Darwin and Evolution: Using Historical Critiques and Responses to Address Student Misunderstanding

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Students often enter our classrooms with a variety of fairly simple misunderstandings of evolutionary theory, absorbed from popular culture or as collateral damage from the cultural battle between science and religion. Sometimes, dispelling these misconceptions can be a significant challenge, and can leave students feeling as if they've failed to "get" something obvious.

But when we turn to the history of biology, what we find is that many of the same kinds of mistakes that our students make are precisely those that characterized the period surrounding Darwin's introduction of evolution. To put it simply, evolution is a difficult idea to master, and our students are making not silly or stupid mistakes, but the very same mistakes made by professional, practicing scientists! Our goal in this session is to talk through some of those mistakes, and provide you with examples of how to integrate this material into your classroom!

Instructor's View

Here is a brief overview, designed for instructors, of the challenges and responses that we'll discuss in the following. The rest of the handout, then, is an example of how you might present this material to students, along with example quotes and images to support the historical presentation. We close with a bibliography if you're interested in doing further reading!

- Organisms evolve by striving for success, and pass the results of that striving to their offspring
  - *Lamarckism* – Not necessarily what Lamarck himself believed, but a belief that was prevalent for decades after Darwin's work.
- All organisms are constantly evolving "up the ladder" of "progress" – those that are bacteria now will soon be fungi, amphibians will soon be fish, monkeys will soon be humans
  - *This* is what *Lamarck* himself actually believed, and it, too, held adherents for a number of years.
- How can some of the more complex features of organisms, like eyes, evolve?
  - *Darwin* himself offered this criticism of his own theory, not yet knowing how the evolution of complex traits could be described, and only demonstrating optimism that eventually we would figure out the intermediate, gradual steps

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by which such traits came to be. In some cases, he was right, and in some cases, mechanisms were required that Darwin couldn't have envisioned.

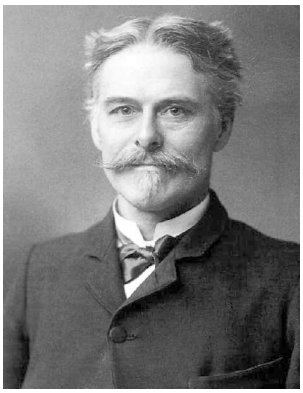
- How can one single organism which does better than its fellows, no matter how much better, actually cause permanent change in a species?
  - This was *Jenkin's* criticism of Darwin, and it took the development of contemporary genetics for us to see how an adaptive change might take root in an entire population.
- Does the fact that Darwin doesn't actually mention religion anywhere in the theory of evolution mean that it's incompatible with religious belief?
  - This was a common criticism of Darwin, and we can best see Darwin's reaction to it in the context of his response to *Clémence Royer's* unusual French translation of the *Origin.*
- Mendel's work in genetics means that traits are "binary," either "on or off" as we might draw up in a Punnett square
  - Even the very traits that Mendel himself used to derive his theory are not as straightforward as students are often led to believe, as *Weldon* discussed in the early days of genetics. Genetic variation is complex and multifaceted, and it is rare that there is a single "gene for" a complex trait.

Organisms Evolve by Striving for Success

Even in our evolution textbooks, we often see language that makes it sound like organisms evolve what they need just by *working really hard* at the problems that they face during their lives. For example, have you ever heard the evolutionary story that giraffes evolved longer necks because they *really wanted* to get the leaves at the tops of trees? Because they stretched out their necks, the story goes, their children wound up with longer necks, and now we have giraffes.

This was a very popular view of evolutionary theory, particularly in the United States, in the first seventy years or so after Darwin published *The Origin of Species.* It's called *Lamarckism* – the idea that evolution is driven by the behaviors and habits of organisms, which have a direct influence on the behaviors and habits of their offspring.

Scientist Spotlight: Edward Drinker Cope (1840–1897)



Edward Drinker Cope was an American paleontologist, perhaps most famous for discovering a wide variety of dinosaur fossils over the course of his career. He was personally responsible for naming more than a thousand species, in part as a result of a feud – the famous "bone wars" – with paleontologist Othniel C. Marsh, in which the two men scoured the entire Western United States looking for examples of fossils that would prove their competing theories of dinosaur anatomy.

