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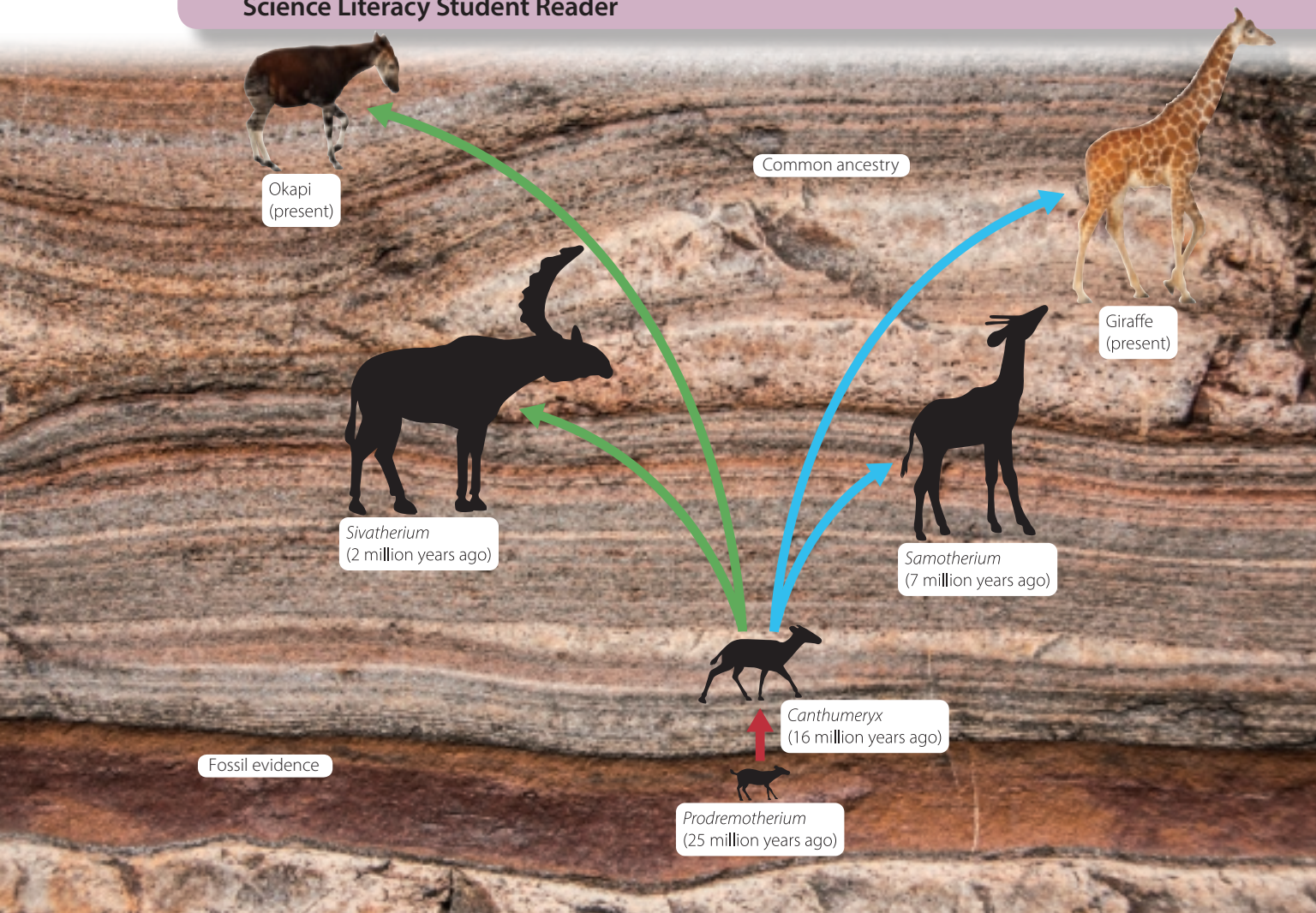
Natural Selection and Common Ancestry:

How could living things today be connected to things that lived long ago?

Science Literacy



Science Literacy Student Reader



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Natural Selection and Common Ancestry

Science Literacy Student Reader



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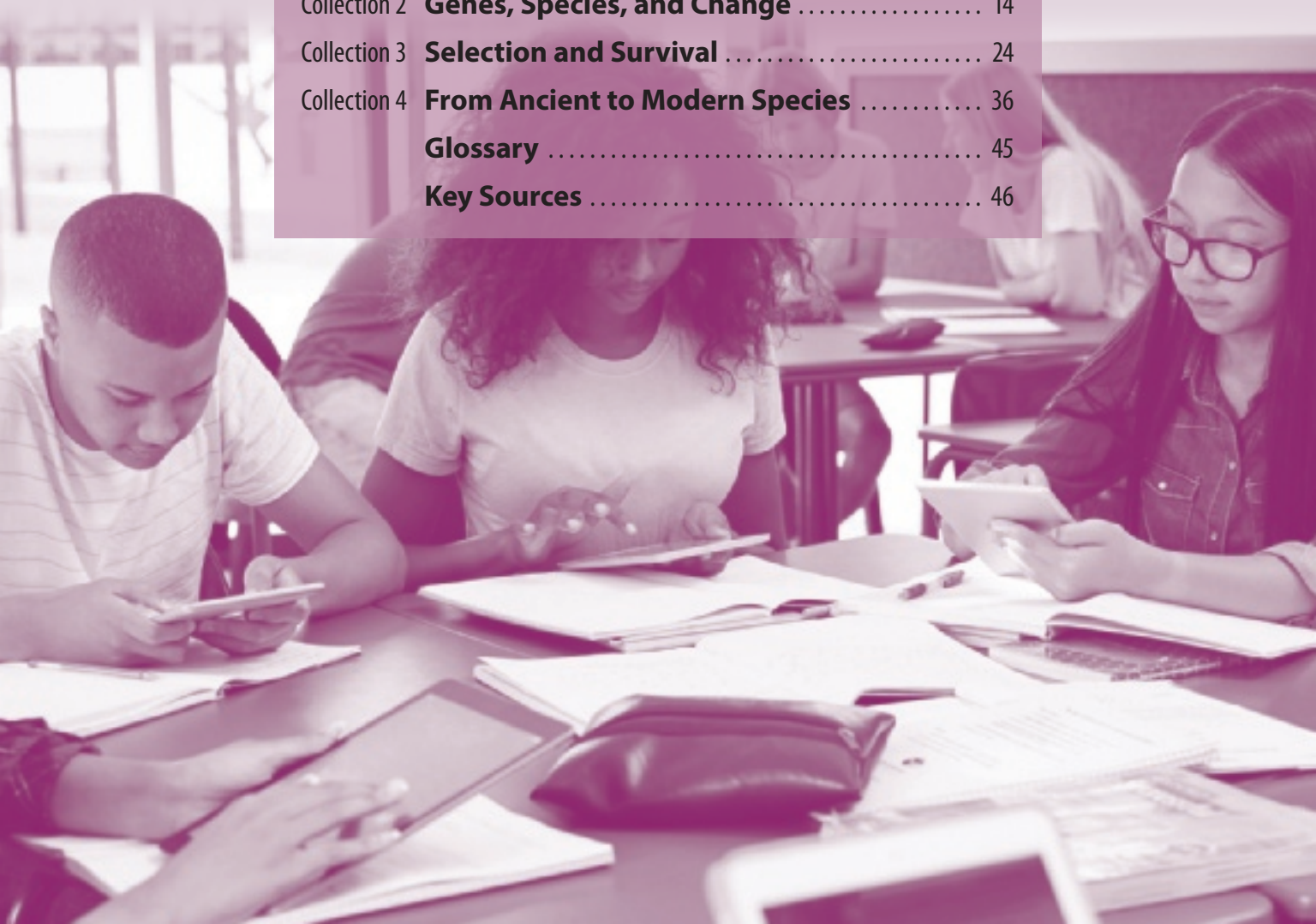
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Natural Selection and Common Ancestry

