Structure and Composition of the Skeleton

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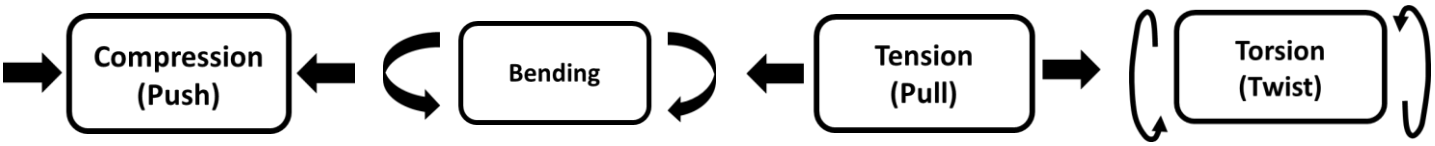
Introduction/Abstract to Lesson Plan (max. 100 Words) Include aspects of the lesson that are unique and innovative.	Bone is a composite living tissue that is composed of both proteins and minerals. This composite material provides strength and flexibility, allowing bone to resist fracture without being brittle. The structure of different types of bone and different regions of a single bone have different properties that are indicative of their function. This lesson will allow students to discover the functions and composition of bone, how form/structure adapts to meet function, and how different material properties and orientations can influence strength.
List of Standards Addressed Common Core, NC Essential Science, Next Gen, etc. (This should be list of all full standards addressed by the lesson) Optional: Standards Mapping Grid	<u>NSES/NCES:</u> **3.L.1.1** Compare the different functions of the skeletal and muscular system. **5.L.1.2** Compare the major systems of the human body (digestive, respiratory, circulatory, muscular, skeletal, and cardiovascular) in terms of their functions necessary for life. **5.L.3.2** Give examples of likenesses that are inherited and some that are not. **Bio.3.2.3** Explain how the environment can influence the expression of genetic traits. <u>Next Gen:</u> **3-LS1-1** Science findings are based on recognizing patterns. **5-LS1-1** Support an argument with evidence, data, or a model.
Learning Objectives using Measurable Verbs (what students will be able to do)	- Identify the purpose of structure and material properties of bone based on observations from an experiment. - Interpret function of different bones based on their shapes and structure. Estimate how changes in loading or function will change bone structure. - Compare the skeletons and bones of different organisms and recognize how similarities and differences between species arise from natural selection. - Design a fictional creature with a skeleton and choose bone properties that best suite its environment and function.
Appropriate Grade Levels	3rd/5th
Group Size/# of students activities are designed for	Any
Setting (e.g. indoors, outdoors, lab, etc.)	indoors
Approximate Time of Lesson (Break down into 20-50 minute periods)	**1 or 2 30 minute lessons**
Resources Needed for Students (e.g. scissors, paper, pencils, glue, etc.)	popsicle sticks or tongue depressors, 2+ per student chalk (longer than an inch, optional: two different diameters), 2+ per student very optional: long bone, can be from chicken leg (cooked, flesh removed)
Resources Needed for Educators (e.g. blackboard, Powerpoint capabilities, etc.)	blackboard/whiteboard/transparency projector computer projector

Introduction

Bone is a composite living tissue that is composed of both protein and minerals. This composite material provides strength and flexibility, allowing bone to resist fracture without being brittle. The structure of different types of bone and different regions of a single bone have different properties that are indicative of their function. This lesson will allow students to discover the functions and composition of bone, how form/structure adapts to meet function, how structure scales, how different material properties and geometric orientations can influence strength, and how changes in diet, lifestyle, or genetics can alter bone systems. The lesson can be extended to discuss evolution and evolved structural similarities and differences between animals, as well.

Background

A beam-like material can have loads applied to it in four main ways: compression, tension, bending, and torsion.



