Teaching Louisiana Students About Evolution by Comparing the Anatomy of Fishes and Humans

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Students in my Ichthyology class sometimes complain I talk about evolution too much: but my Evolution class never complains that I'm talking about fish too much. I think in the latter case I make an argument about evolution that they normally don't hear: The human body sucks—and because most of our body parts originated in an aquatic environment, these body parts suit fishes much better. For students that have the preconceived notion that humans are at the top of some imaginary evolutionary ladder, the fact that their professor is arguing that fishes might be better than humans—in anything—is perplexing. But this little seed of disbelief starts them on the path to understanding that evolution results in a Tree of Life where humans are just a single tiny and young branch and not a "Ladder of Life," with humans sitting firmly on top far removed from the rest of the animals.

I have taught Evolution several times now at Louisiana State University (LSU). I must admit I was pretty scared the first time I taught it. I do not know if I expected students to get angry or throw holy water on me, or what—I just remember working very hard to try to make clear arguments about science and theory. I also tried to make it entertaining—and at times

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funny, these being my only tools for making the subject matter and myself approachable. Students are often very intimidated taking an evolution class—they think that their personal beliefs or opinions will be ridiculed or attacked—just as the professor might think the students will push back against science that tries to explain their origins. It makes for a potentially tense standoff. I find humor helps alleviate the tension. Unfortunately—to most 20-year-olds—no professor is very funny.

Box 1 Humorous Videos for Teaching Evolution Using humor to teach is a well-established and very effective means of getting messages across to students of all ages. For instance, there are numerous YouTube videos that utilize humor and creativity to teach or discuss evolution or evolution principles. A few of our favorites include the many well-produced videos of Baba Brinkman from his album Rap Guide to Evolution (https://www.youtube.com/channel/UCz9Qm66ewnY0LAlZlL4HK9g), who has been kind enough to come down South and perform his shows live several times as well, and many of the video podcasts of Hank Green's SciShow (https://www.youtube.com/channel/UCZYTClx2T1of7BRZ86-8fow), who is from Birmingham, Alabama. (C.D. Lynn)

My evolution class is for upper-division students, mostly juniors. These kids love Comedy Central, so early in my first lecture (after talking about exams and schedules) I show a three-minute clip from a *South Park* episode about evolution. Luckily, the video works to break any tension and sets up the entire first lecture—and really the entire course. Before I start the video, I preface it by saying, "This is how NOT to teach evolution." This infamous video clip shows the *South Park* fourth-grade kids learning about "evolution" from their foul-mouthed schoolteacher Mrs. Garrison (who is usually a Mr. but not that season—let's not go there). Mrs. Garrison starts off by saying, "Now I for one think evolution is a bunch of bull-crap, but I've been told I have to teach it anyway. It was thought up by Charles Darwin, and it goes something like this…" She then starts pointing at a poster straight from Neil Shubin's wonderful *Your Inner Fish*.[1]

[1] Shubin, N. 2009. Your Inner Fish: A Journey into the 3.5-Billion-Year History of the Human Body. Vintage Books, New York.

It includes trilobites and fishes, even showing *Tiktaalik roseae* the transitional fish/tetrapod fossil moving up from the water onto land along with varying stages of tetrapod evolution until you get to modern humans. Mrs. Garrison says, "In the beginning, we were all fish, swimming around in the water…one day a couple of fish had a [mutant] baby, and it was different so it got to live." She goes on to make several vulgar remarks about fish evolution all the way up to humans—the students eat it up. I'm never sure if it is the clip that they like or that their professor is showing them something so inappropriate. But there is method to my madness.

I recently learned that other evolution professors have shown this video as well, and one at another institution got quite the reprimand. Apparently, a student told their mother who called the Dean to complain. The Dean gave a stern warning to the professor who promised not to show it again. I think something about my approach might make the use of the video more informative and fun rather than just shocking. Every student in the class knows about, and probably watches, every episode of *South Park*. If they had watched that particular episode before, they probably didn't realize the significance of what Mrs. Garrison was saying. So I ask them, "What's wrong with how she is explaining evolution?" I have the 100 or so students break into groups and do a "Think-Pair-Share." What a buzzkill, right? Not really, students just saw a video from a crude TV show, and their college professor is asking them to critique it. (What is this UCLA?) I am always surprised by the responses because the answers display how competent the students already are in understanding natural selection without me having introduced any evolutionary biology to them yet.