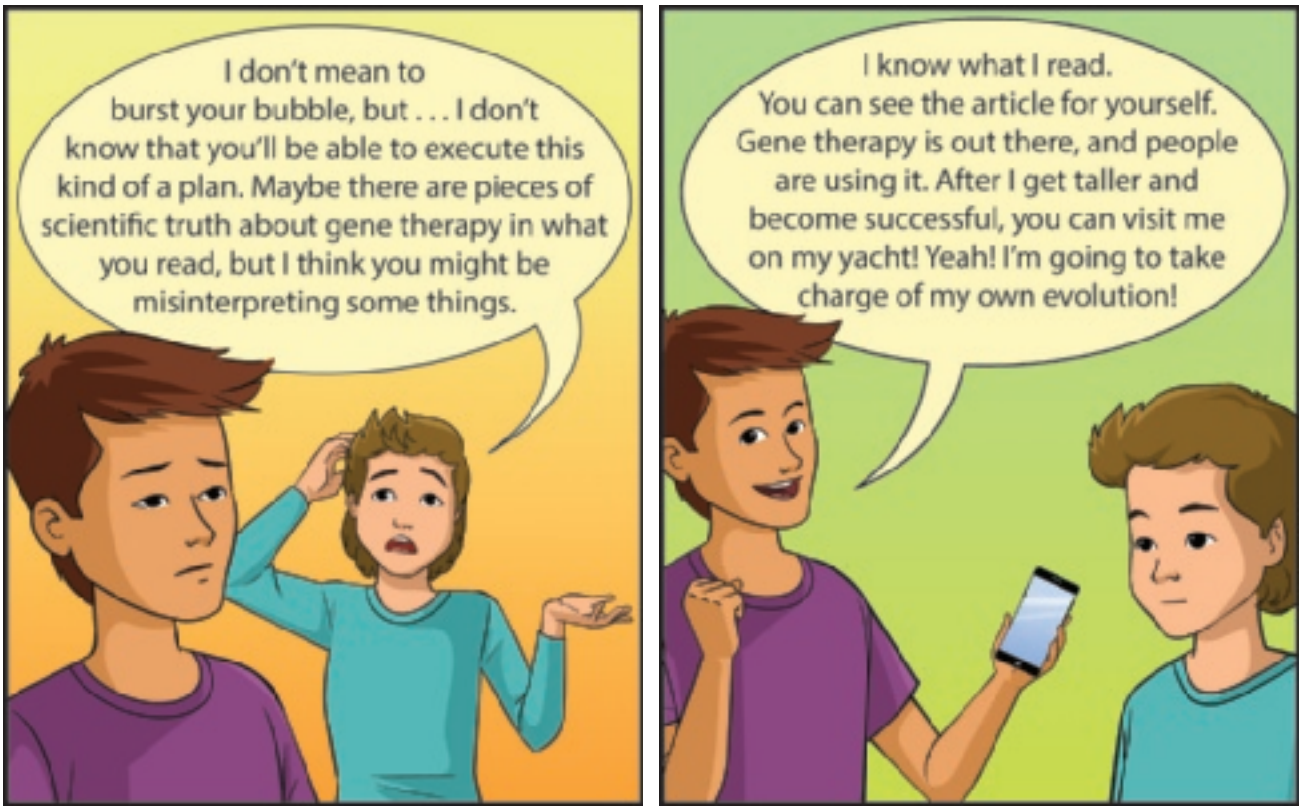
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Put Yourself in This Scene





How can we tell who's right? That's what this book is about—scientific literacy, which means knowing how to think about science topics that you read or hear about. Our world has 24–7 news, social media, and too many websites to count. The amount of information we have to sort through is overwhelming, and all the information is not reliable. In the internet age, sources of information are often obscure or not trustworthy. It is good to process information with a healthy degree of skepticism.

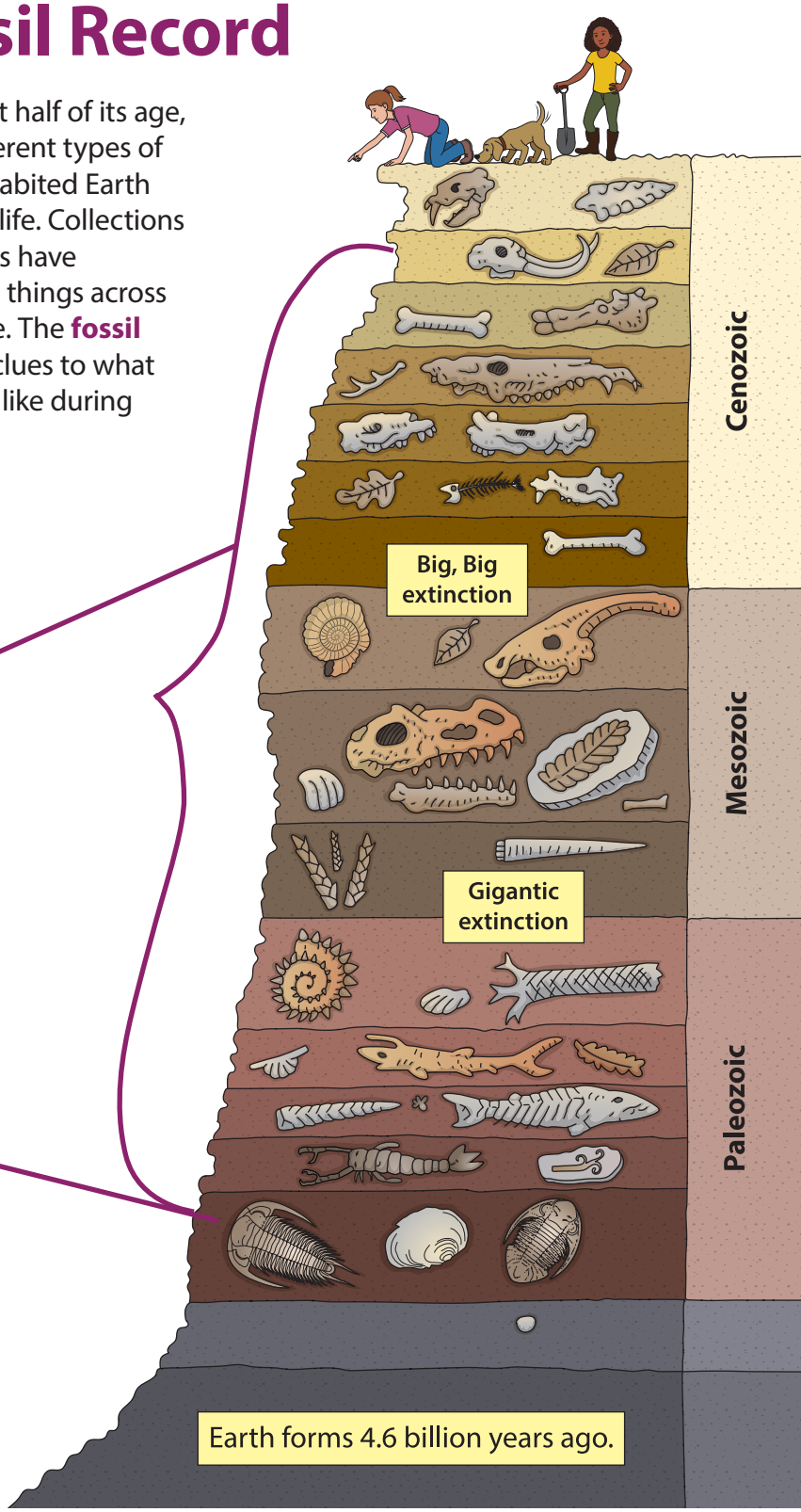
We will make our way back to this topic of gene therapy by the end of the book. Along the way, the series of reading selections and the writing exercises that go with them will help you flex your mental muscles and sharpen your science literacy skills. The ability to read about science, understand the information, and tell truth from fallacy or misrepresentation is really important. Science literacy helps you as an individual and as a consumer, and it shapes the ways you affect the community in which you live.