Different materials are stronger under different types of loading directions based on their properties and shape. Bone is a composite of both minerals (which are brittle but strong in compression) and proteins (which are pliant). This exercise will allow students to explore how two types of materials in different configurations resist load differently. Tongue depressors/popsicle sticks are made of wood (long fibers, not unlike proteins in the bone) and are good at resisting tension. Chalk is a rock containing a mineral (calcite, or calcium carbonate) that is very brittle but good at resisting compression. Both chalk and popsicle sticks are fairly good at resisting other types of load, too, depending on which direction the load is applied (i.e., bending the popsicle stick across the thin vs. thick part of the cross section).

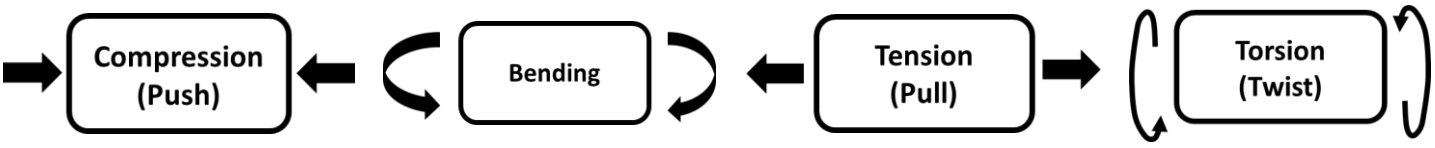
The concept that different materials are better or worse at resisting different types of load depending on their orientation can be used to explore how different properties are scaled in animal bones to match the functional loading of the bone. Wolff's law states that bone adapts to meet the loads under which it is placed (see the Wolff's law picture on p. 7). Another way to state this concept is "use it or lose it," which is a great way to emphasize the importance of exercise in maintaining bone health throughout life. Encourage the students to discuss what types of loads different bones experience and what they think is the most effective shape to resist that load and not break.

An optional second day activity could cover how different animals have very similar bone structures, a concept called structural homology. For example, fish, birds, and mammals all have very similar limb bones despite being used for different functions – swimming, flying, and land movement, respectively (see coloring book activity on p. 11); different bone structures all resist fracture but have different secondary functions (human bone vs. bird bone example, p. 9); and seemingly distant animal relatives to humans have almost the same bone structure as us, save for small differences (sewer rat rib cage video, p.11).

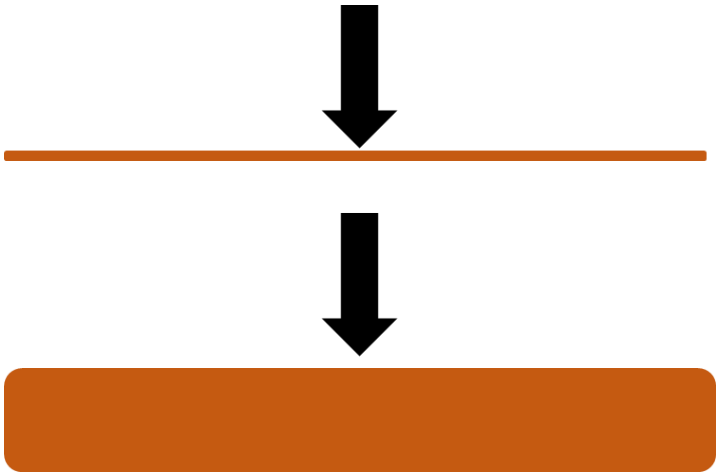
Step by Step Activity

Day 1

1. Explain the four loading directions using a measuring stick or large piece of chalk.



2. Allow the students to mechanically test the strength of popsicle sticks and chalk using their hands. Ensure that they attempt to apply loads in different directions and different orientations. Ask the students if they note any differences in ease of breaking the materials in different ways. Which was easiest and which was hardest for each material? What orientation was easiest and which was hardest to bend the popsicle stick?



3. Have them describe and draw the differences in the broken ends of the chalk and popsicle stick. Why do you think they broke that way? Have them record their hypotheses along with their sketches of the broken ends.

