5.1

THE EVOLUTIONARY EPIC

0:00–0:40

THE ULTIMATE EPIC

Hi, I'm John Green. Welcome to Crash Course Big History. Today we're going to be traversing the evolutionary epic — the great story of magnificent beasts, terrifying predators, quite a lot of extinctions, and countless varieties of evolutionary forms. It's the ultimate epic — millions upon millions of species playing out a drama that has so far lasted 3.8 billion years with 99% of the actors having already left the stage forever. And you thought finding employment in this job market was tough. You've already won the lottery, my friend.

0:40–1:36

NATURAL SELECTION

The keystone of our story is evolution by natural selection. So, in the 1830s, a young Charles Darwin traveled around the world on the H.M.S. Beagle. Inarguably, by the way, the most important beagle of all time. I apologize, Snoopy, but it's true. Darwin had the rare and amazing opportunity to study a great variety of the world's wildlife, and upon returning to England, he discovered that a variety of finches he had collected on the Galapagos Islands had beaks that were subtly adapted to their different environments and food sources.

Darwin later combined this idea with the observation of how populations tend to overbreed and strain their resources. I mean, if there's competition for resources in an environment, then animals with useful traits would survive and pass those traits on to their offspring. Those who didn't survive long enough to reproduce would have their traits wiped out from the evolutionary tree: natural selection.

1:36–2:12

GOOD SCIENCE

We talked some on Crash Course Big History about good science, and Darwin was a good scientist. He worked on his ideas for two decades, systematically finding new evidence to support his case, and then finally in 1859, he published On the Origin of Species, and it sent shockwaves around the world.

The book offered an explanation for why so many species that seemed perfectly adapted to their environment could have been formed by a blind but elegant law of nature. Darwin's theory was so elegant yet so effective that his colleague Thomas

Huxley exclaimed, "How extremely stupid not to have thought of that!"

2:12–2:38

ON THE ORIGIN OF SPECIES

Side note: if you ever read *On the Origin of Species*, try to get a first edition because in later editions, Darwin made a bunch of revisions in answer to some critics, but he got it actually more right the first time. Speaking of which, one of the phrases only included in the later editions and commonly attributed to Darwin was "survival of the fittest." But that phrase was actually coined by Herbert Spencer, father of the more troubling Social Darwinism, which tried to apply nature's rather harsh laws to human social orders.

2:38–3:31

NATURAL SELECTION

I prefer Darwin's original phrase: natural selection. Everything from cuckoo birds that lay their eggs in the nests of other birds to giraffes whose long necks are good for reaching food in high trees, to humans whose brains make up for their fragile bodies are selected for naturally.

An even better phrase, though, would be "non-random selection" or maybe even "non-random elimination." While all genetic mutations are generated by a random copying error or a random variation completely beyond the animal's control, the selection of those traits is not random. Successful variations that allow you to survive and reproduce are determined by the very specific circumstances of your environment where elimination — death — might not be far away. So the selection of your traits is done by a very specific and sometimes brutal list of criteria. This is why people who say

that they don't understand how all animals could have "evolved by chance" don't really understand how evolution works.

3:31–4:14

EVOLUTION

Here's another phrase that doesn't get it right, "evolution is just a theory." In everyday speech, "theory" means "guess," but in science, a theory is something that was tested time and time again, explains many different observations, and is backed up by a mountain of evidence. Evolution is a theory like gravity is a theory, and you don't go jumping out your window because gravity is just a theory. Why are we so certain? Emily knows.

Evolution is one of the most tested, most utilized, and widely accepted theories in science. It's backed up by literal tons of fossil evidence, which can show us shared traits with species that no longer exist and help us map out lines of descent for creatures around today.

4:14–5:08

DNA SEQUENCING

DNA sequencing further tells us about lines of descent, and you can measure the commonality of the DNA possessed by two animals to tell how closely related they are and when they may have split off from a common ancestor.

Radiometric dating allows us to assign dates to various fossils, further helping us map out lines of descent. Then there's the simple fact that extinct species are always found in the same rock layers you'd expect to find them. Which is why you don't see a bunny skeleton in Cambrian rock layers from half a billion years ago. That's also how we know that *Dimetrodon* is not a dinosaur.

Closely related species are often geographically distributed near one another. That's not to mention that we can see evolution happening before our very eyes. Whether it be the discovery of a new species that recently moved into a different environment, the development of newly adapted bacteria into superbugs, the evolution of new breeds of rapidly reproducing insects, or the almost constant changes in gene distribution in animal populations all over the world.

