Build-A-Bird (a lesson in bird anatomy)

By Sarah Winnicki (MSc student, Kansas State University)

Understanding bird anatomy starts with understanding the history of birds. The ancestors of modern-day mammals and modern-day birds split approximately 252—315 million years ago; at the time, earth was covered in mosses that grew to the size of trees, giant dragonflies with wingspans over 2 feet wide, and many sharks. Because birds and mammals are related, they share many similar features, like a four-chambered heart and similar skeletons. To the best of our knowledge, those early bird-ancestors evolved into raptor-like dinosaurs (think velociraptors!) with grasping hands, into gliding-like reptiles with feathered wings, and ultimately into modern-day birds. The **external and internal anatomy of all modern birds is ultimately a product of evolution for flight**—even flightless birds like ostriches or penguins evolved from ancestors capable of flight!

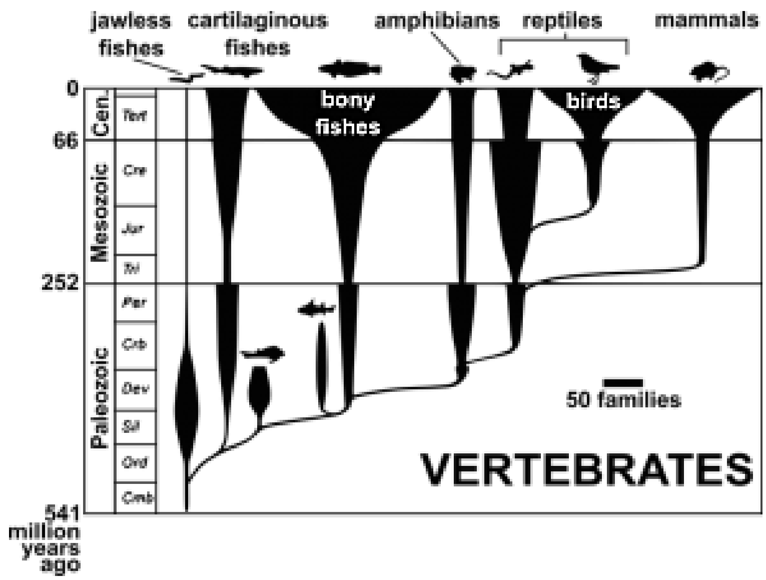

Figure 1: Evolutionary tree of vertebrates, with the animal groups at the top and the number of years on the right, with modern day at the top of the figure. Note the split between mammals and birds at ~252 million years. Image by David Lin, Wikimedia Commons

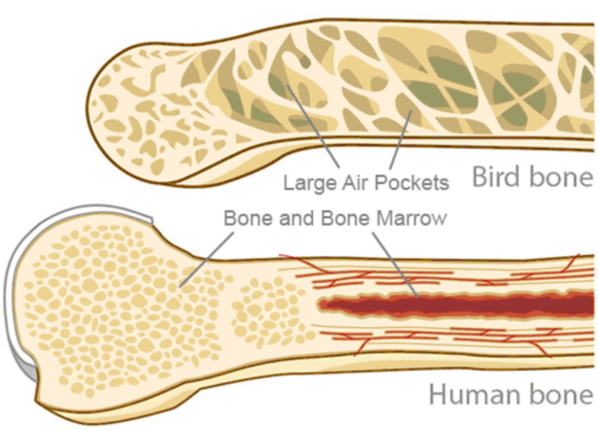

Figure 2: Internal anatomy of a bird bone (top) and human bone (bottom). Note the large air pockets in the bird bone. Image from https://askabiologist.asu.edu/human-bird-and-bat-bone-comparison

Flight is complicated and energetically expensive—to fly like a bird, human bodies would need to have 80-foot-long wings! Therefore, birds' anatomy evolved to reduce their weight, support large wings, and protect birds during flight. **Heavy structures like teeth have been totally lost**—birds instead have grooves and spines in their beaks and mouths to help capture and swallow food. Mammal bones are heavy and often too weak to support the body during flight, so **birds have modified bone structures that are dense, thin, and have so many large air pockets they often look hollow.** We call these air-filled bones "pneumatic bones," and humans have some too; our facial bones have large holes we call the sinuses!