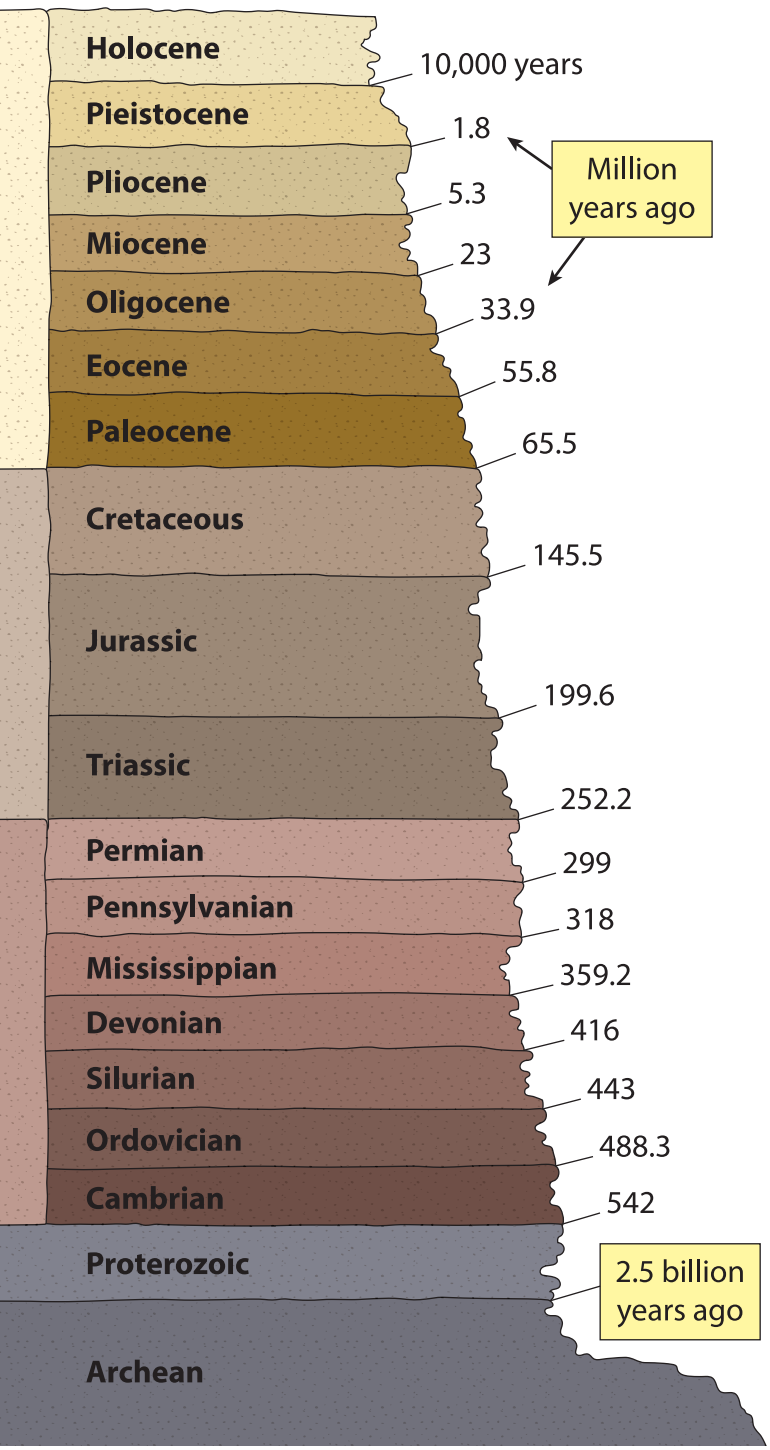
Picturing the Fossil Record

Earth is about 4.6 billion years old. For at least half of its age, the planet has been inhabited by a *lot* of different types of creatures. No one type of living thing has inhabited Earth during the entire time the planet has hosted life. Collections of life-forms have died out, and different ones have emerged. Such changes in the types of living things across time are used as boundaries for spans of time. The **fossil record**, in layer upon layer of rock, provides clues to what types of organisms lived and what Earth was like during those different time spans.

Fossils found embedded in a rock layer are used to figure out the age of the layer. Fossils appear in older layers and then disappear in younger layers if the species become extinct.

Trilobites were a group of related ocean species. They're extinct now, but that doesn't mean they weren't well adapted to their environment. These creatures were plentiful in the Cambrian, and a few species lasted into the Permian period. That's over 240 million years of trilobites!





Divisions of geological time have a hierarchy. Briefer divisions (which are still millions of years long) are called *eras*. Those are spelled out horizontally in the diagram. The divisions of time spelled out vertically consist of several eras and are called *eons*.

Sedimentary rock forms when sediments settle in water and compress to form solid rock. Scientists can determine how long ago each rock layer formed by looking at the layers' positions and what fossils are found in each layer. The oldest layers are at the bottom, and the youngest layers are at the top. The fossils reveal species that lived at the time the rock in each layer formed.

Vocabulary

fossil record, n. the history of life on Earth according to fossils that have been found throughout time

Gone but Not Forgotten

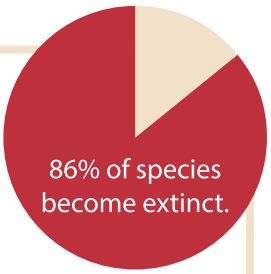
Scientists estimate that more than 99% of species that have existed on Earth are extinct. Still, it's rare when more than half of living species disappear at the same time. Such events have occurred, though, and they are known as **mass extinctions**. Here are the top five mass extinctions in Earth's history. The circle graphs show what percentage of species went extinct.

Vocabulary

mass extinctions, n. events in Earth's past during which large percentages, usually about 75%, of species became extinct during short periods of geologic time



Trilobite



End-Ordovician Extinction:
440 million years ago

At the end of the Ordovician era, Earth's climate cooled. The sea level fell as glaciers spread over the land. Many small ocean-dwelling species disappeared, including most of the trilobite species.