5:08–5:50

SYMBIOSIS

So, remember the prokaryotes and the eukaryotes? Gradually some single-celled eukaryotes began to work together in a thing called symbiosis, where one cell did something in exchange for another cell doing something else, thus aiding the survival of both. Some eukaryotes became so cooperative and even interwoven that one cell could not possibly live without the other. Symbiosis was particularly handy in times of disaster.

Around 650 million years ago, the Earth was completely frozen over. Snowball Earth was not a great place for life. Many underwater bacteria survived under the ice in oceans. Photosynthesizers may have survived in small hot spots where there was liquid water. In such constrained conditions, it's likely that individual cells started to work together more and more.

5:50–6:46

COMPLEX MULTICELLULAR LIFE

Now is where we start to blaze through the evolutionary epic of complex, multi-cellular life. Between the start of complex multicellular life and today, there have been 5 mass extinction events.

In nature, species compete in niches. It's also called niches, depending on where you're from, but I call them niches, as an area of the environment that requires a special set of skills or traits to extract food and reproduce. When niches are full, competition is heavy, traits become finely tuned, and evolution generally slows down a little.

But, when a disastrous extinction event wipes out the majority of the animals living in a niche, the surviving species have room in a lack of competitors to evolve new traits very fast to fill the niche again in what we call an adaptive radiation. The evolutionary epic is dotted with periods of niches filling up, being swept clean by disaster and filling again by new rapidly evolving species.

6:46–7:12

DINOSAURS AND MAMMALS

Example: for the longest time dinosaurs ruled the Earth and mammals were a puny, timid race of small shrew-like creatures that stayed out of their way. Sometimes we burrowed in the ground or only came out at night or confined our diet to tiny bugs. We could not compete with dinosaurs in their niches.

Then the dinosaurs were wiped out and mammals were able to rapidly fill all the empty niches, creating apes and elephants and horses and even whales.

7:12–7:56

EDIACARAN ERA

So after Snowball Earth, the Ediacaran era gives us the first extensive fossil evidence for multicellular organisms. There were various ancient forms that resembled today's worms, corals, mollusks, various underwater plants.

But then in the Cambrian era, adaptive radiation really got underway and multicellular life filled thousands upon thousands of niches unlocked by their new traits. A lot more is just possible for multi-celled organisms than for single-celled ones. Like, not to brag or to bring up my astonishing strength again, but I can bench much more than a eukaryote.

Some of the most famous creatures that got their start in the Cambrian were trilobites, these bug-like creatures with exoskeletons that existed in a variety of species and forms, occasionally in swarms of thousands. And they didn't go extinct for nearly 300 million years. That's over a thousand times longer than *Homo sapiens* have been on the planet.

7:56–8:52

PREDATORS

Also, as my four-year-old son can tell you, the Cambrian era had predators, like *anomalocaris*, which reached sizes of nearly a meter long with razor sharp teeth and grasping limbs.

By the time of the Ordovician period, photosynthesizers were making their first tentative steps out of the sea into a new niche, the land. Plants colonized coastlines first and then gradually, over millions and millions of years, moved further and further inland. In the oceans, life continued to be abundant with fish and sharks multiplying into a variety of forms. And there were all kinds of crazy life forms, like underwater scorpions that were two-and-a-half meters long. I mean, for the first 100 million years of complex evolution, a mind-boggling diversity of creatures was emerging. But that also meant all the niches on the planet were getting very full and many competitors in the same niche made it difficult for a new species to enter it with ease.

8:52–10:00

EXTINCTION!

And then came extinction. I feel like extinction is going to be a thing, Stan. Is there anyway we can make a thing for extinction? Yes!

Ordovician Earth went through first a major freezing period, killing off many warm water species, and then a radical heating period, killing of many cold water species. Many ecological niches were swept clean and this removal of competition meant that new species could enter empty niches and evolve rapidly in one of those adaptive radiations. There was also incentive to move out of the seas and onto the land.

In the Silurian period, one of those groups that evolved rapidly by filling terrestrial niches was the arthropods, those exoskeleton species and the ancestors of many of today's bugs. Since plants continue to colonize the land and more and more of the Earth's surface was becoming forested, that increase in the number of photosynthesizers increased the percentage of oxygen in the atmosphere to between 30% and 35%. Today, it's approximately 21%.

Arthropods came out of the sea, started filling niches on land, and their metabolism took advantage of this all-you-can-respire oxygen buffet, growing to enormous sizes, like a dragonfly with a meter-long wingspan or a scorpion 1.8 meters long. Again with the scorpions!