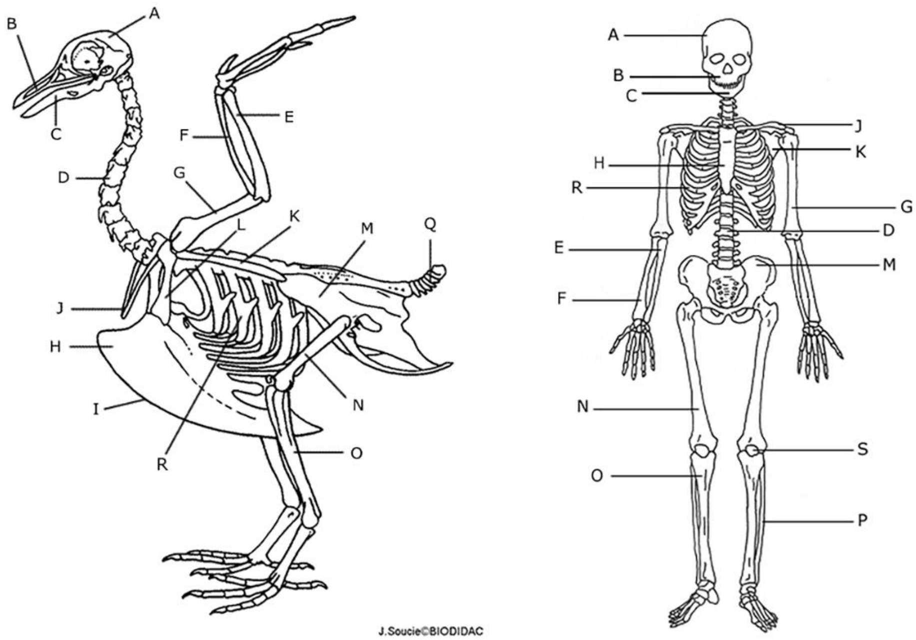

Figure 3: Bird and human skeleton with homologous features labelled. Especially note the clavicle/furcula (J), the sternum/keel (H/I), the fused pelvic region (M), and the structures humans don't have (tail Q, coracoid L, which is a small structural support in humans that is much larger in birds). Which other bones can you name?

In addition to modified bone structure, **birds also have fewer bones total because many of their bones are fused together**! Birds' collarbones (or clavicles) are fused together to form a structure known as the furcula. This furcula is the "wishbone" that is broken for good luck during a turkey dinner! Most of birds' vertebrae are fused, making a strong rigid backbone that provides support for the wings during flight. The lowest vertebrae are joined to the pelvis, giving birds a strong platform to facilitate walking around and to absorb the shock of landing. Their legs are modified too—what looks like a "knee" on a bird is actually homologous to our ankle, and the structure that makes up the lower half of their legs is actually the tarsus bones we have in our feet! Birds' true knees are inside their body, so we cannot see them on living birds. Not all bird bones are smaller or fused, however. As much as 40% of the bird's weight is attributable to their large flying muscles (homologous to our pectoral muscles), so the bird's sternum has a modified structure known as a "keel" to anchor and support these humongous muscles.

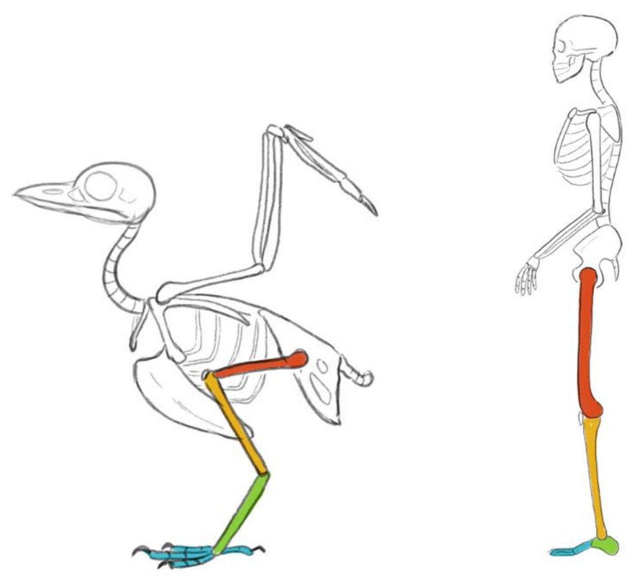

Figure 4: Bird and human skeleton with homologous leg structures labeled. Note that the most prominent visible joint on a bird is the ankle and the lower half of the leg is actually a modified foot bone (green)