He was also one of the leading proponents of Lamarckism in the United States. In his work *The Origin of the Fittest,* he writes that:

"The effects of use are well known. We cannot use a muscle without increasing its bulk… The hands of the laborer are always larger than those of men of other pursuits. […] Use thus determines the locality of new repetitions of parts already existing, and determines an increase of growth-force at the same time, by the increase of food always accompanying increase of work done, in every animal." (pp. 195-6)

He then gives us examples of instances where, he says, use and disuse have in fact driven evolution: the respiratory and circulatory system, rattlesnake rattles, and horns. His proposal is that there is a kind of *growth force,* which encourages some parts to become larger (or even to duplicate themselves – think about adding more vertebrae to the neck of the giraffe) and some to become smaller. These changed expressions of the growth force would then be passed on to offspring.

We now know that this is not, in fact, a mechanism by which evolution takes place. It is only changes in DNA that are reliably passed from parents to offspring, and no amount of neck-stretching can alter the genetic basis for building a giraffe's neck. In cases like

those that Cope identifies, while it *seems* like organismic “striving” would cause evolution, it is in fact nothing more than the appearance of genetic mutations which improve precisely those behaviors that drives evolution – and without those mutations, no evolution would take place. An early mutation gave a rattlesnake a small rattle, and successive mutations that made the rattle louder, or produced more rattles, and were therefore better at alerting large creatures of the snake’s presence (and keeping it from getting stepped on!) were preferentially passed down from parents to offspring, as they increased the fitness of those organisms.

Today, there are some mechanisms of genetic transmission – particularly those described by the field of *epigenetics* – that could allow some behavioral traits to pass from parents directly to offspring. It’s still a matter of debate today just how often this occurs, and whether or not it would be significant enough to count as “Lamarckism.”

Organisms Progress Toward Perfection

One of the most common objections to evolutionary theory: if organisms are evolving all the time, why are there still “lower” forms around, like bacteria or monkeys? This picture of evolutionary theory – that every organism should be constantly moving “forward,” in the direction of “higher” qualities and more “perfection” – comes from an older picture of evolutionary theory, one that existed prior to the work of Darwin.

Yes, while Darwin invented the modern theory of evolution by natural selection, he wasn’t the first person to have invented an “evolutionary” theory, on which species are created by changes in other species. These theories, which were called “transmutationism” before Darwin came along, proposed different kinds of mechanisms for how species might change into new species. One of these was the work of Jean-Baptiste Pierre Antoine de Monet, Chevalier de Lamarck – who went by Lamarck for short.

Scientist Spotlight: Jean-Baptiste Lamarck (1744–1829)

Lamarck was an independently wealthy botanist, soldier, doctor, and anatomist who, after fighting with distinction for the French Army in his youth, published a variety of vitally important works on biology, particularly a characterization of invertebrate organisms and his transformist theory of evolution, which he published in a book called *Zoological Philosophy.* Describing the overall order of life on earth, he writes:

“It may then be truly said that in each kingdom of living bodies the groups are arranged in a single graduated series, in conformity with the increasing complexity of organization and the affinities of the object. This series in the animal and vegetable kingdoms should contain the simplest and least organized of living bodies at its anterior extremity, and ends with those whose organization and faculties are most perfect. Such appears to be the true order of nature, and such indeed is the order clearly disclosed to us by the most careful observation and an extended study of all her modes of procedure.” (p. 59)

Nature is, he claims, constantly creating new microscopic organisms: prior to the widespread acceptance of the status of microorganisms as regular, reproducing living beings (which didn’t happen until after Lamarck’s death), it was believed that in mud, water, and in the process of decay new beings were simply constantly created from nothing. Those organisms will evolve into insects, and onward to worms, molluscs, fish, reptiles, birds, and mammals, given enough time.

Of course, we now know that this is view is mistaken. Bacteria aren't "failed insects," and chimpanzees aren't "failed humans." Each of the organisms on the planet has been "evolving" ever since life first appeared, and each is adapted to the particular niche in which it finds itself. And even if a speciation event were to take place in chimpanzees, say, it wouldn't magically produce humans – it'd produce two new species, neither of which we'd ever have seen before.

Evolution of Complex Features

Darwin himself was worried about whether or not it would be possible for evolution to explain the existence of features of organisms that are extremely complicated. His favorite example was the eye. He writes:

“To suppose that the eye, with all its inimitable contrivances for adjusting the focus to different distances, for admitting different amounts of light, and for the correction of spherical and chromatic aberration, could have been formed by natural selection, seems, I freely confess, absurd in the highest possible degree.” (*Origin of Species,* p. 186)

This was also one of the most common critiques of the *Origin* when it was published. The American scientist Francis Bowen wrote in a review of Darwin’s *Origin* the following critique:

