moves toward head for more efficient gas exchange. Some of this gas is used in the swim bladder, which helps with buoyancy; gases are added and removed from blood to empty/fill. Fish have a two-chamber heart and a single loop circulatory system.
Dogfish shark: Sharks have gills and a two-chamber heart (single loop circulatory system)

Organ Identification & Comparison Instruction and Discussion Questions

The presentation that precedes this round will give the instructor the opportunity to introduce many other important organs that have not yet been discussed, including accessory organs and gonads, and what their roles are in the body. This is the main chance for the students to test their knowledge of where to find the organs based on homology of the animals they already studied and then to compare and contrast the systems across all of the groups. The main points that should be discussed are listed below.
Cat: very similar to human, can discuss what would be different in a human versus the cat (both mammals)
Pigeon: No bladder, crop and two stomachs (proventriculus and gizzard)
Snake: Only has one functionally lung, may have a second tiny lung to save space in its long body. The spleen and pancreas are very closely associated (probably adhere to one another); you can tell them apart because the spleen is reddish, and the pancreas is the same color as the intestines.
Mudpuppy: Has very primitive features, like a poorly defined esophagus, kidneys are not retroperitoneal, but are instead supported by a peritoneal fold.
Perch: Vestigial bladder, undefined large intestine, swim bladder
Dogfish shark: No bladder, no large intestine, humungous liver, long claspers at cloaca means it's a male. Testes or ovaries are up in its "neck"

Module 3: Phylogeny

The goal of this module is to have students apply what they have learned from inspecting the animals' anatomy to predict the evolutionary progression of these groups by drawing a phylogenetic tree.

Phylogeny instruction and discussion questions

The students will use their homology table (Table 2) that they completed during the first two modules to draw a phylogenetic tree placing each group along an evolutionary line. The students can start by summing up the numbers for each animal, and that will give them a clue as to how "evolved" each one is. Depending on how much freedom you want to give them, you can present them with a straight line with each of the characteristics from the table as a node of divergence, and have them fill in where each of the group fits in. See the "Cheat Sheet" for an example.

This section can be expanded in multiple ways; at a basic level, you may talk more specifically about a certain branch of the tree, such as the mammals, or have them predict the placement of other animals that were not covered in the dissections. Further expansion may include zooming out to include invertebrates, or even starting from the divergence of eukaryotes from prokaryotes and archaea. You may also opt for an in-depth discussion of clades and a more accurate depiction of a phylogenetic tree.

Acknowledgments

A special thank you to Christina McGuire and Marina Freytsis for the invaluable input after the inaugural demonstration of this lab. Also, much appreciation goes to all of the BIOBUGS and UBMS teaching assistants and participants who have helped improve this laboratory exercise over the years, including the authors Eric Crandall, Timery DeBoer, Jess Gonynor, Amy Mertl, Emily Marquez, and Cynthia Brossman who designed the original Bones and Phylogeny sections from which this lab was built.

About the Authors

Joslyn is a Postdoctoral Research Associate at Brown University in the lab of Louis Lapierre, where she is studying organellar dynamics associated with aging. She earned her PhD in Cellular and Molecular Physiology from Tufts University in 2018 and worked in collaboration with Boston University to develop her teaching skills and curriculum development.

Melissa is an IRACDA postdoctoral fellow in the lab of Dr. Bradley Yoder at the University of Alabama at Birmingham. She completed her PhD at Tufts University in Boston in 2018. While in Boston, she helped teach this lab for the BIOBUGS (Biology Inquiry and Outreach with Boston University Graduate Students) program at Boston University.

Nafis is a PhD candidate at Tufts University Sackler School of Graduate Biomedical Studies. He works on understanding how vitamin D3 affects breast development as it relates to cancer. He is also invested in issues that lie in the intersection of politics, society and science, and is an avid supporter of general scientific literacy.

Angela has been the Physiology Laboratory Manager at Boston University since 2009, where she divides her time among teaching large laboratory courses in physiology for upper level undergraduate students, training graduate and undergraduate students in pedagogical techniques, and advising students in educational outreach programs.