Unlike bats, which fly thanks to modified skin structures between their long fingers, **birds' hand and finger bones are reduced**. Their thumb phalange is at the top of the wing (their wrist), forming a structure called the alula that helps them fly steady in turbulent conditions. The rest of the phalanges are reduced to a handful of digits. This modified hand structure means that **the lift generated by birds' wings comes not from the skeletal structure, but from feathers**! Feathers evolved from scales and likely covered some of your favorite dinosaurs, like raptors and relatives of *T. rex*! Feathers have a distinct advantage relative to bats' skin wings; birds can replace their feathers and do so regularly (at least once a year), so any wear and tear that they take from flying will not reduce their ability to fly long-term like a wing tear would in a bat.

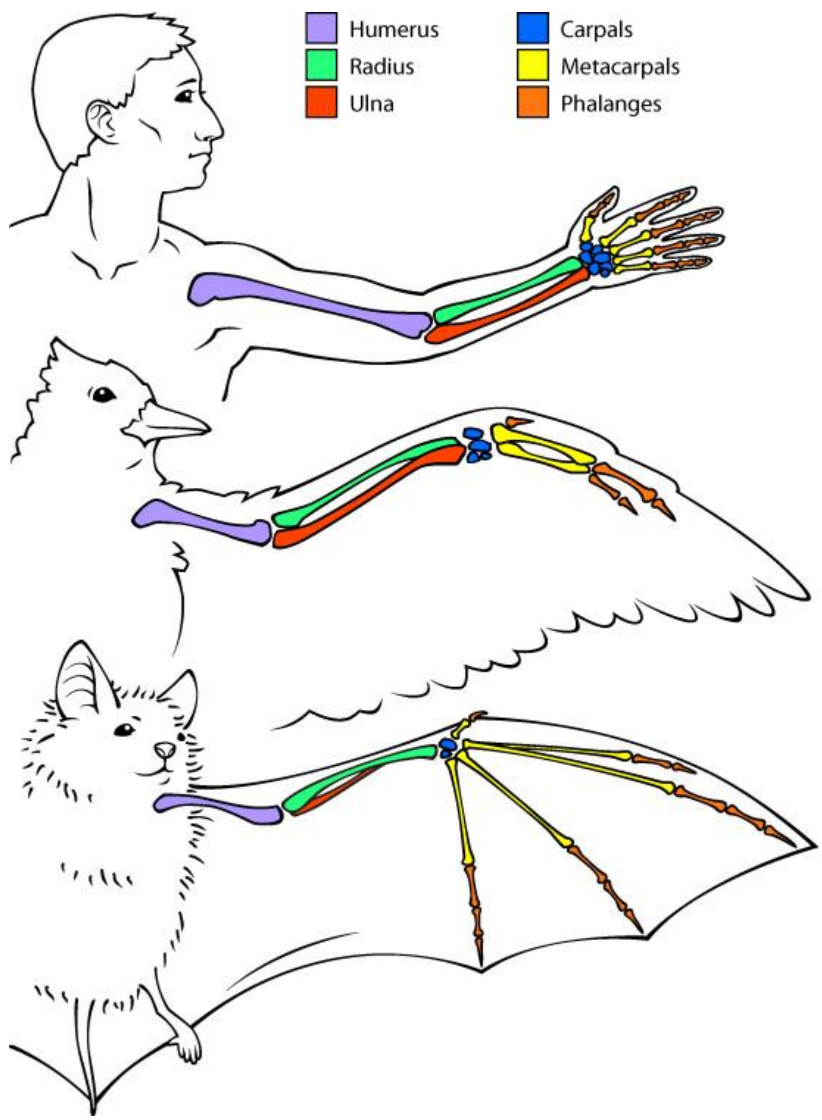

Figure 5: Diagram comparing the homologous structures in a human arm (top), bird wing (middle), and bat wing (bottom). Note the reduction in the number of bird metacarpals (yellow) and phalanges (orange). Image from https://askabiologist.asu.edu/human-bird-and-bat-bone-comparison