“We will take, for instance, one of his own examples,—the commencement of vision, or the rudimentary formation of an eye. If such a rudiment could see at all,—and it must see well enough to give its possessor a decided advantage in the struggle for life,—then its formation was a step of transcendent magnitude; for there is all the difference in the world between *seeing,* however imperfectly, and *not seeing at all.*” (Bowen 1860, p. 499)

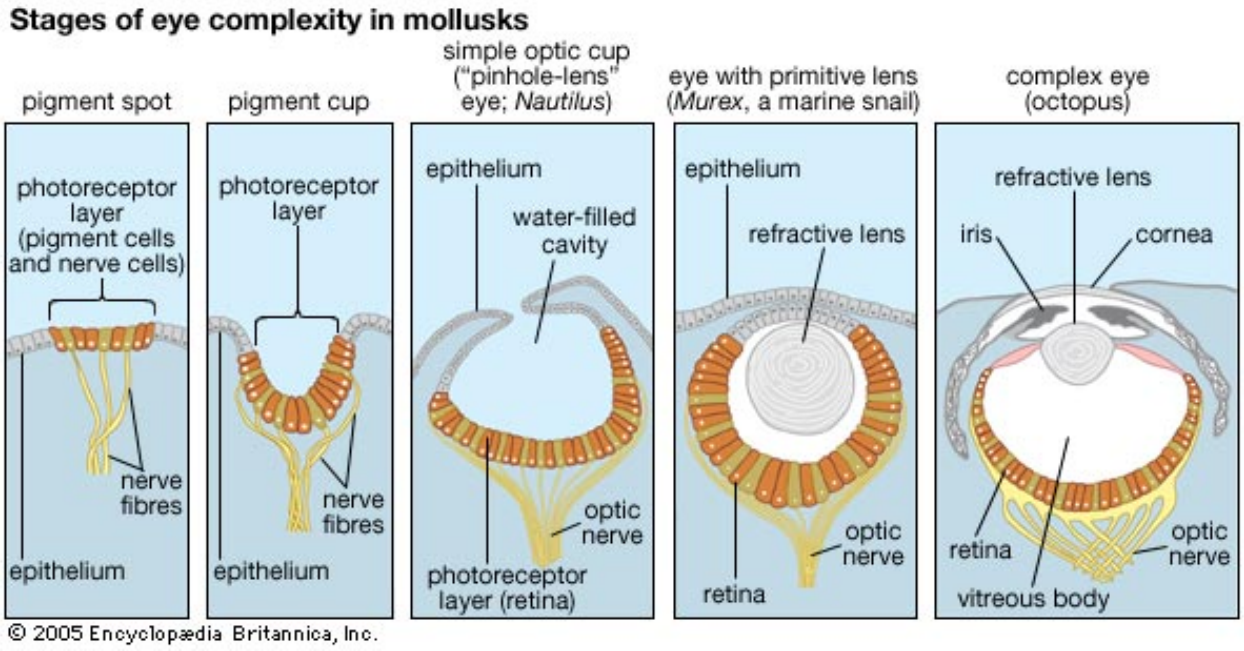
This does seem like a serious challenge for Darwin. If there are any organs that could *only* have evolved *all at once or not at all* – that is, for which the intermediate steps by which the organ evolved would not be useful at all to the organism that possessed them – then there’s no way those organs could have been produced by evolution. At each step in the evolution of something complex, there must be *some* advantage to having that partial organ.

Science Spotlight: The Evolution of the Eye

As Darwin himself put it, we should be able to find this series of organs for the eyeball:

“Yet reason tells me, that if numerous gradations from a perfect and complex eye to one very imperfect and simple, each grade being useful to its possessor, can be shown to exist; if further, the eye does vary ever so slightly, and the variations be inherited, which is certainly the case; and if any variation or modification in the organ be ever useful to an animal under changing conditions of life, then the difficulty of believing that a perfect and complex eye could be formed by natural selection, though insuperable by our imagination, can hardly be considered real.” (*Origin of Species,* pp. 186–187)

And, as it turns out, we can do precisely this. While this evidence was not available to Darwin, we can build a fairly thorough idea of the evolution of the eye in mollusks (through to the octopus, which has very good eyesight):