Cited References

Crandell E, DeBoer T, Gonynor J, Mertl A, Marquez E, Brossman C. 2007. https://www.bu.edu/lernet/biobugs/anatomy/anatomy_worksheet.pdf

Fishbeck DW and Sebastiani AM. 2001. Comparative Anatomy: Manual of Vertebrate Dissection. Englewood, CO: Morton Pub.

Appendix A: Suppliers

The bones and skeletons were available from the Boston University Biology “museum;” these are occasionally available at universities; however, photos may be used in their place if they are not.
Preserved specimens were purchased from BioCorporation (3910 Minnesota Street, Alexandria MN 56308): cat (#CT1014P), snake (#SN1418P), pigeon (#PG0002P), mudpuppy (#NT1014P), perch (#YP0709P), dogfish shark (#SK1822P)

Appendix B: Instructions for Preparation

Bone Station Set Up

Station 1: Skulls 1
Skulls with full dentation from a deer, bear, and coyote
Station 2: Skulls 2
Skulls with full dentation from a shrew and a bat
Station 3: First in Flight
Human arm bone with full skeletons from a pigeon and bat
Station 4: Fusion Power
Human hip girdle with full skeletons from a salamander, a frog, and a pigeon
Station 5: Pet Cemetery
Full skeletons of a cat, turtle, snake, and fish
Station 6: Human Skeleton
Full skeleton of a human

Dissections

If you are going to dissect the specimen and pin organs before class, please refer to the dissection resources found at the links in Table 4.

Table 4. Links to Dissection Resources

Dogfish Shark	
Images	https://www.savalli.us/BIO370/Anatomy/2.SharkDissectionLabel.html
Video	https://www.youtube.com/watch?v=uJrT7lHg5Lw
Perch	
Images	https://www.savalli.us/BIO370/Anatomy/3.PerchDissectionLabel.html
Video	(start at 4:34): https://www.youtube.com/watch?v=J2URdwTA3Q8
Mudpuppy	
Images	https://www.savalli.us/BIO370/Anatomy/4.NecturusDissectionLabel.html
Video	https://www.youtube.com/watch?v=maHaS6uOUEo
Pigeon	
Images	https://www.savalli.us/BIO370/Anatomy/7.PigeonDissectionLabel.html
Video	(start at 1:40): https://www.youtube.com/watch?v=0EpQsZR4BLM
Snake	
Images	https://www.savalli.us/BIO370/Anatomy/5.SnakeDissectionLabel.html
Video	(start at 5:17): https://www.youtube.com/watch?v=vijNX_l3IlY
Cat	
Images	http://anatomycorner.com/main/image-gallery/cat-dissection/
Video	(start at 3:00): https://www.youtube.com/watch?v=4IhOdVprJ0w

Appendix C: Evaluations from High School Students and Their Teachers

This lab has been presented in two formats described below.

BIOBUGS is a program at Boston University that invites classes of up to 24 students from local high schools in the Boston area to attend a lab organized and taught by graduate students. These labs are offered five times over a span of a week as a three-hour lab. CVA&P was offered during the fall semester of 2015, and Table 5 is a compilation of the students' ratings and comments, as well as comments from their teacher that chaperoned them.

Table 5. Evaluations from BIOBUGS participants.

	Teacher's knowledge of material	**Teacher's speaking voice**	**Teacher's presentation**	**Lab worksheets**	**Would they recommend the lab to a friend**
Average (Scale 1-5, 5=highest)	4.6	4.8	4.6	4.3	4.4
Student Comments	-The most favorite activity was the internal anatomy part and a couple really liked the competition. -"It was awesome/fun" -"Good job" -"Less talking = ☺" -"I don't like the smell" -"Uber cool" -"I'm into the bioscience"				
Teacher Comments	- They would definitely recommend this lab to other teachers -Feel this is a great experience for their students -Suggested more relevance to human anatomy - Suggested referencing the evolution/phylogeny throughout the lecture rather than just at the end -Live mini dissection -"Impressed you were able to keep the students interested for 3 hours :)"				

Science Wednesdays is part of a summer program that allows high school students from UBMS to participate in three six-hour labs taught by volunteers to complement their academic events during the remainder of the week. CVA&P was offered during the summers of 2015 and 2016 as one of the labs. Table 6 is a compilation of the student's ratings and comments from both of these administrations.