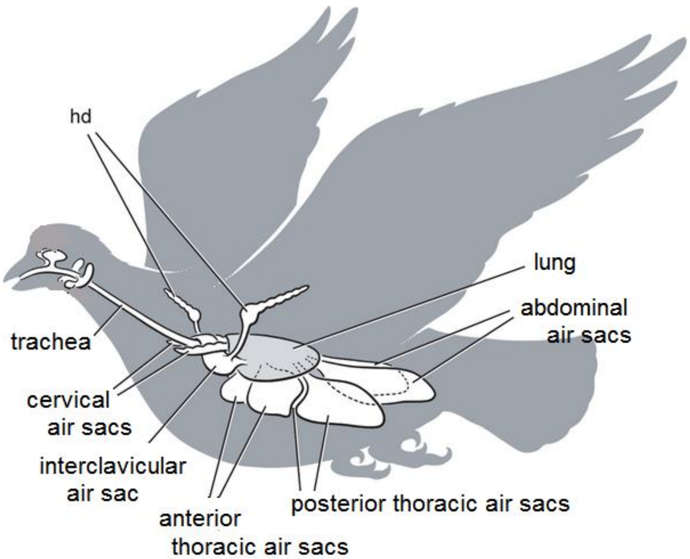

Figure 6: Image showing the location of the lungs (shaded) and air sacs in a bird. These air sacs keep the bird light and allow them to breathe more efficiently From: http://people.eku.edu/ritchisong/birdrespiration.html

Birds also have neat **adaptations to their organs to reduce weight and transport the amount of oxygen necessary to supply muscles during flight.** We mammals breathe in to bring oxygenated air into our lungs, allow the air to interact with capillaries in our lungs and perform an air exchange (oxygen into blood, carbon dioxide out passively through diffusion), and exhale to push the air out of our lungs. This is surprisingly inefficient—the air we exhale still contains oxygen, and our blood is never saturated with oxygen because the capillaries reach equilibrium with the surrounding air (meaning there would be as much oxygen in the capillary blood as there is in the air). Birds are much more efficient. They breathe in air like we do, but instead of going into the lungs and out again the **air flows through the lungs and a series of air sacs spread throughout the body**. Air is pushed through this respiratory system as the bird inhales again, meaning that a single "breath" by human standards stays in the body through two bird "breaths," since the bird inhales twice! These air sacs also help to keep the bird light.

As the air moves through the lungs, it does so in a way that facilitates "cross-current exchange." In this system, the blood does not come into contact with a capillary and exchange air until equilibrium is achieved all at once. Instead, the air flows past the capillary as the capillary flows in the opposite direction. Therefore, when the capillary first enters the lungs, it is oxygen-poor and interacting with air that has already been oxygen depleted but still contains more oxygen than the capillary, so oxygen passes into the capillary in order to reach equilibrium. As the capillary continues to travel through the lung, it comes in contact with fresher and fresher oxygenated air—during the entire route through the lungs, the capillary always has a lower oxygen content than the air it is interacting with, so oxygen always flows from the air into the capillary to reach equilibrium. With this cross-current exchange, birds can pull more oxygen out of the air than mammals, making their breathing more efficient!

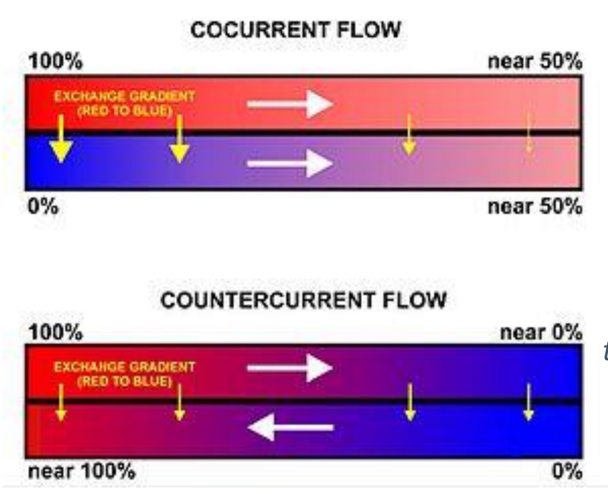

Figure 7: Cocurrent flow (which occurs in mammal lungs) leads to air (top bar) moving from 100% oxygenated (on left) to 50% oxygenated (on right) while blood (bottom bar) moves from 0% oxygenated (on left) to 50% oxygenated (on right) through diffusion. Countercurrent flow (which occurs in bird lungs) leads to air (top bar) moving from 100% oxygenated (on left) to 0% (on right), while blood (on the bottom) moves backwards alongside the air, starting at 0% (on right) and moving to near 100% oxygenated (on left) because along the way there is always more oxygen in the air than the blood. Image from: https://en.wikipedia.org/wiki/Gas_exchange