10:00–10:43

THE DEVONIAN

In the early Devonian period, the forests of the Earth were composed of mosses, ferns, and short shrubs. Some plants eventually evolved a woody covering, which provided some back support and allowed them to grow taller and taller and compete with others in their niche by grasping higher and higher for sunlight. In the first episode, we did promise to explain the existence of trees. Bingo.

Also, by the Devonian, our vertebrate ancestors had arrived on land. Unlike arthropods, vertebrate skeletons are on the inside and our skin is more porous, making it easier for water to escape. This limited our ability to fill land-based niches. At first, we were amphibious. From this amphibious ancestor, all tetrapods gain their characteristic skeletal structure — four limbs, five digits.

And then, once again: extinction.

10:43–11:22

THE CARBONIFEROUS

Scientists debate about what caused the Devonian extinction, but once again, a couple of sharp rises in disappearances from the fossil record shows that the niches were being swept clean. Again, the number of species on the Earth drastically declined. But only temporarily.

The Carboniferous intensified the forestation of the planet even more. Meanwhile, amphibians were filling up coastal niches with competition. So to escape into new niches, some evolved less porous skin to venture further inland without drying out, and they also laid eggs with a protective shell, meaning that they didn't have to return to the water to hatch their young. These were reptiles. They were able to fill up the inland world where real estate was cheap. And, come to think of it, real estate still is cheap.

11:22–12:22

THE PERMIAN

Next up was the Permian. Many of the forests dried out, creating deserts. Reptiles thrived in this transformed environment with less competition from the forest and river dwellers. Also during this time, the ancestor of mammals evolved. I'm talking, of course, about the synapsid. So, considering that they were the ancestors of everything from you to your dog to elephants and whales, it gives you an idea of how radically things can change in just 250 million years of evolution. Because then, once again, at the end of the Permian era, we have extinction.

Often referred to as the Great Dying, it was the single largest extinction event of the past half-billion years. Its cause is still debated, but the most dominant theory is an environmental disaster caused by volcanoes in Siberia. All told, over 90% of marine life and 70% of terrestrial life—maybe more—died out. Synapsids were hard hit, leaving space for a huge adaptive radiation of giant reptiles. And now we are finally closing in on my son Henry's favorite period of history, the giant reptile period.

12:22–12:59

THE TRIASSIC

In the subsequent Triassic period, the Earth's climate was ludicrously dry with many deserts. And the near the North and South poles, it was warm and wet. Again, dry climates were a big win for reptiles and our mammalian ancestors got a bit of the short end of the stick because there was so much reptilian competition in many niches. So we hid on the fringes.

Meanwhile, there were many kinds of giant reptiles in the Triassic of which the dinosaurs were just one kind until extinction.

The Triassic extinction, possibly due to volcanic super eruptions or an asteroid impact, emptied a lot of niches of competition and allowed one particular group of giant reptiles, the dinosaurs, to reign supreme.

12:59–13:50

THE JURASSIC AND CRETACEOUS

And that finally led to those periods that are what most people think of when they hear the word "paleontology" or the word "fossil," The Jurassic and Cretaceous periods.

I'll spare you the snarky commentary about how the *T-Rex* in Jurassic Park actually lived in the Cretaceous. Dinosaurs were the dominant animals on this planet for a whopping 135 million years. That's 540 times longer than our species has even existed.

I hope you understand this. Consider two of the most iconic dinosaurs, *Stegosaurus* and *T-Rex*. S*tegosaurus* was around in the late Jurassic. *T-Rex* was around in the late Cretaceous. They are separated by roughly 88 million years. Humans and *T-Rex* are separated by less time than *T-Rex* and *Stegosaurus*. Approximately 65 million years ago, the reign of the dinosaurs ends — you guessed it — in extinction.

13:50–14:33

RISE OF
THE MAMMALS

A rock roughly 10 kilometers across crashed into the present-day Yucatan peninsula with a million times more force than all the nuclear arsenals of the world combined. Bad for the dinosaurs, but it opened up a lot of niches previously occupied by them.

Many small mammals were able to survive by burrowing or simply requiring less food. They were then in a position for another adaptive radiation. Small mammals quickly evolved into an immense variety of larger forms. And so was the story of complex life on Earth during the evolutionary epic.

Next week we will explore the nascent beginnings of a new phase of complexity, the accumulation of more knowledge generation after generation and the intensification of a newfangled evolutionary invention — culture.

See you next time.