4. Ask them what they think the purposes of bones are. Ask them if they have ever broken a bone or know someone who has. Did they get better? Ask them how long it took for them to get better. Ask them if they think bone acts more like the chalk or the popsicle stick (the answer is neither/both): note that chalk is too brittle and snaps very easily – do their bones break so easily? Do their bones bend like the popsicle stick does? Explain that bone is composed of both minerals (brittle but strong) and proteins (tough but flexible) that allow it to have properties of both materials. Bone is somewhat flexible, but if the load is large enough it will break. Have them describe the

weight of the chalk vs. the popsicle stick. Explain that bones are not very heavy, but if they were made of only mineral they would be as heavy as stone. Would that make moving harder?

5. Show them a picture of a long bone (tibia picture on p. 6) or show them a real bone. Ask them why they think it is shaped the way it is (round with a long middle). Does the roundness remind them of the chalk? Why does the tibia appear to be more flat? Does it remind them of the popsicle stick? This is also a good time to show them the Wolff's Law picture on p. 7 and ask them about the bone struts. Do the small struts remind them of the chalk? What type of loading do they think the struts will experience? What type of loading was the chalk strongest to resist? What about other bones that aren't that shape, like the skull?

6. Explain that bone is a composite material: it is composed of two different types of materials that have different properties. The cool thing about bone that is different from other types of composite materials is that it is alive and can change over time in response to different stimuli (such as diet and physical activity). Explain that the overall shape of a bone is matched to the function of that bone based on what type of loads it generally encounters. Next explain that bone is also composed of complex internal structure as well that further strengthens and adapts to loading. The amount and shape of this internal structure changes with loading. What would happen to the bones in your legs if you could not walk and had to use a wheelchair? What would your bones look like you went to outer space and floated without gravity, never applying any loads to your skeleton? What would your bones look like if you carried weights in your arms all day long? Why? What do you think would happen if you carried weights all day but stopped eating enough food? The mineral in bone contains lots of calcium, which is found in milk and other foods. What would happen if they stopped eating calcium?

<u>Day 2 (optional)</u>

1. Show the sewer rat video (link on p. 11). Do humans have the ability to flatten their rib cage? Explain that humans and rats have extremely similar skeletons, aside from the size differences (and tail). Show them the picture of the human and dog skeletons on p. 8, having them find similarities and differences between the two animals. Are the functions of the skeleton the same or different in the dog and human? Note the difference in length of the femora and humeri between the human and dog and how awkward each looks when mimicking the natural stance of the other. Do other bones or sets of bones appear to be different to aid in natural stance and locomotion? How about the foot and hand?

2. Ask the students if they think fish or birds have similar skeletons to humans? Have them color in the forelimbs of the human, bird, and bat on the coloring book worksheet (link on p. 11). Have them make matching bones the same color across different species. What is similar and what is different? Show them the correct matching colored bones (second page of worksheet). How can it be that different animals (some that fly and some that walk on land) have nearly the same bones? Make sure to mention that not only does bone microstructure change to match loading

(Wolff's Law), but over time animals adapt and evolve such that their skeletons change to meet larger functional needs (walking on two or four limbs and flying. How about swimming?).

3. Ask the students if they think birds have the same internal structure in their bones as do land dwelling animals? Why or why not? What is the purpose of the bird skeleton? What drawbacks are there to the skeleton? Show them the picture comparing the internal structure of human and bird bone found on p. 9. Why do they think the bird bone is different on the inside (it's lighter, better for flight)? Do they think the bone is as strong? What is the biggest bird they can think of? Can it fly?

4. Ask the students if they think fish have hands. If they do, what part of the skeleton would it be? Do fish have fingers? Show them the fin-to-limb transition picture on p. 10. Again explain how form matches function. Talk about evolution. What is the purpose of the fish fin? What is the purpose of the fish skeleton (similar to other animals)? If big bones can make birds not be able to fly, what about making fish sink? Explain that air is much less dense than water and makes it easier to float. Explain that not all 'fish' have bones, such as sharks which have a cartilage skeleton (much lighter but soft and more like the popsicle stick than the chalk).