Table 6. Evaluations from UBMS: Science Wednesday participants.

	Teacher's knowledge of material	**Teacher's speaking voice**	**Teacher's presentation**	**Lab worksheets**	**Would they recommend the lab to a friend**
Average (Scale 1-5, 5=highest)	4.7	5	4.5	4	4.6
Student Comments	-Most really enjoyed the chance to dissect all of these animals and a couple really liked the competition. -They liked comparing the different animals, particularly the shark and the pigeon -Many didn't care for the worksheet because they wanted to focus on the dissections rather than fill it out -"The presentation felt rushed" -"Too much talking"				

Appendix D: Anatomy Volunteer Cheat Sheets from Handout Used by BIOBUGS Sample "Results", key to student worksheet, and addendum to Notes to Instructor

Bone Stations Discussion Points

Station 1: Skulls 1

The skulls will be from a deer, bear, and coyote. Help the students identify the features from Figure 2 on the first skull, and then have them fill in the Skulls Tell Stories table in their worksheet. Recommend that the group split duties in order to complete all 3 skulls in the 6 minutes allotted.

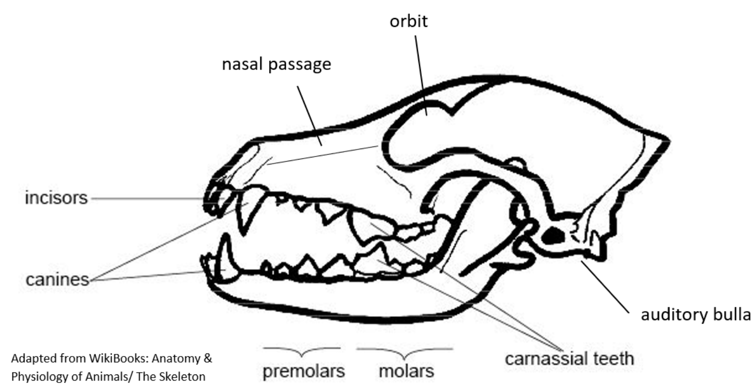

Figure 2. General mammalian skull.

Table 7. Skulls Tell Stories: Worksheet Key, Part 1.

Skull Number	Incisors (short or long)	Canines (Present or absent)	Premolars & Molars (Flat/broad, sharp/ pointy, or in between)	Orbit Relative Size (small, med, or large)	Orbit Position (forward or side)	Nasal Passage Relative Length (short, med, or long)	Auditory Bullae Relative Size (small, med, or large)	Best Senses (Sight, smell, or hearing)	Place in Food Web (herbivore, omnivore, or carnivore)
1 Deer	Long	Absent	Flat	Med	Side	long	Large	Hearing	Herbivore
2 Coyote	short	Present	Sharp	Large	forward	Short	Med	Sight	carnivore
3 Bear	Short	Present	In between	small	Side	Short	Small	Smell	Omnivore
4 Bat									
5 Shrew									
Your skull									

Station 2: Skulls 2

The skulls will be from a bat and a shrew. These are pretty tiny, so you will need to use the dissecting microscopes to look at the details. Help the students identify the features from Figure 3 and then have them fill in the Skulls Tell Stories table in their worksheet. Recommend that the group split duties in order to complete both skulls in the 6 minutes allotted.