Part of the reason for the competent responses is that natural selection is sort of an intuitive concept; and they already had many biology classes by their junior year. Many of those classes teach some or many core concepts of evolution. In past classes some students answered, "Mrs. Garrison is explaining evolution wrong because her version is too simple," or "It's wrong because mutations don't happen that way." By asking them to elaborate on these answers, we get to core concepts like why point mutations (single base-pair changes) rarely lead to major phenotypic differences, and why hybridization isn't a major force in evolutionary change. Still, I don't usually get the complete answer I'm really looking for: "It's wrong because evolution is not directional. We came from fish, but fishes are still evolving, as is everything else; humans are not the end goal of evolution." I try to explain that natural selection isn't making organisms more complex—

it's just the process for selecting the best-fit individuals for the current environment.

I then ask the students what the directional view of evolution implies:

Box 2 Hybridization as an Evolution Mechanism: Is That a Tion or a Liger? Hybridization or cross breeding is the mating of individuals from different species or, according to Darwin, varieties within species. Darwin puzzled over the role hybridization might play in evolution because, as was well known in Darwin's time, some hybrids are reproductively viable and others are sterile or have reduced fertility. However, Darwin was not aware of the pre- and post-zygotic barriers involved in some hybridization. Pre-zygotic barriers, or reproductive isolation, occur before breeding, include temporal or habitat isolation (species don't occupy same area at same time or at all), behavioral isolation (species don't recognize reproductive cues of others), mechanical isolation (species genitals don't fit each other), or gametic isolation (sperm can't fertilize egg). Post-zygotic barriers, those occurring after fertilization, include zygote mortality or inviability or hybrid sterility (e.g., mules). Some fun examples of hybrid animals are the hinny (female donkey/male horse), zeedonk (zebra/horse), beefalo (bison/cow), pumapards (puma/leopard), jaglion (jaguar/lion), liger (lion/tiger), and cama (camel/llama). These most often occur in zoos where otherwise geographically isolated species are put together. (C.D. Lynn)

"That mammals came from reptiles and that humans are perfectly evolved." Another student answers: "It implies all other organisms are lesser than humans." Indeed it does. I ask, "Are humans perfect?" Silence. Many religious texts and even Aristotle thought we were (or close to it)—that's why Aristotle put us on top of the Great Chain of Being/*Scala naturae* just below gods and angels. Religious folks often argue our perfection because we are a reflection of an infallible creator. But if god created all these creatures, why would they be inferior. Is a panda less perfect than a human? Or a snake? Or a fish? If they are inferior, is god flawed? Pretty heavy stuff for the first day of class.

On this first day of class, I make sure the students understand that evolution leads to a bushy Tree of Life and try to make them forget the idea that evolution is a straight line with a single-celled bacterium on one end and a human on the other. I always ask them to tell me why the straight arrow view of evolution is wrong. I don't usually get many volunteers to answer this question.

Time to lighten it up again. How much does the human body suck? It sucks a lot and in many ways. Let's move backward down the Great Chain of Being—are we even the best mammal? We are mammals after all, as I remind the students; we are milk-producing hairy animals. Yes, we humans have giant brains and the consequence is we have babies with huge heads. Perhaps, unfortunately for us, we are also placental mammals, giving birth to live young nurtured in the womb that escape by squeezing through a narrow passageway. Marsupials, on the other hand, have a far better system for giving birth. They are pregnant for just a few weeks and give birth to a tiny underdeveloped fetus. A fetus that makes its way into the mother's pouch, where it nurses until it is big enough to survive on its own. Ask a human mother what kind of baby she would have chosen to give birth to—a giant-headed baby or something more reasonably proportioned. This reasonably sized marsupial baby causes little pain at birth and will develop in a convenient fleshy pocket with nipples in it? Imagine if humans could do that—no need to awkwardly carry your baby in your arms or risk getting kicked out of a department store for breast feeding.

But the major contrast for this first evolution class is between humans and fishes, my area of expertise as an ichthyologist. We return to Mrs. Garrison's *Tiktaalik* poster—what did she say right about evolution? Yes, we came from fish: All tetrapods did. But we didn't evolve out of a series of hybridization events or giant leaps through mutations. Evolution, as Darwin explained, is most typically quite slow and gradual. I explain the short hand for Darwin's theory of evolution via natural selection, "descent with modification." I tell them that Darwin states quite lucidly in *Origin of Species*,[2] "All the organic beings which have ever lived on this Earth have descended from some one primordial form." I ask the students, "How would we scientifically test that statement?" Usually they say through DNA analysis. Yes, we are all linked, all us living beings on Earth, through our DNA, and we can examine this great Tree of Life using that evidence,

[2] Darwin, C. D. 1859. On The Origin of Species By Means of Natural Selection or the Preservation of Favoured Races in the Struggle for Life. John Murray, London.