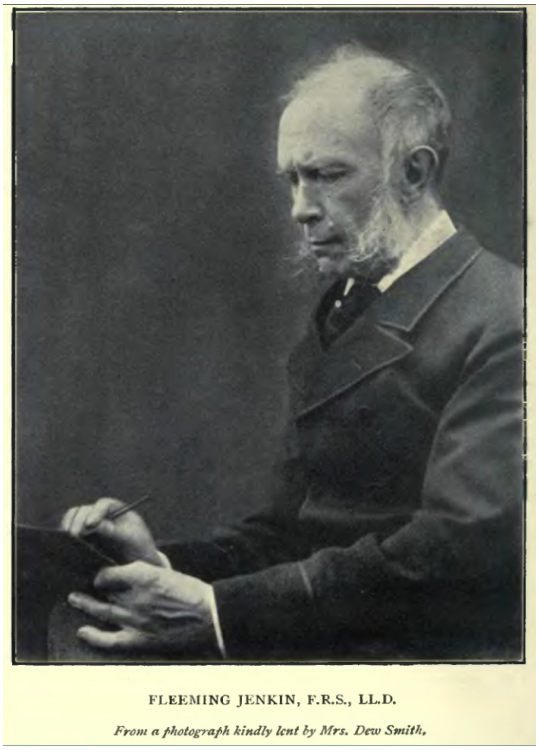


At each of these points, possessing the partially formed organ is better than having nothing at all – organisms successfully use these partially formed eyes to find places to hide, handle ocean temperature changes due to direct sunlight, and to, however imperfectly, navigate their environments. So while Darwin didn't know how to meet this challenge, subsequent science has stepped in and given us precisely the evidence that Darwin thought it would!

Swamping and Evolutionary Change

Imagine that, in an entire population, a single organism evolves with a new characteristic. However beneficial that trait might be, this organism still has to breed with the original population in order to pass on that trait. Those offspring will be a little more average than their exceptional parent. After a few more generations, the advantage will be gone. So how can natural selection get to work?

Scientist Spotlight: Fleeming Jenkin (1833–1885)



FLEEMING JENKIN, F.R.S., LL.D.

From a photograph kindly lent by Mrs. Dew Smith.

This point was made most forcefully to Darwin by the engineer Fleeming (pronounced Fleming) Jenkin. Jenkin is best known as the person who invented the aerial tramway or cable-car, but was a prolific writer in engineering and sanitation, as well as a trained artist. As he put it in a review of Darwin's *Origin of Species*, return to our case of a single organism born with a particular advantage:

"It will breed and have a progeny of say 100; now this progeny will, on the whole, be intermediate between the average individual and the sport. The odds in favor of one of this generation of the new breed will be, say 1 to 1, as compared with the average individual; the odds in their favor will therefore be less than that of their parent; but owing to their greater number, the chances are that about 1 of them would survive. Unless these breed together, a most improbable event, their progeny would again approach the average individual; there would be 150 of them, and their superiority would be say in the ratio of 1 to 1; the probability would now be that nearly two of them would survive, and have 200 children, with an eighth superiority. Rather more than two of these would survive; but the superiority would again dwindle, until after a few generations it would no longer be observed and would count for no more in the struggle for life, than any of the hundred trifling advantages which occur in the ordinary organs." (Jenkin 1860, p. 289)

Jenkin here just works out the math behind the same idea we looked at above. Adding up the numbers of how many organisms might have the trait, and blending that trait with the rest of the population, by two or three generations almost all of the variation would have washed out, and the population would look mostly like it did before our special organism was ever born in the first place.

What Jenkin and Darwin both didn't know was that the effects of genes don't always work by adding up and averaging (what we now call *blending inheritance*). Think of Mendel's peas: if a pea plant has a single copy of the dominant "round" shape gene, then that trait will be expressed – the roundness of offspring isn't an "average" of the roundness of the parents. This form of inheritance, now called *particulate inheritance*, provides an answer to Jenkin's worry.

Evolution Without Religion

Nowhere in Darwin's major work on evolution, *The Origin of Species,* does he directly mention religion. The evolution of man, however, has been taken to be an issue of religious importance since the time that the *Origin* was first published. Does the fact that Darwin's own book doesn't mention religion mean that evolution and religion are not compatible?

The first person to translate Darwin's work into French, Clémence Royer, certainly thought so.

Scientist Spotlight: Clémence Royer (1830–1902)

An eccentric, self-taught scholar, Royer wrote books on a variety of subjects, from economics to philosophy. She was the first woman in France ever elected to a scientific society, having won election to the all-male Parisian Society of Anthropology in 1870. She was also a thoroughgoing radical, and had no qualms expressing her views on religion in the context of Darwin's work. Her preface to her translation of Darwin's *Origin* begins with the following:

"Yes, I believe in revelation, but in a permanent revelation of man to himself and for himself, in a rational revelation which is the result only of the progress of science and contemporary consciousness, in a revelation always partial and relative which is achieved by the acquisition of novel truths, and even more so by the elimination of ancient errors."