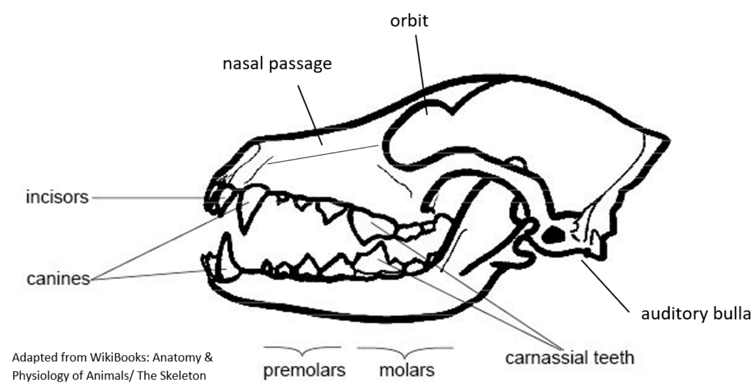

Figure 3. General mammalian skull.

Table 8. Skulls Tell Stories: Worksheet Key, Part 2

Skull Number	Incisors (short or long)	Canines (Present or absent)	Premolars & Molars (Flat/broad, sharp/ pointy, or in between)	Orbit Relative Size (small, med, or large)	Orbit Position (forward or side)	Nasal Passage Relative Length (short, med, or long)	Auditory Bullae Relative Size (small, med, or large)	Best Senses (Sight, smell, or hearing)	Place in Food Web (herbivore, omnivore, or carnivore)
1 Deer									
2 Coyote									
3 Bear									
4 Bat	Short	Present	Sharp	Med	Forward	Short	Large	Hearing	Carnivore
5 Shrew	Short	Absent	In between	Very small	Side	Long	Large	Hearing & smell	omnivore
Your skull									

Station 3: Flight

There will be pigeon and bat skeletons at this station, as well as a human arm. The purpose of this station is to discuss convergent and divergent evolution. Pigeon and bat wings are an example of convergent evolution, meaning they have independently evolved similar traits as a result of adaptation even though they are not closely related. Divergent evolution is the accumulation of different adaptations in the same species that could eventually lead to them becoming different species (i.e.- polar bear versus brown bear, goat versus buffalo versus giraffe (all hoofed animals), cheetah versus lion versus tiger.)

Define convergent and divergent evolution for them then address these discussion points:

Both the pigeon and bat have wings, but what are the differences?

1. Which bones probably support most of the wing muscles and flight surfaces in the pigeon? Are these different from the bat?
In the pigeon, the keel (breastbone) and humerus support most of the wing muscles while the ulna and radius support most of the flight surfaces (proportionally bigger compared to human arm).
Conversely, the bat's clavicle (collar bone), scapula (shoulder blade), and humerus support most of the wing muscles while the elongated metacarpals and phalanges support most of the flight surfaces (much longer "fingers" than human.)
2. Based on your evidence, do you think that bat wings and bird wings are closely related? In other words, did they get their wings from the same ancestor? Is this an example of convergent or divergent evolution?
Not likely, their most recent common ancestor probably didn't have wings, so they evolved separately (analogous/convergent, not homologous/divergent)
3. Based on your evidence, do you think that the bat radius + ulna and the bird radius + ulna are closely related? Did they get their arm bones from the same ancestor?
Yes, shapes and positions are similar, even when compared to humans. The most recent common ancestor may not have had wings, but it is likely the bone positions and shapes were shared in this common ancestor. They evolved from the same ancestor; therefore, this is a homologous trait with divergent characteristics.
What are some other examples of convergent evolution?
Fins of shark versus dolphin versus penguin, skin flaps of flying squirrel versus sugar glider

The students also need to fill in the homology table (Table 2) for the pigeon as best they can. Table 9 shows you what they will be able to fill in. We will discuss the answers as a class during the phylogeny section.

Table 9. Homology table for pigeon.