as well as morphology, behavior, and every heritable character. Following Darwin's lead in *Origin of Species*, I use dogs as he used pigeons to start off his arguments about natural selection. I show a picture of my French Bulldog, Bessie. Where did Bessie come from? Did I snatch her from the wild? Are there roaming packs of Frenchies in the Pyrénées? I wish, but no. They were bred to have these odd characters of a short snout and fleshy face. Breeders selected those characters, just as nature selected characters among all species leading to their evolution. Darwin starts off the *Origin of Species* describing how pigeon breeds were similarly selected by breeders to have particular traits (e.g., feathery legs, odd head crests) in a similar way, just as all dogs descended from wild wolves, and breeders made them into Great Danes, shih tzus, or poodles. I then show the class a phylogeny of dog breeds and then the bigger Tree of Life (like the most recent one from Hug et al.[3]). I explain where we are in that tree (hinting at a big reveal to come). Here are humans, in the little branch of primates, within the group of 5000 other mammals. Here are the reptiles, which once included all the dinosaurs also include all 10,000 species of birds. Mammals and reptiles are each other's closest relatives, descended from the same ancestor at the same time. Add all the mammals and all the reptiles and amphibians together, and you get about 30,000 species. How many fish species are there described today? More than 45,000 species, that's right—more than all the other vertebrates combined. Where are fishes in this Tree of Life? They make up most of the vertebrates, but that isn't very much compared to the vastness of all the life on Earth. But look at the scattering of fishes in that tree, they are not each other's closest relatives are they? What is a fish? Hmmm…more on that later.

The hardest thing to get out of the head of students is that evolution isn't linear. No, it isn't: Fish → Amphibians → Reptiles → Mammals. Evolution isn't leading up to humans. But I don't blame them for thinking that way; from Aristotle in 300 B.C. to A.D. 1858, nearly everyone thought about life on Earth as a hierarchy.[4] It took Darwin to get us to do some real tree thinking in an evolutionary context. His only figure in

[3] Hug, L.A., Baker, B.J., Anantharaman, K., Brown, C.T., Probst, A. J. Castelle, C. J., Butterfield, C. N., Hernsdorf, A. W., Amano, Y. Ise, K., Suzuki, Y., Dudek, N., Relman, D. A., Finstad, K.M, Amundson, R., Thomas, B. C., Banfield, J. F. 2016. A new view of the tree of life. Nature Microbiology 16048: doi:10.1038/nmicrobiol.2016.48.

[4] Leroi, A.M. 2014. The Lagoon: How Aristotle Invented Science. Viking, New York.

the *Origin of Species*[5] was an evolutionary tree. Of course people were tree thinking before then too,[6] but they lacked the context that Darwin provided with his discovery of natural selection.

So why aren't humans the pinnacle of evolution? First of all, there is no pinnacle. Every species is still changing and evolving; they don't have a goal of one day becoming humans. Many of us teaching evolution forget how prevalent this idea remains. During a hearing to repeal the Louisiana Science Education Act (which despite the name, actually promotes the teaching of creationism in public schools[7]), a Louisiana State Senator, Mike Walsworth, asked a local high school teacher who just described Lenski's[8] multigenerational *E. coli* evolution study, if any of those bacteria evolved into a human. For the senator, the fact that *E. coli* wasn't turning into humans meant that there was no evolution. Of course the informed person would know that evolution in this context is a much more subtle change. It's a gradual change in the population of bacteria from one form to another form but remaining the same bacterial species during those few thousand observed generations. Louisiana politicians like Mr. Walsworth, and former governor Bobby Jindal (who signed the anti-evolution Louisiana Science Education Act into law), so misrepresented evolution that LSU professors decided we need a real change in how we teach biology majors. The Evolution course was made part of the core curriculum (and therefore mandatory) for all biology majors in 2011. We didn't want another biology major (as Bobby Jindal was—although he went to Brown University) leaving the program and not having a core understanding of evolution.

For my students, learning that we are not the pinnacle of evolution usually leads to an understanding that we were not designed by an infallible creator during a special creation event. If we had been we wouldn't have so many terribly designed body parts. Like what, you ask? There are many examples. But I like to show the context of why these features are so crappy in humans and so much better functioning in other animals—par-

[5] Pietsch, T.W. 2012. Trees of Life: A Visual History of Evolution. Johns Hopkins University Press, Baltimore.

[6] Kopplin, Z. 2013. Activists Re-Launch Campaign to Repeal Louisiana's Creationism Law. http://www.repealcreationism.com/ [March 18, 2013].