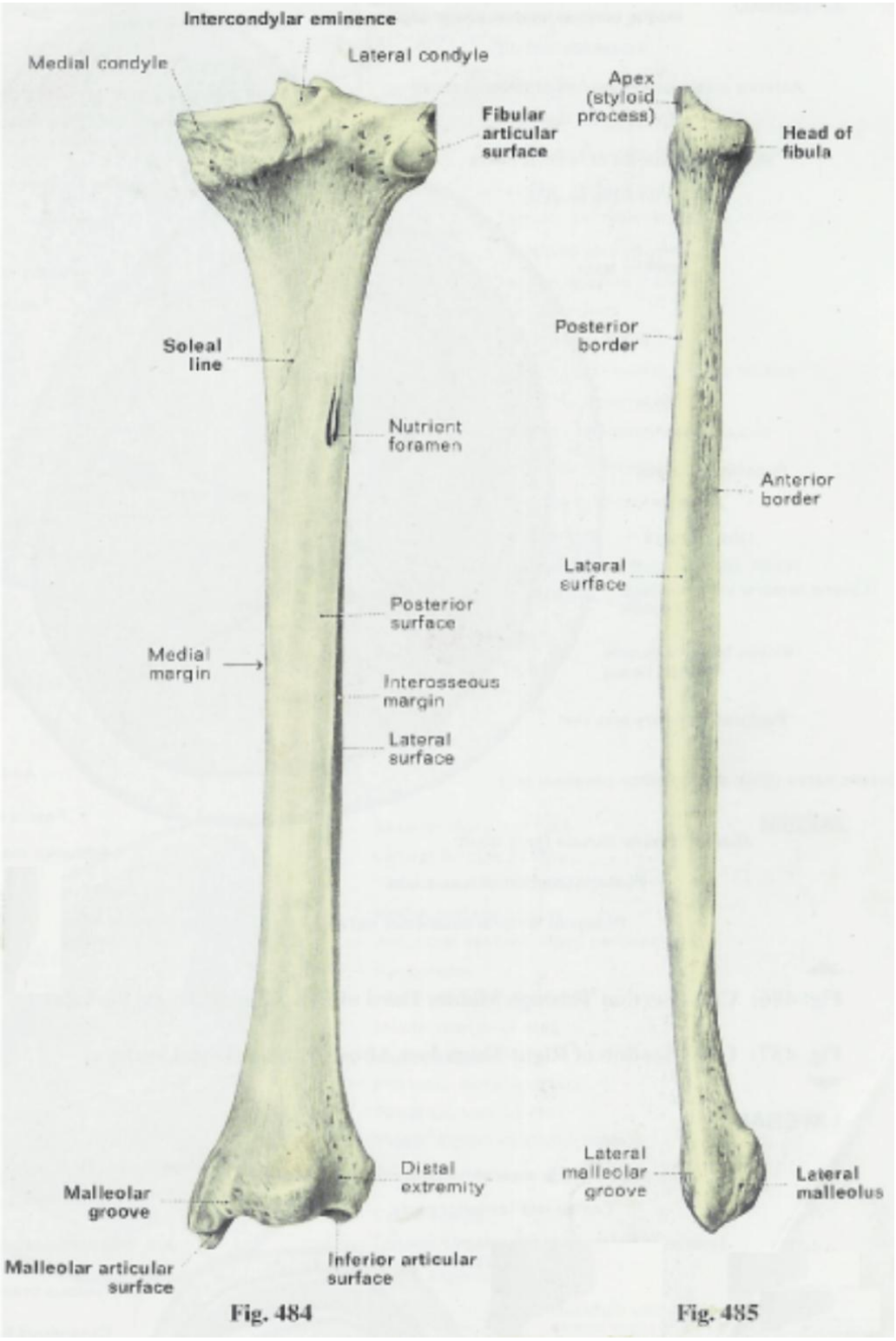
Reflection/Assessment (after day 1 or day 2)

Have the students create/design an alien that lives in another world or in outer space. Does your alien fly or swim? Does it live in a gravity-free environment or in a dense liquid? What would its skeleton and bones look like? Would they be more like chalk, the popsicle stick, or a mix of both?