Placoderms

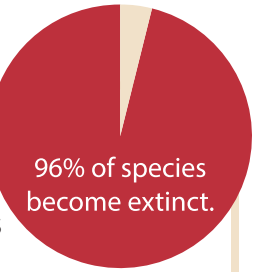


End-Devonian Extinction:
365 million years ago

It's not clear what changes on Earth caused this mass extinction, and it wasn't quite as disruptive as the other events. Nevertheless, many tropical ocean species disappeared, including fish called *placoderms*.



Pelycosaur

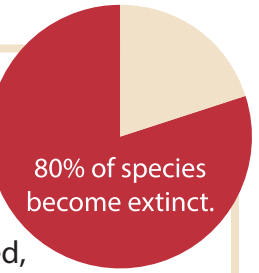


End-Permian Extinction:
250 million years ago

Triggered by volcanic eruptions and followed by wildfires, this most massive of the mass extinctions wiped out many species of trees, ocean corals, amphibians, and ancestors of mammals called *pelycosaurs*.

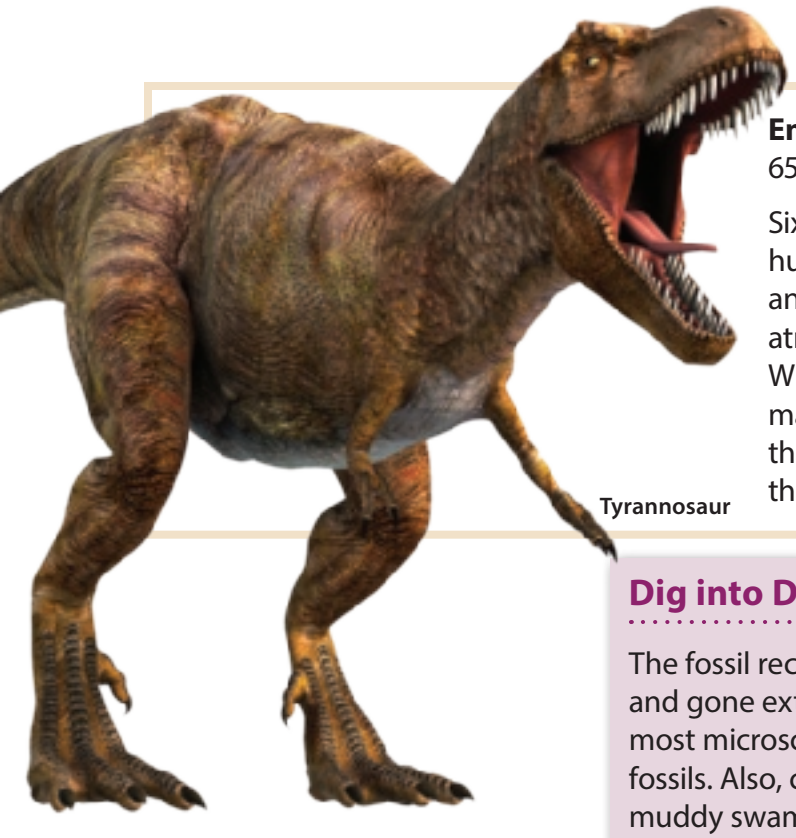


Conodont

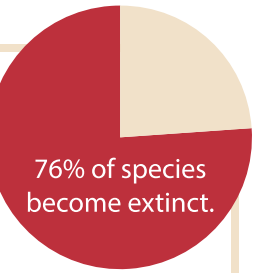


End-Triassic Extinction:
210 million years ago

As the super-continent Pangaea began to break apart and volcanic eruptions increased, these events may have led to climate change. Many species of animals with backbones perished, including reptiles and fish called *conodonts*.



Tyrannosaur



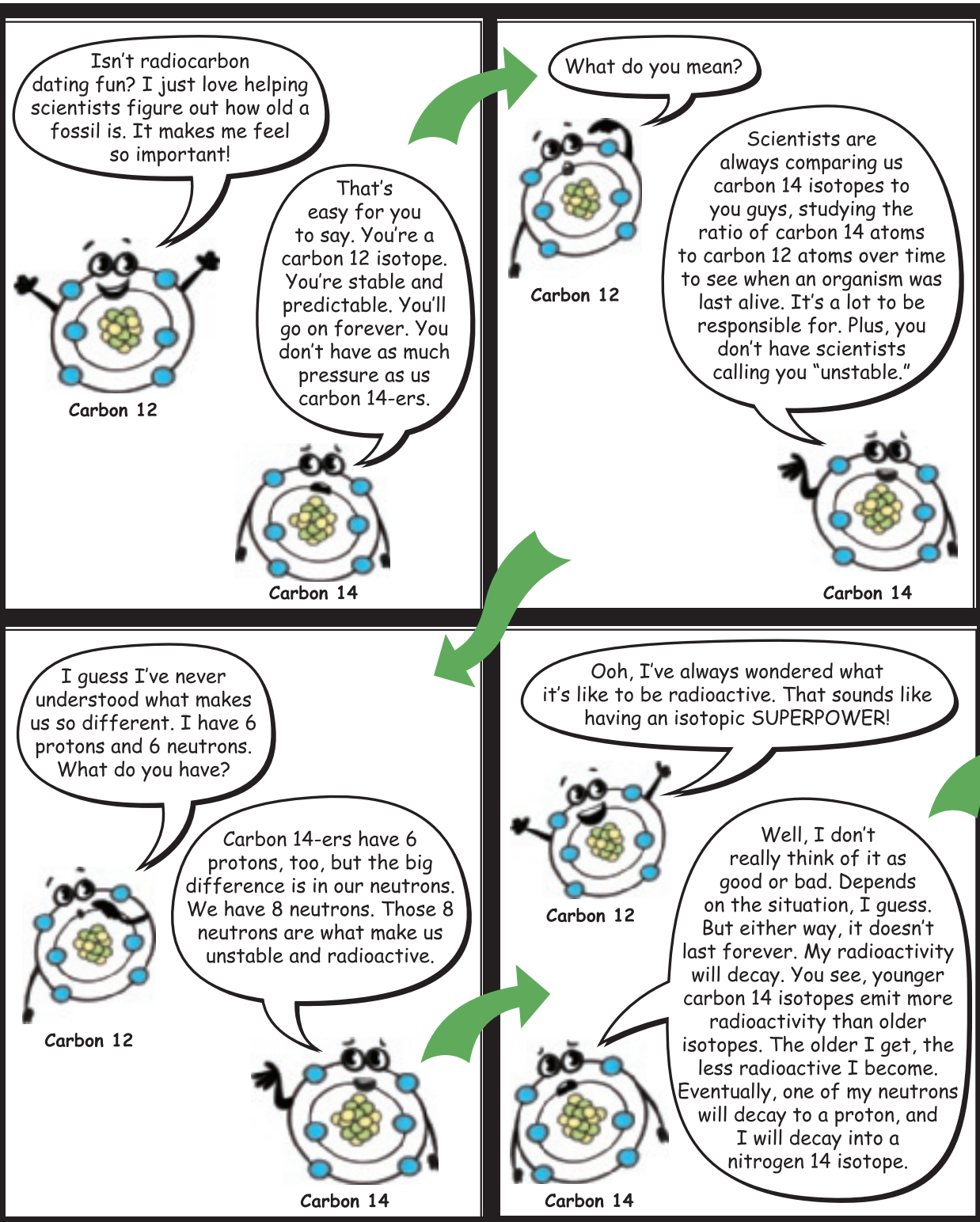
End-Cretaceous Extinction:
65 million years ago

Sixty-five million years ago, a huge asteroid crashed into Earth and sent a dust cloud into the atmosphere that blocked sunlight. Wildfires, volcanic eruptions, and a fall in sea level may have also been culprits in a mass extinction that wiped out all the dinosaur species except those that were the ancestors of birds.