One of the best ways to gauge Darwin's own feelings about religion was to see what he did when a preface like this was placed at the beginning of one of his books – and he wasn't at all sure what to do with it. He wrote in a letter to his colleague Asa Gray that "I received 2 or 3 days ago a French Translation of the Origin by a Mad$^{elle.}$ Royer, who must be one of the cleverest & oddest women in Europe: [she] is [an] ardent Deist & hates Christianity, & declares that natural selection & the struggle for life will explain all morality, nature of man, politics &c &c!!!" (June 10, 1862).

Darwin's own views on religion are difficult to discern – and it's not clear that those views were even particularly well formed. But it's definitely clear that he intended his theory to be *compatible* with religious belief. Having been challenged on this point by the geologist Adam Sedgwick, he wrote to a friend that he wished he could ask Sedgwick "whether it was not allowable (& a great step) to invent the undulatory theory

of Light – i.e., hypothetical undulations in a hypothetical substance the ether. And if this be so, why may I not invent hypothesis of natural selection" (May 8, 1860). If, that is, it was okay to explain light as a bunch of tiny waves, *without* having to say that each little wave was somehow caused by God, then why wouldn't it be okay to describe natural selection without having to constantly invoke the divine?

While there is certainly contemporary debate, this point has been reaffirmed by a number of contemporary biologists and theologians, who have argued that there is no fundamental incompatibility between religious belief and evolution.

Genetic Traits and On-Off Switches

When we describe the facts of genetics that were discovered by Mendel, we usually talk about traits that produce the expected, Mendelian 3:1 ratio. Think of Mendel's own round and wrinkly peas, or blood type.

But as you of course know, not every trait in real life is like this, and this was noticed early on by a variety of biologists who were worried about Mendel's results.

Scientist Spotlight: W. F. R. Weldon (1860–1906)

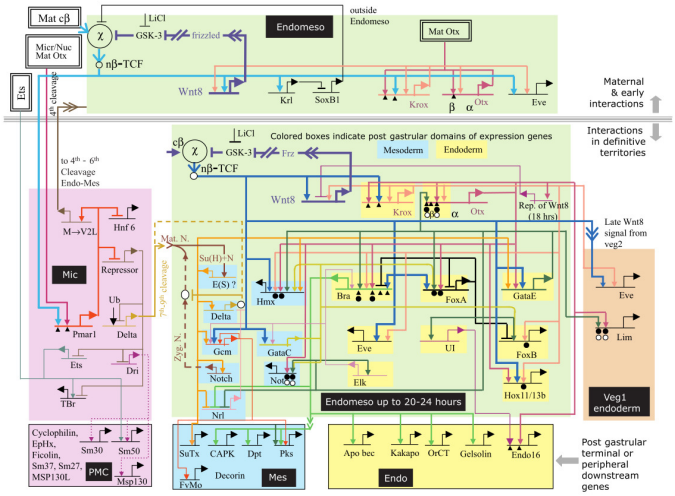
W. F. R. Weldon, known as Raphael, was an biologist who worked in England in the late 19th and early 20th centuries. Most famously, he was part of a group that was the first to use statistical methods to study evolution, and was the first to experimentally demonstrate natural selection, in a species of crabs. He was also, however, worried about Mendel's results. He bred several varieties of peas himself, looking to reproduce Mendel's results, but could not. He wrote:

"I think we can only conclude that segregation of seed-characters [Mendel's ratios of the pea colors, wrinkles, etc.] is not of universal occurrence among cross-bred Peas, and that when it does occur, it may or may not follow Mendel's law. The law of segregation, like the law of dominance, appears therefore to hold only for [varieties] of particular ancestry." (Weldon 1902, p. 251)

He went so far as to print the following photograph:

If Mendel is right, Weldon is arguing, peas are supposed to be either green or yellow, with yellow dominant. But here we have a pretty clean gradation, from all the way green to all the way yellow peas, and it seems like dividing these into "green" or "yellow" would introduce errors. (Weldon didn't go so far as to say that Mendel faked his data, but later biologists did!)

Now we know that this doesn't mean that Mendel is wrong – only that peas, along with almost all genetic characters, are far, far more complex than we might have hoped. Most character traits that we'd actually care about, things like height, or weight, or ability to run fast, will be governed by massively complicated networks, containing hundreds of genes. In 2002, a group of scientists led by Eric Davidson described the gene network for one small portion of development in the embryos of sea urchins, and even this network was incredibly complex. Each of the genes in this network (of which there are more than fifty) is inherited, and each connects to a number of others in increasingly complex ways.



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