Images

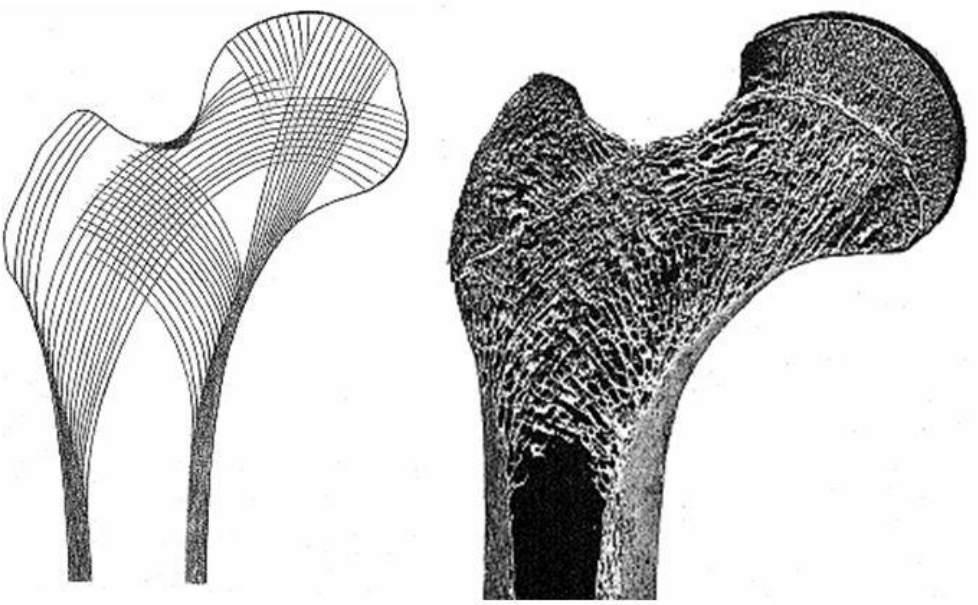
Long Bone Picture (tibia)