Dig into Data

The fossil record doesn't show all the species that have lived and gone extinct. Not all species form fossils. For example, most microscopic, bacteria-like species never became fossils. Also, creatures didn't always die in places such as muddy swamps where fossils could form. For these reasons, counts of extinct species are always broad estimates.

Carbon 14's Disappearing Act

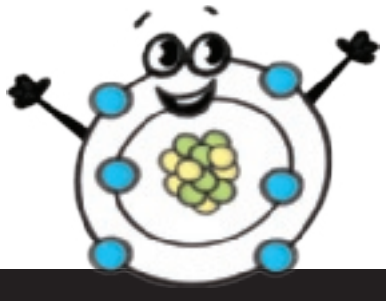


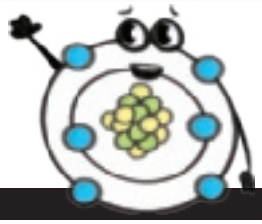
Connection

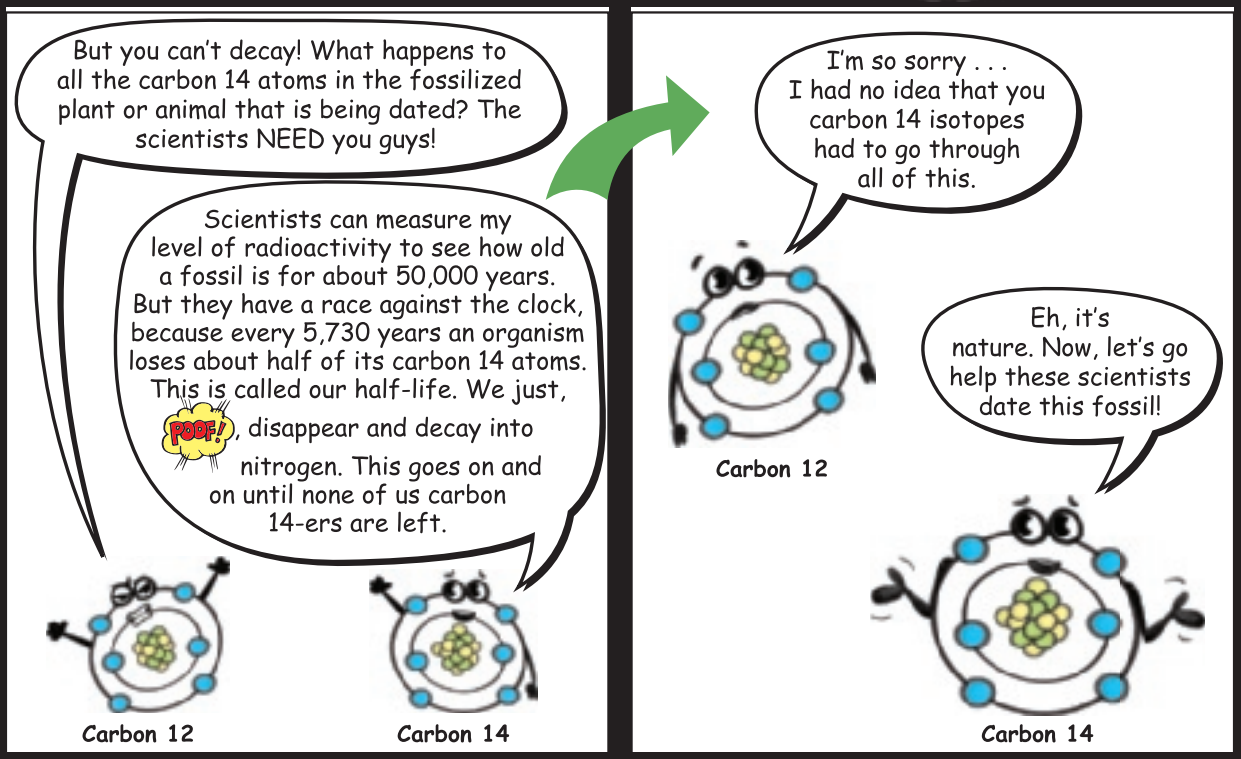
Have you ever wondered how old something is? When you meet a new person, you might ask them their age. If you want to know how old a tree is, you can count the rings on its trunk. For fossils, scientists use radiometric dating.

Word to Know

Radiocarbon dating is a process in which scientists study the ratio of carbon 12 to carbon 14 atoms in a fossilized organism to tell how long ago the organism was alive. Scientists can tell how old a fossil is by analyzing the remaining amounts of carbon 14 atoms, but this process is limited to going back about 50,000 years. *Radiometric dating*, studying isotopes that decay over longer periods of time, is used for older materials.







Living Things

What makes something alive? Humans have wrestled with this question for thousands of years. Today, scientists' definition of *living* centers on several defining abilities:

Word to Know

Homeostasis is a stable internal environment.

The ability to react to stimuli



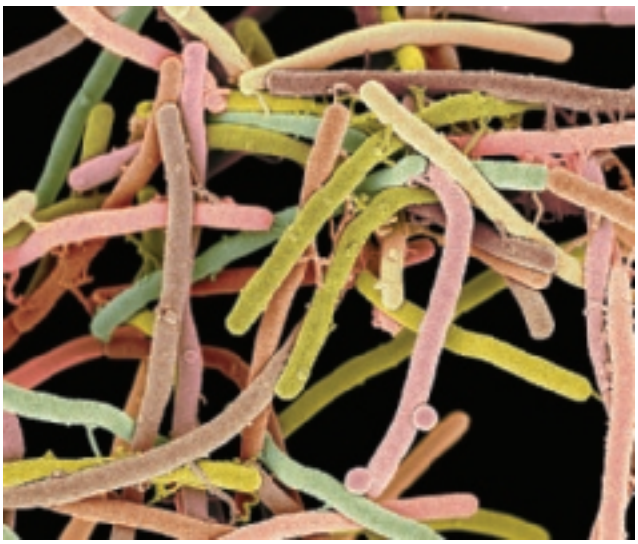
A bat uses its large ears to hear mosquitoes in the air.

The ability to maintain homeostasis



A turtle suns itself to gain thermal energy and make its internal environment more stable.

The ability to reproduce and grow



Bacteria can reproduce very quickly.

The ability to acquire energy



A shark preys upon fish.

Fungi, animals, plants, protists, archaea, and bacteria are all considered living things because they have the four abilities listed on the opposite page. Each of these large groups, or **taxa**, can be further divided into other taxa. Each taxon farther out on a branch of the tree of life has organisms that are more closely related. Organisms that can reproduce with each other and produce offspring that are also capable of reproducing are part of the same **species**. Within a species, scientists sometimes identify types that have distinguishing characteristics. These are known as subspecies.

Taxonomy is now guided by genetics. When the genomes of organisms are analyzed, scientists can determine that two organisms that look the same on the outside are distinct species. In 2013, biologists in South Carolina determined that some of the scalloped hammerhead sharks they had sampled from coastal waters were genetically distinct from most of the others and also had ten fewer vertebrae. Otherwise, it was impossible to tell the two types apart. Sharks that would've been lumped in with others of the species *Sphyrna lewini* are now called *Sphyrna gilberti*, named after a scientist, Carter Gilbert, who first noticed the difference in the number of vertebrae among some scalloped hammerheads years earlier.