[7] Lenski, R.E., Rose, M.R., Simpson, S.C., Tadler, S.C. 1991. Long-term experimental evolution in *Escherichia coli*. I. Adaptation and divergence during 2000 generations. American Naturalist 138: 1315–1341.

[8] Center for Disease Control: http://www.cdc.gov/heartdisease/facts.htm

ticularly in fishes. Because, it turns out, Mrs. Garrison was right: "In the beginning we were all fish, swimming around in the water." And it is that aquatic habitat where most of our visceral, skeletal, and nervous systems evolved—and some of them haven't really adjusted well for life on land.

Let's start with our hearts. This most vital organ for our survival is supplied oxygenated blood by the coronary arteries, one for the left and one for the right side. A blockage to either one will cause a heart attack—a.k.a. "a coronary"—and you are toast. Heart disease is responsible for the death of one in four Americans.[9] How do fish do it better? First of all, our asymmetrical hearts aren't even shaped like those cute symmetrical Valentine's Day hearts. But a fish's heart is—at least more so—with just two chambers, one atrium and one ventricle. A fish's heart is close to the head and near the points of oxygenation—the gills. Blood travels through a large aorta to all the major organs and returns to the heart as cardinal veins and a large bulbous arteriosus or sinus venosus. Oxygen is also supplied to the heart through a coronary artery, but the distance traveled from the point of oxygenation is very short. All of the gas exchange is also taking place between the gills and the environment, in one neat step rather than multiple awkward steps. The simple design of fish bodies and their circulation system is a thing of beauty and the reason why we use dogfish sharks in anatomy courses (bony fish have a similar system but are messier to dissect). Their bodies aren't simpler because they are less evolved; they are simpler because they are made more efficiently for their environment. Because we live on land, our bodies don't get oxygen from gills but from lungs. So our process for obtaining oxygen and releasing carbon dioxide and other toxins is more complicated and requires more loops and tubing. We could also avoid the whole heart attack thing with multiple hearts like a hagfish. There are many more examples of bad human heart "design issues"[10] than I can get into here. Of course you say, "If we had a simple fish heart, we would be giving up warm bloodedness by getting rid of a few heart chambers." Except some fish like tuna can facultatively achieve warm blood, and others have it permanently, such as opahs, through an efficient counter-current circulation.[10] The difference in the complicated circulation systems in humans versus fishes is kind of like the difference

[9] Sawyer, D.B. 2005. Heart Failure Research Continues to Reveal the Flaws in Nature's Unintelligent Design. Circulation 112:2891–2893.

[10] Wegner, N.C., Snodgrass, O.E., Dewar, H., Hyde, J.R. 2015. Whole-body endothermy in a mesopelagic fish, the opah, *Lampris guttatus*. Science 348, 786–789.

between heating a house with a simple wood stove versus using central heating through all the walls. Fish hearts continue to evolve, and a recent fossil even shows that the vertebrate heart really evolved to work in the low-pressure environment of the aquatic world in conjunction with gills.[11] Because we don't use gills anymore, we also need higher blood pressure than fishes; even more so because of our bipedalism (pushing blood against the forces of gravity).

Speaking of bipedalism—what a fool's errand that was. You might notice there aren't too many other biped animals (sure, you have your occasional ostrich, or kangaroo, but they have tails or feathery wings to help balance things out). You are constantly fighting against gravity as a biped, carrying that awkward big head around. Let's start with fishes—they have beautiful neutral buoyancy achieved in most species by a balloon-like swim bladder that allows them to float at rest peacefully in the water with little or no effort. Once you move onto land, you need to fight gravity, which is made worse by standing on two feet. Fishes have a nice straight spine with little to aggravate it, not even pelvic girdles attaching to the vertebrae—except in one recently discovered cavefish species[12] (silly fish—hips are for tetrapods). Your S-shaped spine is an abomination. A consequence of once having a straight horizontal spine as an aquatic vertebrate, then tilting it to make your torso balance on your legs, and then balancing that big ol' head. This puts a lot of pressure on the vertebrae and on your knees. Fish obviously don't have knees, and in fact, humans are the only species that is both plantigrade (soles of our feet touch the ground when we walk) and bipedal.[13] And that isn't a good thing. My wife, who has had five knee surgeries, can tell you more about the pain that comes with the wear and tear in this joint caused by bone rubbing on bone. There has to be a better way—and most other animals avoid it by not being upright most, or any, of the time.