http://www.anatomyfacts.com/muscle/anatomyillus_files/image018.jpg



Wolff's Law Picture

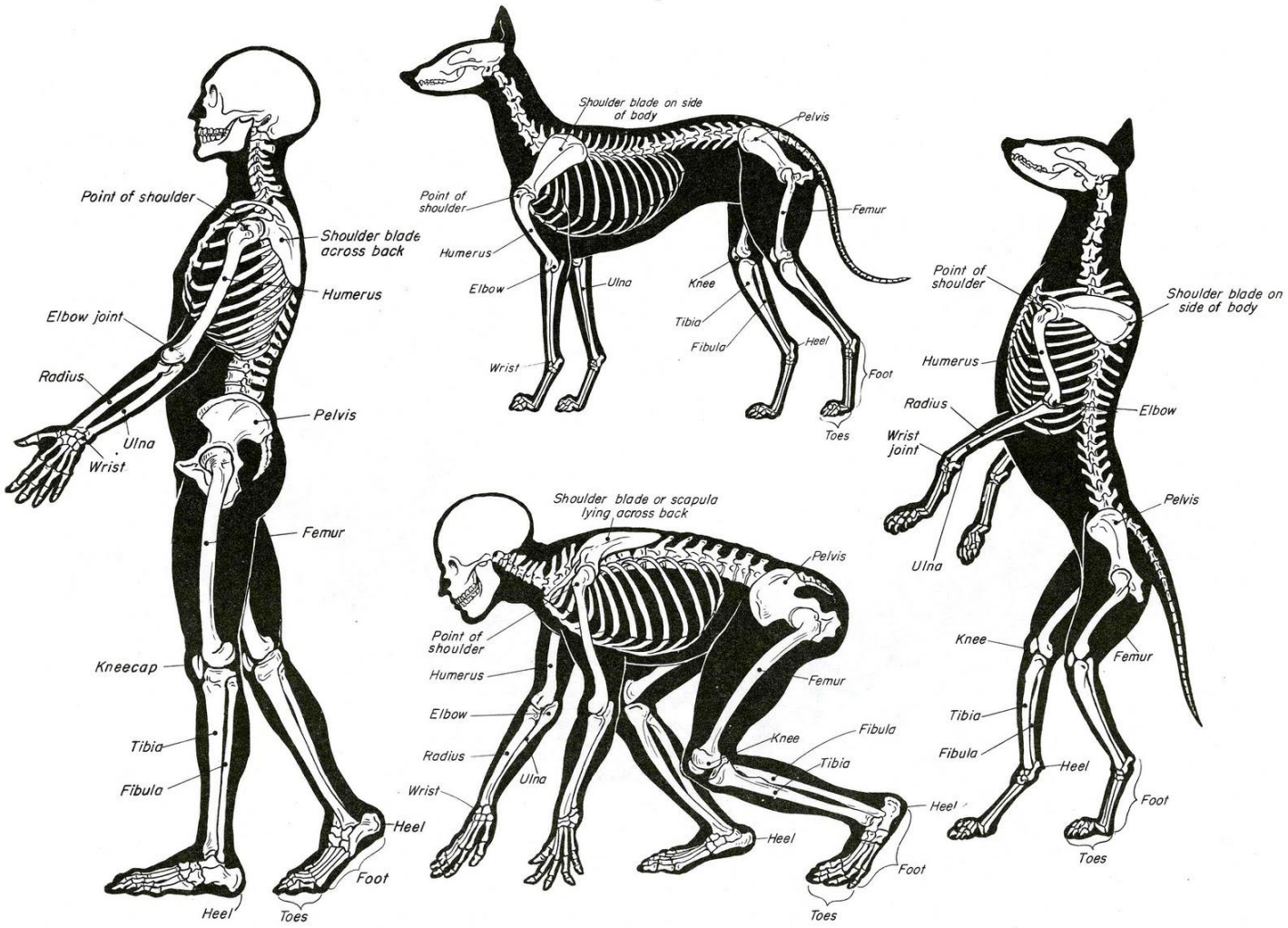
http://jwi.charite.de/fileadmin/user_upload/microsites/m_cc09/jwi/Institut/Julius_Wolff/Wolff_2originalBilder.jpg



This is the top of a femur, which articulates with the pelvis to form the hip joint. Note the lines of stress on the left diagram and the orientation of the bone struts (called trabeculae) within a real bone on the right. The struts are oriented in the direction of loading (stress) so that they are loaded in compression and can direct load evenly down the walls of the bone (like pushing on the ends of chalk, rather than bending it). This allows bone to be the most strong while minimizing bone volume and bone weight, which optimizes efficiency in terms of the amount of energy required for walking and other activities of daily living.