Vocabulary

taxa, n. plural of *taxon*, a group of related species

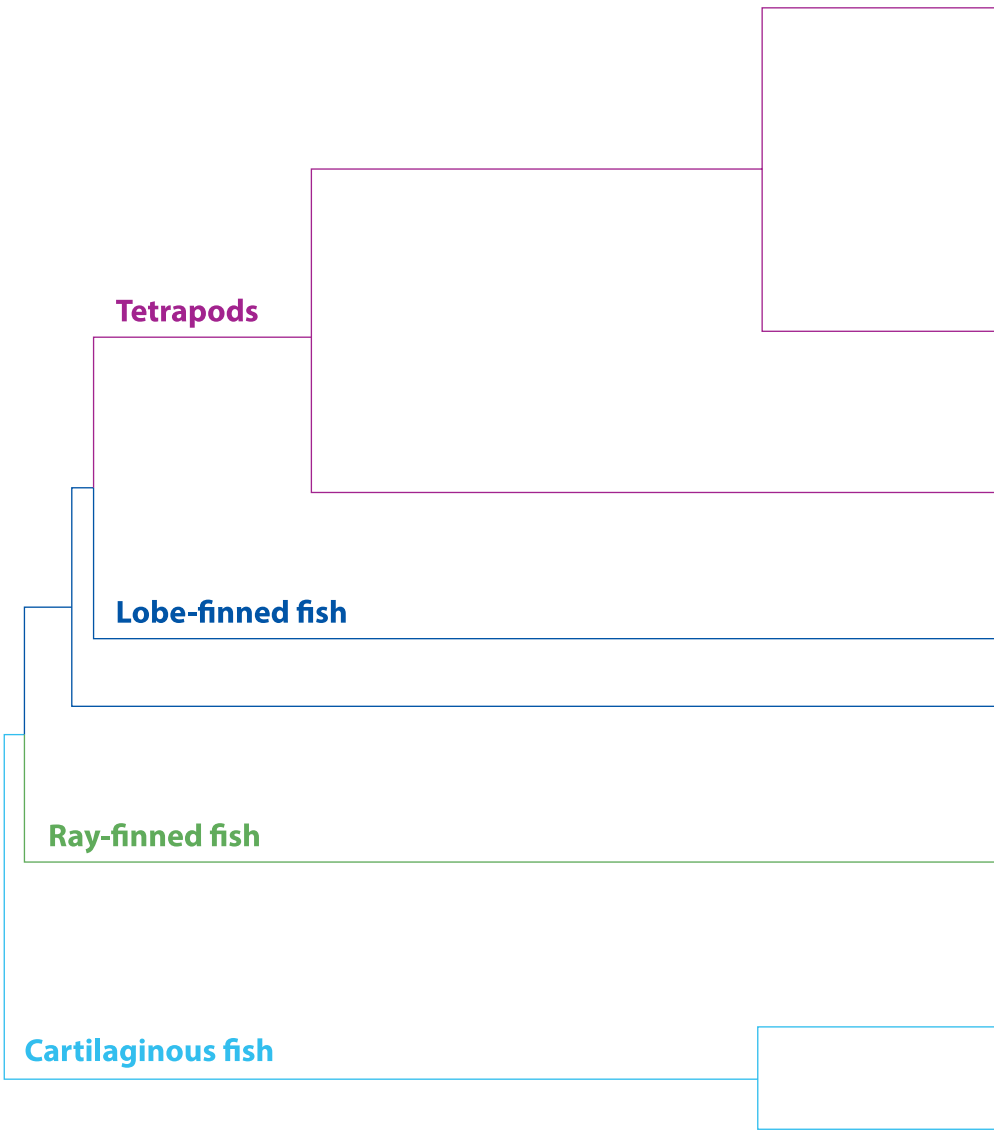
species, n. a group of living organisms consisting of similar individuals capable of exchanging genes or interbreeding