Homology Data Table
1 = Present, 0 = Absent

	1. Vertebrae	2. Calcified bone	3. Four walking limbs	4. Egg with amniotic membrane	5. Pronounced large intestine	6. Skin Covering (describe)	7. Pronounced dorsal process on vertebrae	8. Egg with mineralized Shell	9. Lower Jaw Bones fused into beak - no teeth	10. Keeled breastbone	11. Diaphragm	12. Number of chambers in heart
Pigeon *Columba livia*	1	1	1	1			0		1	1		

Station 4: Fusion

At this station there will be skeletons from a salamander, frog, and pigeon. The purpose of this station is to stress the importance of surface area.

Identify the pelvic girdle and pectoral girdle on each skeleton for them then address these discussion points:
1. Compare the pelvic girdle in the salamander to the pelvic girdle in the frog. Which one has more bones?
Salamander, frog has fused girdle
2. Compare the pectoral girdle in the salamander to the pectoral girdle in the pigeon. Which one has more bones?
Salamander, bird has fused pectoral bones
3. The flat bone centered in the frog's pelvis is called the urostyle, and the flat bone centered in the pigeon's pectorals is called the keel of the sternum. Both are formed by the fusion of several bones into a single, large, flat bone that serves a common purpose in both animals. What is this purpose? (hint: think about specialized forms of locomotion in both animals, and all that tasty meat in chicken breasts and frog legs…yummm)
Increase surface area for muscle attachment
The students also need to fill in the homology table (Table 2) for the salamander as best they can. Table 10 shows you what they will be able to fill in. We will discuss the answers as a class during the phylogeny section.

Table 10. Homology table for mudpuppy.

Homology Data Table

1 = Present, 0 = Absent

	1. Vertebrae	2. Calcified bone	3. Four walking limbs	4. Egg with amniotic membrane	5. Pronounced large intestine	6. Skin Covering (describe)	7. Pronounced dorsal process on vertebrae	8. Egg with mineralized Shell	9. Lower Jaw Bones fused into beak - no teeth	10. Keeled breastbone	11. Diaphragm	12. Number of chambers in heart
Mudpuppy *Necturus maculosus*	1	1	1	0			0		0	0		

Station 5: Pet Cemetery

At this station, there will be skeletons of a fish, snake, turtle, and cat. The purpose of this station is to compare and contrast skeletons of popular pets. They will also gather further information for their homology table. (Table 2)

Discussion Points:

1. Why do you think you haven't seen a shark skeleton yet?

Sharks are cartilaginous fish; therefore, they don't have calcified bones

2. How are the bodies of cats specialized for their predatory habits?

Nimble, flexible backbone, tail for balance, claws for climbing and holding prey, teeth for eating meat, eyes positioned for hunting (forward)

The students will need to fill in the homology table (Table 2) for the fish, snake, and cat as best they can. Table 11 shows you what they will be able to fill in. We will discuss the answers as a class during the phylogeny section.

Table 11. Homology table for perch, snake, and cat.

Homology Data Table

1 = Present, 0 = Absent

	1. Vertebrae	2. Calcified bone	3. Four walking limbs	4. Egg with amniotic membrane	5. Pronounced large intestine	6. Skin Covering (describe)	7. Pronounced dorsal process on vertebrae	8. Egg with mineralized Shell	9. Lower Jaw Bones fused into beak - no teeth	10. Keeled breastbone	11. Diaphragm	12. Number of chambers in heart
Perch *Perca flavescens*	1	1	0	0			0		0	0		
Snake *Thamnophis sirtalis*	1	1	0	1			0		1	0		
Cat *Felis domesticus*	1	1	1	1			1		0	0		

Station 6: Human Skeleton

At this station, there will be a human skeleton. The purpose of this station is to make observations of our skeleton and compare it to what they have or will see at the other stations. This is also an opportunity for the students to fill in Table 2 with anything they missed at previous stations.