Comparing Human and Dog Skeletons

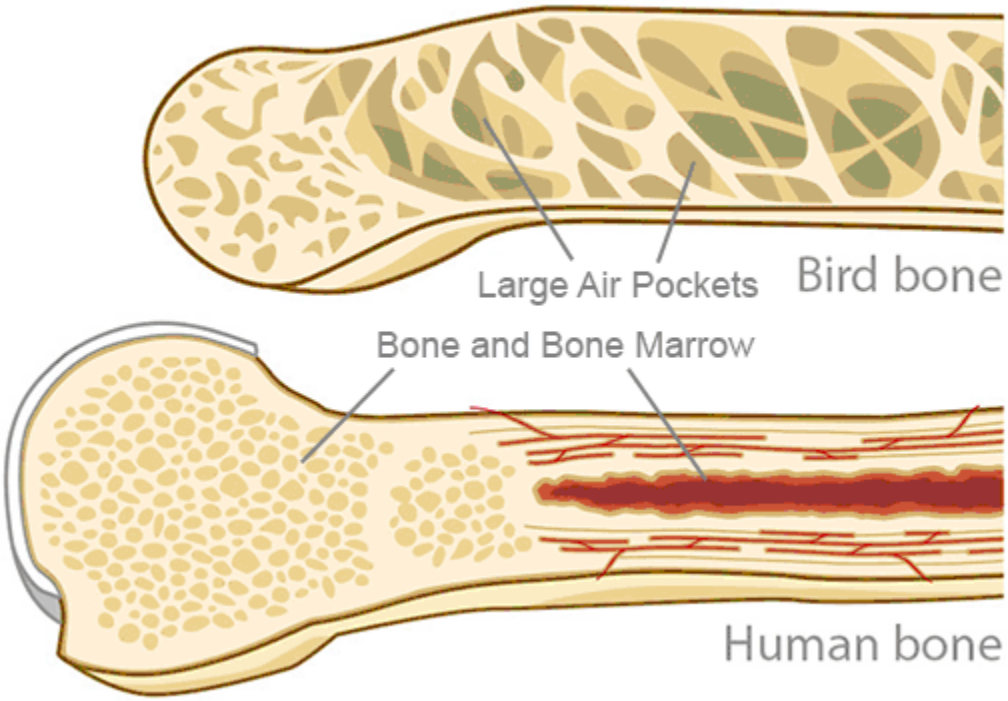
http://4.bp.blogspot.com/_oR7sYJzWZ1k/TM0WR4B3kyI/AAAAAAAAAaI/0wq23tT4q0g/s1600/humananimal+comparitive+anatomy.jpg



Have the student note the similarities and differences. Explain that the rat skeleton is also very similar to that of the human and dog.

Comparing Human and Bird Bone

https://askabiologist.asu.edu/sites/default/files/resources/articles/bats/human-bird-bone-comparison-540.gif