How about our eyes? The things that "intelligent designers" pointed at for so many years as something that couldn't be explained by evolution. Do humans have the best eyes? Actually, our eyes are essentially the same

[11] Maldanis et al. 2016. Heart fossilization is possible and informs the evolution of cardiac outflow tract in vertebrates. eLife 2016;5:e14698 https://prod.elifesciences.org/content/5/e14698v1/article-info

[12] Flammang, B.E., Suvarnaraksha, A., Markiewicz, J., Soares, D. 2016. Tetrapod-like pelvic girdle in a walking cavefish. Scientific Reports 6: 23711.

[13] Dye, S.F. 1987. An evolutionary perspective of the knee. The Journal of Bone and Joint Surgery of America 69:976–83.

as the ones most fishes have, same muscles and nerves and parts of the eyes, with the exception of the lens being spherical in aquatic vertebrates and those living on land having a curved, flatter lens. That's why we can use cavefishes to study the loss of vision.[14] As we age, the fluid of the cornea becomes less transparent, obscuring what we see. Our ability to focus breaks down too as the muscles that control the iris atrophy. Even the same genes are involved in our vertebrate vision.[15] But I'd rather have the eye of a cephalopod like a squid or an octopus. Why? Anyone who has ever had their retina detach can tell you. In vertebrates, the optic nerve goes through the retina. That's why we have a "blind spot." The retina is responsible for transmitting images to the brain and can easily and painfully detach because of the placement of the optic nerve through it. In cephalopods the nerve goes around it, making detachment far less likely.

We also have other consequences of our evolution from our aquatic ancestors. One of my favorites—or least favorite, really—are those damned testicles. Left dangling to their own devices, ready to be crushed by the nearest blunt object. The testes of fishes and most animals are safe and snug inside the body cavity. But because our bodies are so warm (not sure how elephants and birds get away with having them tucked inside), our testes drop during development to keep them cooler. As they drop, they actually (stupidly) cause the vas deferens to loop around the ureter. This exposes all that baby-making machinery to the environment and weakens the abdominal wall (so good luck not getting a hernia).

Look at fish, especially the 30,000 species of the advanced fish group "Teleosts"—from the Greek for "end bone" or perfect bone—you could hardly imagine a more perfectly made organism. They don't have bad backs or knees; their hearts are close to the source of oxygen. I could go on and on, and I do in my classes. Of course a fish can't study evolution. Or can it?

I usually get to the big shocking twist in my story near the end of the first lecture. "We—you and I—my dear students—we are fish." The gasps of disbelief run through the crowd like the sounds of a window opened during a tornado. I show them again the great Tree of Life. Fishes to the

[14] Moran, D., Softley R., Warrant, E.J. 2015. The energetic cost of vision and the evolution of eyeless Mexican cavefish. Science Advances. Vol. 1, e1500363.

[15] Niemiller, M.L., Fitzpatrick, B.M., Shah, P., Schmitz, L., Near, T.J. 2013. Evidence for repeated loss of selective constraint in rhodopsin of amblyopsid cavefishes (teleostei: Amblyopsidae).

left of us, fishes to the right, here I am, stuck in the middle with you. The first organisms to come on to land, like *Tiktaalik*, was a fish. A sarcopterygian fish to be exact, like coelacanths or lungfishes. That branch of sarcopterygians includes all amphibians, reptiles (including all dinosaurs and by extension also includes all birds), and mammals. *Tiktaalik* (or a coelacanth or a lungfish) is more closely related to you, and you to it, than either of us is to a shark or a Largemouth Bass. I show them the simplified vertebrate tree: split down the middle with cartilaginous fishes (sharks and their kin) and bony fishes. Bony fishes are further subdivided into ray-finned fishes (Actinopterygii) and lobe-finned fishes (Sarcopterygii). Where do we go? Yep, we are just another lobbed-finned fish with all the other tetrapods. Sure, we might not look like a typical fish, but does a seahorse? Maybe we'd be better off with some of those fish parts of our body still left over to do fish things? Like the protagonist in *Gould's Book of Fish,*[16] I let them wonder, "Is it easier for a man to live his life again as a fish, than to accept the wonder of being human?"

So by teaching students about some of the aquatic origins of our body parts, they start to stop thinking about evolution as a goal-oriented process with humans being the top of the magical golden pyramid of life. We are just another evolving animal that evolved from other evolving animals; all of us life forms together trying to adapt to life on this ever changing planet. In fact, most of us humans, with our mostly hairless bodies, blunt teeth, and lack of defenses wouldn't last long out in the wild. So it is with fish, and maybe a little *South Park*, that I think the evolution to understanding evolution happens with my students at LSU. Class dismissed.

[16] Flannagan, R. (2001) Gould's Book of Fishes. A Novel in Twelve Fish. Atlantic Books.