Points of Discussion:

1. What is different about a human that allows them to walk on 2 legs rather than 4?

Pelvic girdle positioning/ longer connection of femur and hip, stronger knees, no tail but instead a curve to the lower back to absorb shock, neck and head adaptations so head sits on top of spine instead of tilted forward, larger gluteus (butt) muscle

2. You can discuss some diseases of bone and how they may change the shape of the skeleton.

Fractures or breaks
Bone loss: Osteoporosis, Osteopenia, Osteitis deformans, makes bones weak
Osteopetrosis- too much mineralization makes bones brittle
Leukemia- bone marrow cancer
Spinal curve disorders: Scoliosis (curve in middle of spine), Kyphosis (curve in spine to produce hunchback), and Lordosis (curve in spine to produce protruding lumbar/butt)

Internal Anatomy Discussion Points

Dogfish Shark

<u>Round 1- Integument</u>

Dermal denticles cover the shark- reduces drag in the water
When you run your hand from the head to tail, it is really smooth, but if you go in the opposite direction, it's rough

<u>Round 2- Lower Digestive Tract</u>

1. Why is the small intestine so short, and why isn't there a large intestine?

Has a very short small intestine and does not have a large intestine; instead have a lot of internal spirals to increase surface area for nutrient absorption. Doesn't need large intestine because its main function is to reabsorb water into body to solidify waste.

2. Does your species have any modifications? What is its function?

Sharks do not have a bladder, all waste (and reproductive material!) leave from the cloaca
Huge liver which also assists with buoyancy because they lack a swim bladder
Look at the lining of the stomach.

3. Why are there so many "wrinkles" inside the stomach?

The *rugae* allow the stomach to expand when a meal is eaten, but while it is empty, it folds nicely into a small space.

<u>Round 3- Respiratory and Circulatory Systems</u>

Gills
2 chambers, 1 loop circulatory system
The spleen will be a deep red or gray color- its responsibility is to filter out old red blood cells from the circulation

<u>Round 4- Organ identification hints</u>

No bladder, no large intestine
Long claspers at cloacae means it's a male. Testes or ovaries are up in its "neck"

Perch

<u>Round 1- Integument</u>

Scales

<u>Round 2- Lower Digestive Tract</u>

1. Does your species have any modifications? What is its function?

In addition to kidneys and bladder, fish can use their gills to remove nitrogen waste from the blood. All other waste (and reproductive material!) leave from the cloaca, like the shark

Tiny vestigial bladder, undefined large intestine

Round 3- Respiratory and Circulatory Systems
Gills: counter current flow= oxygenated water moves away from head as blood moves toward head for more efficient gas exchange
swim bladder helps with buoyancy, gases added and removed from blood to empty/fill
2 chambers, 1 loop circulatory system

Round 4- Organ identification hints
Vestigial bladder, undefined large intestine

Mudpuppy
Round 1- Integument
Mucus, doesn't dry out, assists respiration

Round 2- Lower Digestive Tract
1. Why is the large intestine so short?
Doesn't need a long large intestine because its main function is to reabsorb water into body to prevent dehydration and to solidify waste; its habitat is always moist

2. Does your species have any modifications? What is its function?
Short and poorly defined esophagus, short trip for food to get from mouth to stomach
Short large intestine; its main function is to reabsorb water into body

Round 3- Respiratory and Circulatory Systems
Skin, gills as a juvenile but some amphibians including the mudpuppy retain these gills as an adult (neotenic), develops lungs as adult
3 Chambers, 2 loops

Round 4- Organ identification hints
Very primitive features
Poorly defined esophagus
Kidneys are not retroperitoneal, but are instead supported by a peritoneal fold- not labeled on your specimen

Pigeon
Round 1- Integument
Feathers with scales on feet

Round 2- Lower Digestive Tract
1. Why is the small intestine broken up into segments?
Proventriculus (1st stomach) is where digestive enzymes are secreted and the gizzard (2nd stomach) is where food is crushed (seeds), and it usually contains small rocks or pebbles
2. Does your species have any modifications? What is its function?
Crop: outcropping of esophagus, storage of food to digest later
2 stomachs (see above)
no bladder- less weight to carry while flying, the waste from the kidney is mostly uric acid (not high in urea like in mammals), which is less toxic and does not need to be diluted with water in the bladder, the uric acid mixes with the feces from the digestive tract and all waste leaves through cloaca