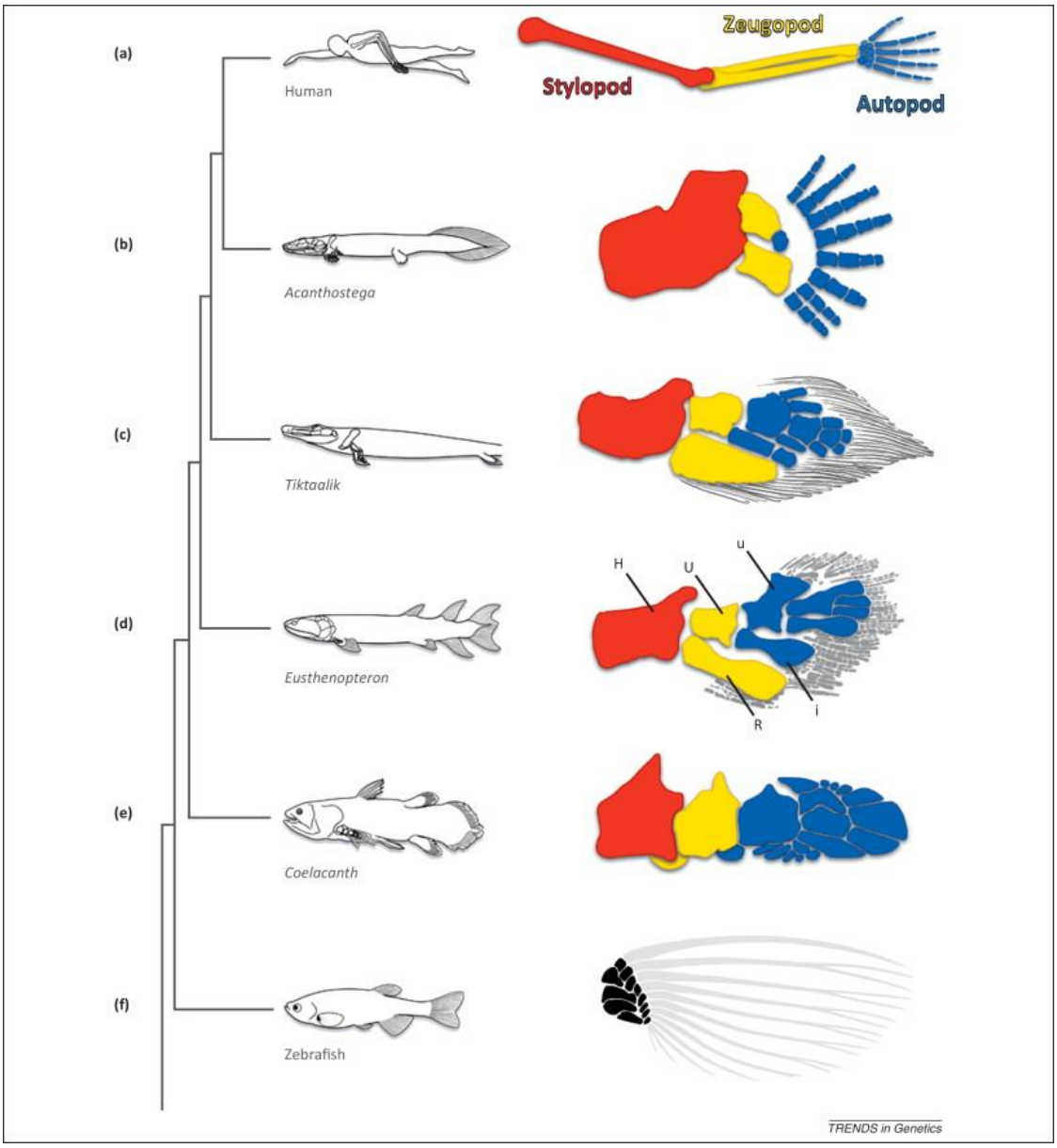
Which bone has more bone material (denser)? Which do you think is stronger? Which do you think is heavier? Why does the bird bone have less bone material? How does the structure of the bird bone help it fly? What would happen if the bird bone had the same structure as the human bone? What would happen if the human bone had the same structure as the bird bone?

Fin-to-Limb Transition

http://www.cell.com/cms/attachment/2007960439/2030638558/gr1.jpg

Image from

Igor Schneider, Neil H. Shubin, The origin of the tetrapod limb: from expeditions to enhancers, Trends in Genetics, Volume 29, Issue 7, July 2013, Pages 419-426



Interesting to show the students how different functions (fin swimming, arm and hand for quadruped and biped locomotion) have different forms that evolved from common ancestors. Most animals have the same types of bones that are merely different in shape or configuration. See the coloring book worksheet in the appendix.

Appendix

Sewer Rat in the Toilet Video:

http://video.nationalgeographic.com/video/news/150811-rats-toilet-swimming-vin

This video shows how rats can swim through your sewers and enter your home through a toilet. Or rather, it shows how rats have hinged ribs that allow them to compress their body to fit through tight spaces. Do humans have the ability to compress their rib cage (no)? Humans and rats have nearly identical bone structures, but subtle differences like this exist and make each species unique.

Comparative Bone Structure Coloring Activity

https://askabiologist.asu.edu/sites/default/files/resources/coloring_pages/pdf/AAB_bats_coloring_page.pdf

Note how different bone groups are retained across different species, despite the fact they are used for different activities (flying vs. manipulating objects). Be sure to remind the students of the internal differences between human and bird bones. What do they think bat bones will look like inside (they are more similar to birds than human)?