Birds make use of this cross-current exchange technique in other ways as well, such as transferring heat. Birds' veins and arteries in their legs are very close together. When a bird stands on ice, the blood coming through the arteries from the warm heart cools in the foot, which in a human would mean cold feet. In birds, when the cool blood re-enters the leg in a vein, that vein comes very close to the warm artery, warming the vein blood up so the heart is not shocked by the cold and cooling the artery blood down so the cold foot is not shocked by the warm blood!

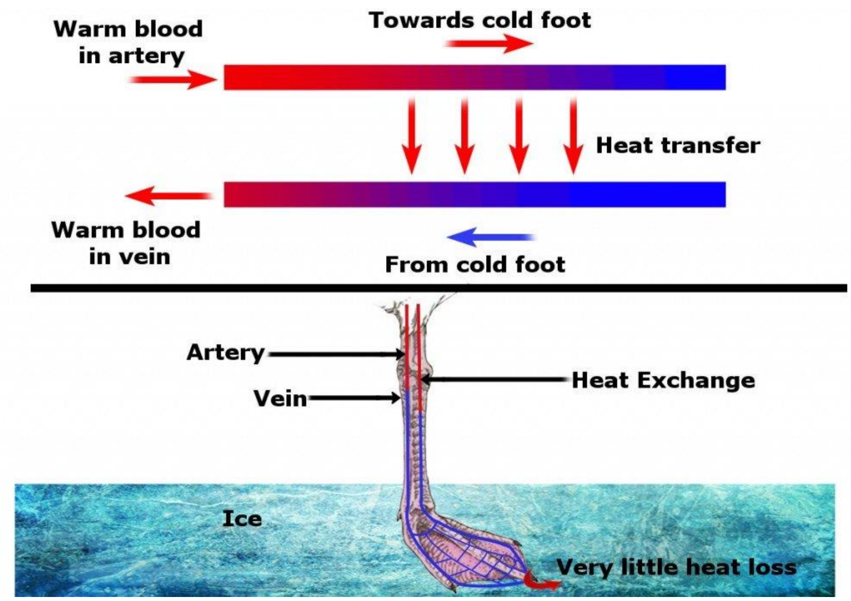

Figure 8: Another example of cross-current exchange. Instead of oxygen, here heat is being transported between an artery and a vein in the bird's leg. Warm blood in the artery (top) moves in the opposite direction of cold blood coming up from the foot in a vein (bottom). The heat transfers from the artery to the vein, cooling the artery blood as it moves down into the cold feet of the bird (preventing heat loss from the foot) and warming the blood as it moves up the vein towards the heart. Image from: https://www.thinglink.com/scene/880844954677542913

Birds are also **adapted to store little water**, which is heavy. Mammals sweat to cool down, but birds do not—they pant to cool down without losing water. When mammals digest food, the nitrogen-containing wastes that would harm their body are dissolved in water and passed out of the body as urine. Birds do not add water but instead pass that waste out as a similar compound called uric acid. Making uric acid takes more energy than making urine, but the water savings make birds significantly lighter. Some birds' uric acid is so potent it can ruin ecosystems and destroy human structures like docks (check out the bird known as a cormorant)!

Figure 9: Cormorants (a type of sea bird) on rocks showing off their uric acid stains. This very acidic waste product will, over time, break down rock and human-made materials, like boats. Image from: http://cimioutdoored.org/wp-content/uploads/2015/01/IMG_9049.jpg

Figure 10: An adult Brown-headed Cowbird, photo by S. Winnicki

I am interested in not only the evolution of all birds' anatomy, but also in the continued evolution of individual species. Why do some living bird species have larger legs than others? Why are beak shapes different? In many ways, birds' anatomy and body shapes can be linked to their habitat and food: birds that wade in water have long legs, raptors that eat fish have sharp tearing bills, etc. My research goes even further, asking why individuals within the same species are different and how those differences arose. Why do some Grasshopper Sparrows have larger bills than their neighbors? Why do some Eastern Meadowlarks weigh more than others? How is evolution acting on those individuals—are the larger meadowlarks surviving more frequently (driving the evolution of larger meadowlarks overall) or are the smaller meadowlarks surviving more frequently (driving the evolution of smaller meadowlarks)?