Round 3- Respiratory and Circulatory Systems
Lungs with air sacs: air sacs store air so there is oxygen rich air in lungs during inhale AND exhale
Super-efficient respiratory system to meet high oxygen demand of flight to breath
4 chambers, 2 loop circulatory system (may not be able to find spleen, its responsibility is to filter out old and deformed red blood cells from the circulation

Round 4- Organ identification hints
No urinary bladder
Gall bladder is not labeled (couldn't find it)

Snake
Round 1- Integument
Scales- 2 different kinds: the bottom (ventral) scales correspond to the number of ribs the snake has and allows greater flexibility of movement

Round 2- Lower Digestive Tract
1. Does your species have any modifications? What is its function?
Elongated organs to fit elongated body, super elastic esophagus to fit big food
Gall bladder not associated with the liver, it's closer to the stomach to assist in digestion

Round 3- Respiratory and Circulatory Systems
Lungs (only 1 functional),
to breath, snakes use muscles to expand and contract rib cage to bring air in and push air out (no diaphragm)
Heart: 3 chambers, 2 loop circulatory system
The spleen will be a deep red color- its responsibility is to filter out old and deformed red blood cells from the circulation

Round 4- Organ identification hints
1 functional lung, may have a second tiny lung
Spleen and pancreas are very closely associated (probably adhered to one another); the spleen is reddish, and the pancreas is the same color as the intestines

Cat
Round 1- Integument
fur

Round 2- Lower Digestive Tract
1. Why is the small intestine so short? How would this compare to a cow?
Has a short small intestine because meat breaks down faster and doesn't need all the length for absorption, cows have long intestines and multiple-chambered stomachs to break down and absorb nutrients from grass and other plants
2. Does your species have any modifications? What is its function?
Presence of anus rather than cloaca as seen in the non-mammalian vertebrates: intestinal opening for excretion
Well-defined esophagus, stomach, small and large intestines

Round 3- Respiratory and Circulatory Systems
Lungs
Point out diaphragm, it is unique to mammals
4 chambers, 2 loop circulatory system
The spleen will be a deep red color- its responsibility is to filter out old and deformed red blood cells from the circulation

Round 4- Organ identification hints
Very similar to humans

Summary
Table 12 can be used as a guide for pinning organs of dissected specimens.

Table 12. Organ Identification Table: Example Key (example from December 7, 2015).

	DOGFISH	PERCH	SALAMANDER	SNAKE	PIGEON	CAT
Esophagus	3	9	5	13	8	6
Stomach	4	4	14	7	11	13
Pancreas	7	12		5	14	10
Spleen	5	6	12	12		9
Small Intestine	6	2	3	2	12	5
Large Intestine	None	None		4	10	12
Liver	2	5	1	11	1	11
Gall bladder	10	8	7	1		8
Heart	1	11	13	9	13	4
Kidney	8	3		8	3	14
Bladder	none	10	8	None	None	1
Air exchange	9	1	6	6	7	2
Gonads (M or F?)	11 (F)	7 (F)	9 (M)	10 (M)	2 (F)	3 (F)

Phylogeny

The completed Homology table (Table 13) presents information that can be used to construct a phylogenetic tree such as the one in Figure 4.

Table 13. Homology Table used to create phylogenetic tree

	Dogfish ***Squalus acanthias***	**Perch** ***Perca flavescens***	**Mudpuppy** ***Necturus maculosus***	**Snake** ***Thamnophis sirtalis***	**Pigeon** ***Columba livia***	**Cat** ***Felis domesticus***
1. Vertebrae	1	1	1	1	1	1
2. Calcified bone	0	1	1	1	1	1
3. Four walking limbs	0	0	1	0	1	1
4. Egg with amniotic membrane	0	0	0	1	1	1
5. Pronounced large intestine	0	0	0	1	1	1
6. Skin covering (describe)	Denticles	Scales	Mucus	Scales	Feathers	Fur
7. Pronounced dorsal process on vertebrae	0	0	0	0	0	1
8. Egg with mineralized shell	0	0	0	1	1	0
9. Lower Jaw Bones fused into beak (no teeth)	0	0	0	0	1	0
10. Keeled breastbone	0	0	0	0	1	0
11. Diaphragm	0	0	0	0	0	1
12. Number of chambers in heart	2	2	3	3	4	4