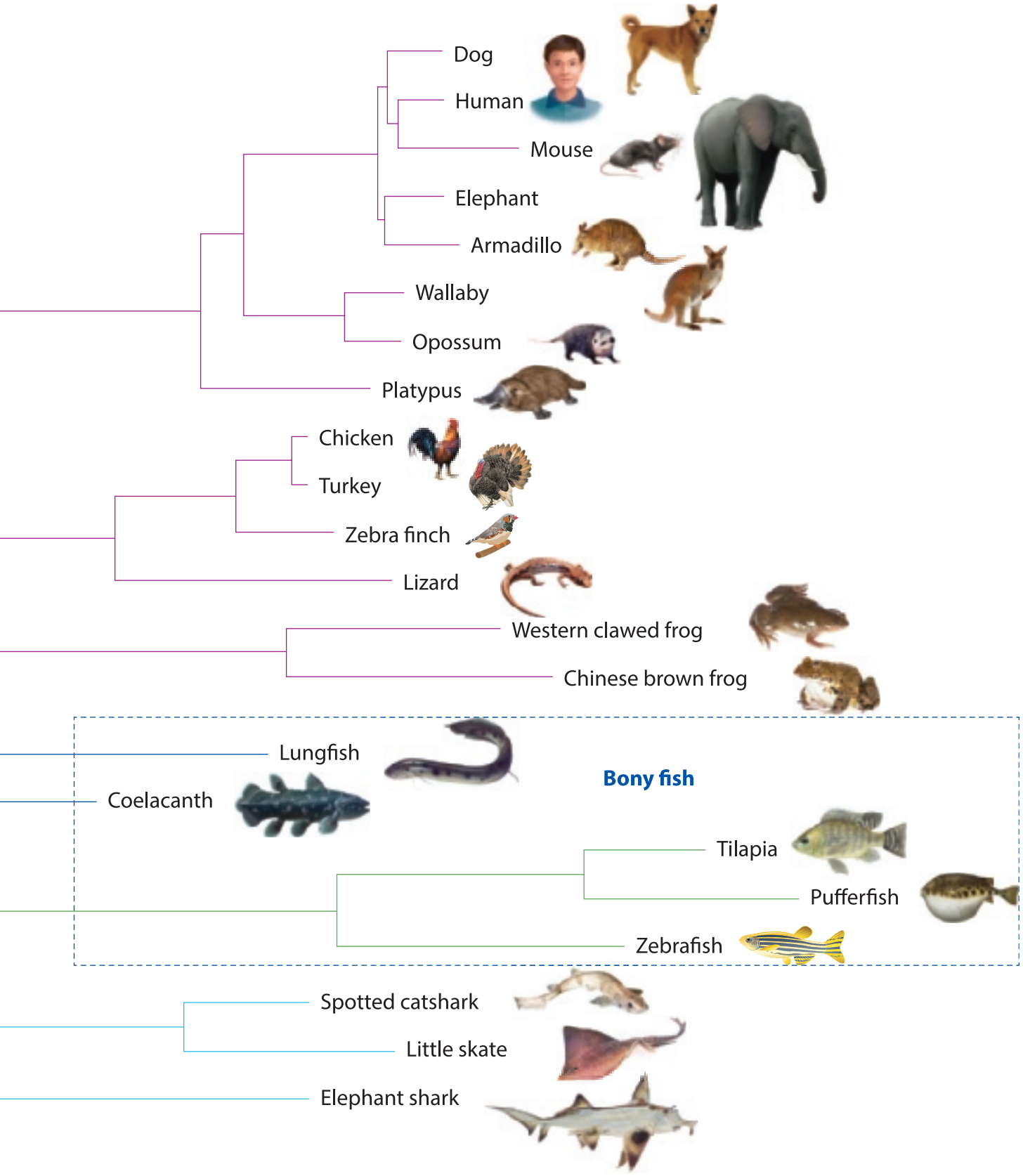


One goal of taxonomy and DNA analysis is to develop a phylogenetic tree. This is a diagram that shows how different life-forms are associated with each other. In this tree, which shows many kinds of vertebrate animals, you can see that all the land vertebrates can be traced back to common ancestors that are fish. By following the branches of the tree, you can tell which animals are more closely and less closely related to one another. Genetic analysis shows that humans and other animals known as tetrapods are more closely related to bony fishes than bony fishes are to sharks and rays. This comes as a surprise to many people, because sharks and rays are usually lumped in with other fish and their physical features and behaviors make them seem closely related.

Word to Know

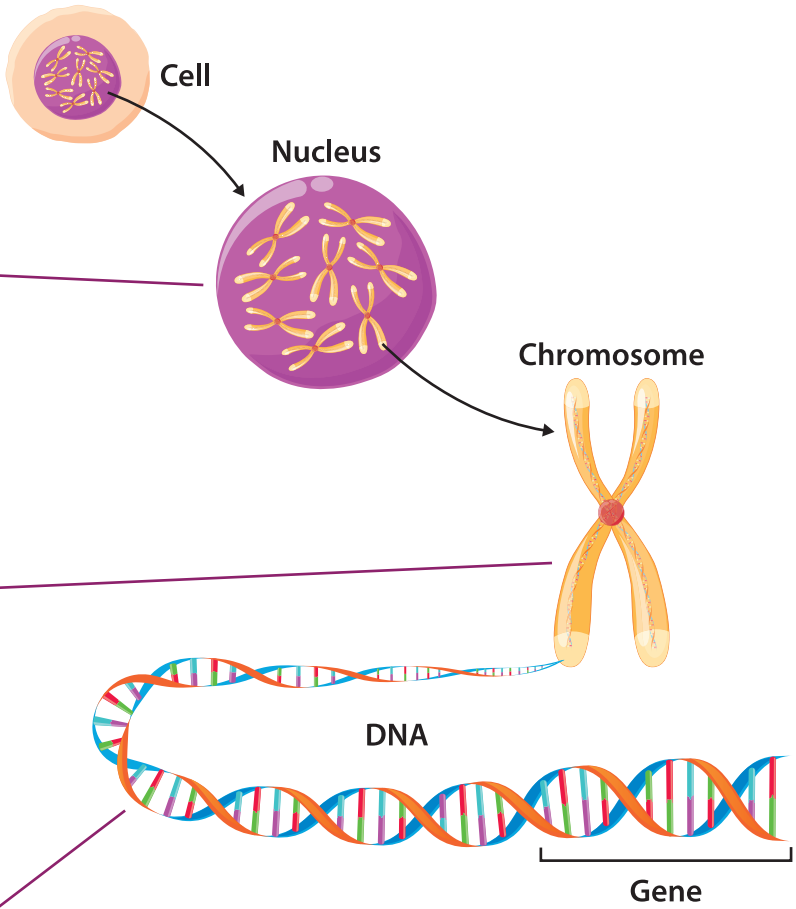
Phylogeny, or *phylogenesis*, is the evolutionary history of organisms. The word *phylogeny* comes from the Greek *phylon*, which means "race" or "tribe," and *genesis*, which means "origin."




Dog
Human
Mouse
Elephant
Armadillo
Wallaby
Opossum
Platypus
Chicken
Turkey
Zebra finch
Lizard
Western clawed frog
Chinese brown frog
Lungfish
Coelacanth
Bony fish
Tilapia
Pufferfish
Zebrafish
Spotted catshark
Little skate
Elephant shark

It's All in the Genes

Cells are the building blocks of life, and all living things are made of them. Your cells are responsible for many functions, one of which includes carrying the instructions that determine how you become the unique organism that you are.



The instructions for determining how a person forms and what they look like are found within a cell's nucleus. The nucleus is an inner part of a cell that contains chromosomes.

Chromosomes are materials located within a cell's nucleus. They are made of proteins and deoxyribonucleic acid, or DNA. Each chromosome is a single molecule of DNA wrapped up tightly around proteins so that the DNA fits within the cell and is isolated from many cell activities. However, if the number or structure of chromosomes changes as new cells are formed—such as if some chromosomes break or go missing—this can cause offspring to have certain diseases or disorders.

DNA is a molecule that carries genetic information and is known for its double helix structure. A DNA molecule is made up of sugars and phosphates, and each sugar has a base attached to it. There are four bases that can attach themselves to a sugar—adenine, cytosine, guanine, and thymine—and the bases are organized in a particular sequence that is unique to an individual.

Genes are long segments of DNA and are primarily responsible for inheritance. Genes are passed down from parents to their offspring, and they contain codes for proteins, which the body reads like a recipe. The specific proteins and sequences are what make people unique and create physical variations from person to person. They determine a person's eye and hair color, face shape, height, and other traits and structures based on the genetic information inherited from the parents. However, genetic information can change or mutate, and these mutations can be passed to offspring.

Connection

Have you ever seen siblings that look similar but have different hair or eye colors? The siblings came from the same set of parents, but because everyone's genes are coded differently, there are variations in their traits despite being so closely related.

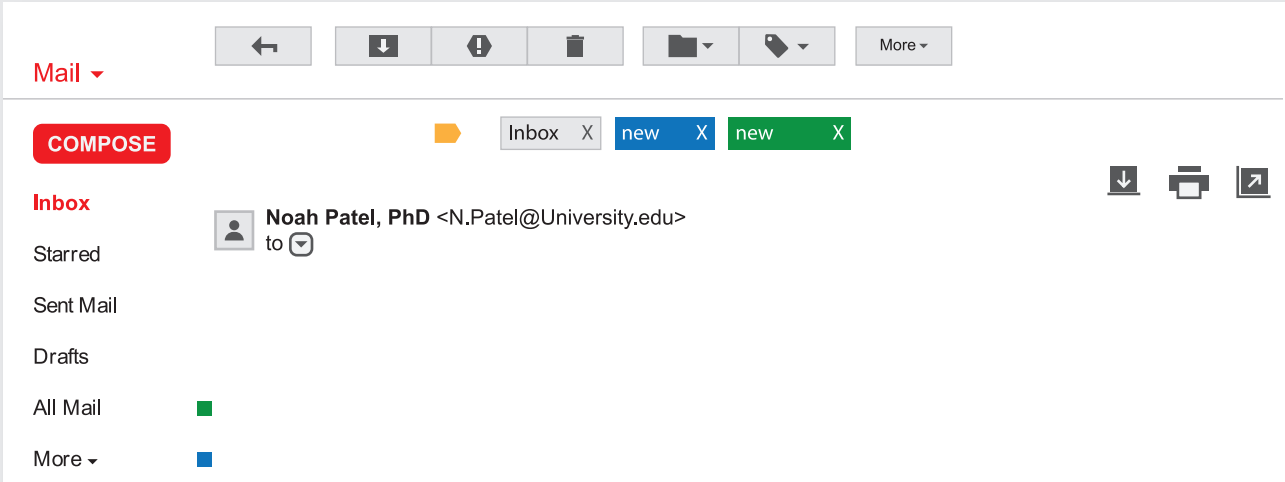


Imagine having a tolerance for pain so high that it's almost superhuman. A woman named Jo Cameron can describe such a life. She experiences minimal or no pain from injuries like burns and broken limbs—and even surgeries! After studying Cameron's DNA, pain specialists in London found specific genetic mutations that affect how pain is signaled and interpreted within her body. This "recipe" for minimizing or eliminating pain is being researched and tested by bioengineers and geneticists who study gene therapy. Gene therapy is a technique in which the genes within a person's body are altered to treat certain types of diseases and disorders. A pain-reducing gene therapy protocol would be life-changing for millions of people around the world who experience chronic or acute pain and depend on medications for relief.