To begin to answer these questions**, I look at the ways in which different environmental drivers affect the growth and development of these birds' bodies.** Birds grow very fast—if humans grew as fast as my sparrows, human children would weigh 70 pounds and would measure 4-foot-tall when they were just one week old! The ways birds develop as nestlings will ultimately affect their bodies as adults, potentially affecting their chances at surviving and reproducing. We know from past research that nestling growth is altered by many aspects of the environment. Birds that receive more food will grow faster than birds that receive less food. Female birds in areas of high predation risk (lots of predators nearby) can alter the hormone levels in the eggs they lay, producing nestlings that grow faster to be able to avoid predators sooner. **What we don't know, however, is how brood parasitism affects nestling growth.** Brood parasitism is a neat reproductive strategy wherein birds don't build their own nest and raise their own nestlings, but rather lay their eggs in other birds' nests and force those host birds to raise those parasite babies. In North America the most common brood parasite is the Brown-headed Cowbird, which parasitizes over 200 different bird species! What is the effect of these competitive cowbird babies on the host nestlings' development?

Figure 11: On top, a Speckled Kingsnake at a nest with Dickcissel host eggs (blue) and cowbird parasite eggs (speckled). On bottom, a large hungry cowbird nestling (on left) in a nest with Dickcissel host nestlings (right). We know predators affect the growth of nestlings, but how does the competition with cowbird nestlings? Photos by S. Winnicki

Figure 12: Common sights at the Konza Prairie include lovely sunrises (left) and wild bison (right). Photos by S. Winnicki

We work at the Konza Prairie Biological Station in Northeast Kansas, searching every day of the week from April-August for nests of three cowbird host species: giant Eastern Meadowlarks, medium-sized Dickcissels, and tiny Grasshopper Sparrows. We keep track of the number of host and parasite nestlings in each nest and take over 30 measurements of their growth every other day, including measurements of their beak, feathers, tarsus, wings, and mass. When the nestlings leave the nest, **we compare the growth patterns of birds without and without cowbirds in their nests.** So far, we know that having a hungry cowbird in the nest slows down the growth of medium-sized birds and forces the other species to make trade-offs. Parasitized nestlings grow their skeletons faster than the same species in a nest without a cowbird parasite, likely to compete with the cowbird for food, but in order to do so they have less energy to devote to the growth of their feathers and eyes. How do these trade-offs affect the body of these species in the presence of cowbird parasites? Will their skeleton and feather structures ultimately change over many generations of parasitized nests? What sort of internal mechanisms (hormone levels? fat storage and transport?) ultimately allow them to change their growth in the presence of cowbirds? Hopefully our continued work on these prairie babies will help us start to unravel our questions about cowbird parasitism, nestling growth, and bird anatomy! For more information about our research, check out www.sarahwinnicki.com, email me at skwinnicki@ksu.edu, or follow project #prairiebabies on my Twitter @skwinnicki.

Discussion Questions:

1. Superheroes like Superman and Captain Marvel are capable of flight. If you could alter human anatomy to produce a body capable of flight, what modifications would you make?
2. Why might birds have evolved the ability to fly in the first place?
3. Now that they can't fly, why do birds like penguins still retain body parts evolved for flight, like a big keel bone?
4. Some mammals, like desert mice, produce uric acid like birds. Why might these species produce uric acid instead of urine like other mammals?
5. Cowbird nestlings grow very quickly, are often larger than host nestlings, and compete for food by begging for parents' attention. Birds can prioritize the growth of one body part over others. Which body parts could birds choose to prioritize to compete with the cowbirds, and why?
6. Why study anatomy in the first place? What can we learn from doing so? What qualities would make for a good anatomist or evolutionary biologist (a person studying anatomy or the evolution of bodies)?