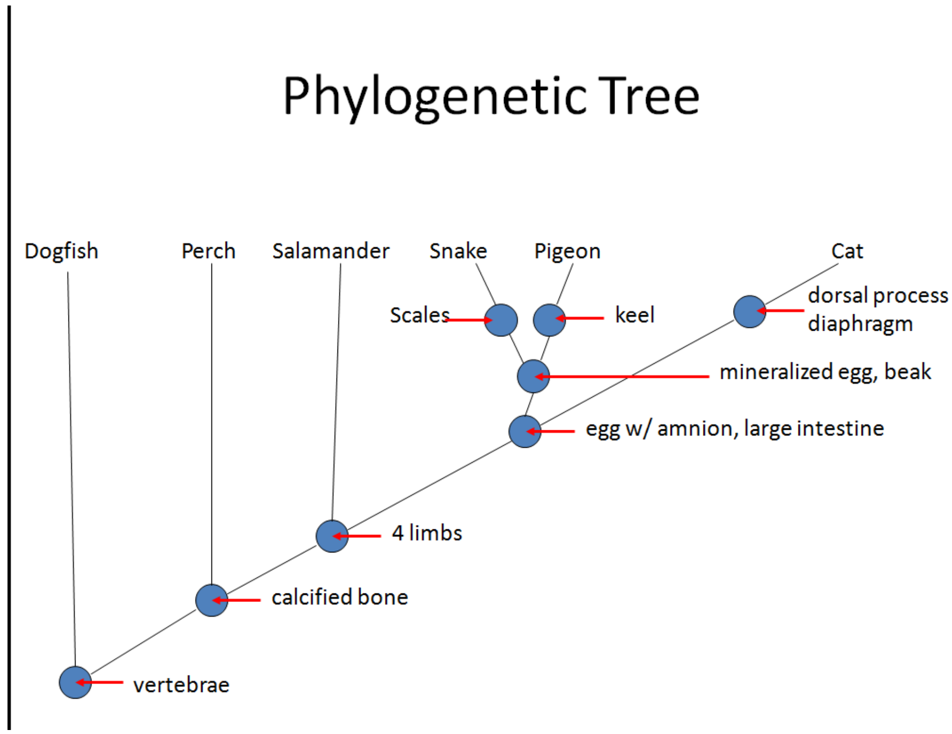

Figure 4. Example of a phylogenetic tree produced from the information in Homology Table 13.

Mission, Review Process & Disclaimer

The Association for Biology Laboratory Education (ABLE) was founded in 1979 to promote information exchange among university and college educators actively concerned with teaching biology in a laboratory setting. The focus of ABLE is to improve the undergraduate biology laboratory experience by promoting the development and dissemination of interesting, innovative, and reliable laboratory exercises. For more information about ABLE, please visit **http://www.ableweb.org/.**
Papers published in *Tested Studies for Laboratory Teaching: Peer-Reviewed Proceedings of the Conference of the Association for Biology Laboratory Education* are evaluated and selected by a committee prior to presentation at the conference, peer-reviewed by participants at the conference, and edited by members of the ABLE Editorial Board.

Citing This Article

Mills J, LaBonty M, Hasan N, Seliga A. 2019. Comparative Vertebrate Anatomy and Phylogeny. Article 13 In: McMahon K, editor. Tested studies for laboratory teaching. Volume 40. Proceedings of the 39th Conference of the Association for Biology Laboratory Education (ABLE). **http://www.ableweb.org/volumes/vol-40/?art=13**