A mutation is a type of variation or alteration that deviates from the norm, so for scientists to identify a genetic mutation, they must first have a deep knowledge of "normal" genes. And to understand genes, scientists also need to study and understand DNA and chromosomes—the set of instructions that work together to make you who you are. Genes, DNA, and chromosomes are passed down from parents to children to determine the traits and structures of offspring.

Hunting for Mutations



Hi Professor Patel,

Thank you again for recommending me for this internship in London. Working in a biology lab has turned out better than I expected. Who knew that hunting for genetic mutations could be such an emotional roller coaster for the people involved?!

The scientists here have been looking for years for genes that control how people feel pain and have had some success. A few years ago, they heard about an Italian family that feels pain at first, but after a few seconds, the pain disappears—even the severe pain from a broken leg. The fact that three generations in the family shared this trait meant that it was likely caused by a genetic mutation that they inherited.

Blood samples from the family members were sent to England, and it took a couple of weeks for their DNA to be sequenced, determining the order of the chemical components that make up the DNA molecule. Then the lab compared the family's DNA to that of people who sense pain in the normal way. Computer software does most of the work—without computers and database software, this kind of search would be nearly impossible.

Next, our lab team looked at the family's genes that differed from the "normal" group. They found a mutation of a gene that helps control the nervous system. That seemed promising. But after months of trying, no differences were found in the proteins produced by the mutated and normal genes. Discouraging!

Meanwhile, the software improved, and the lab tried again to find a mutation. Sure enough, one turned up in a gene known to be involved in sending pain signals along neurons to the brain. Even better, all the Italian family members with the condition had this mutated gene!

The next step was to have another lab breed mice that have the exact same mutation as the human family. When the mice arrived at our lab and were tested, the team found out that the mice were also less sensitive to heat and pressure than mice with the normal gene. It was exciting to be able to tell the Italian family that the cause of their condition is a mutation to the gene named *ZFHX2*!

The best part of it all is the possibility that research into this gene may help people who suffer from long-term pain. For my next internship, I hope to be able to join a lab where scientists are working on a gene therapy to help these patients. Stay tuned!

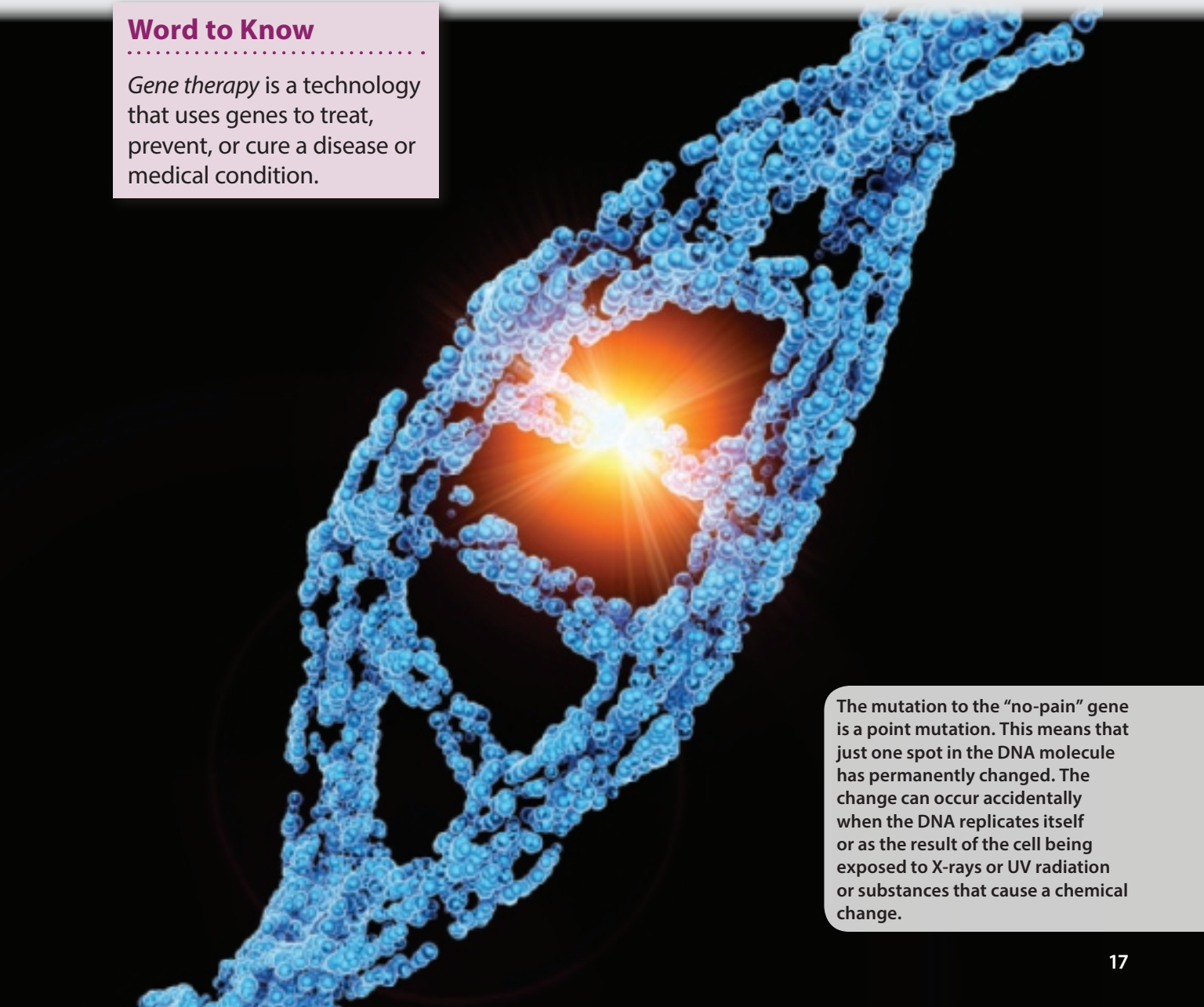
Best,

Kara Nguyen

Undergraduate Biological Sciences, Class of '25

Word to Know

Gene therapy is a technology that uses genes to treat, prevent, or cure a disease or medical condition.



The mutation to the "no-pain" gene is a point mutation. This means that just one spot in the DNA molecule has permanently changed. The change can occur accidentally when the DNA replicates itself or as the result of the cell being exposed to X-rays or UV radiation or substances that cause a chemical change.

Variation Within Species

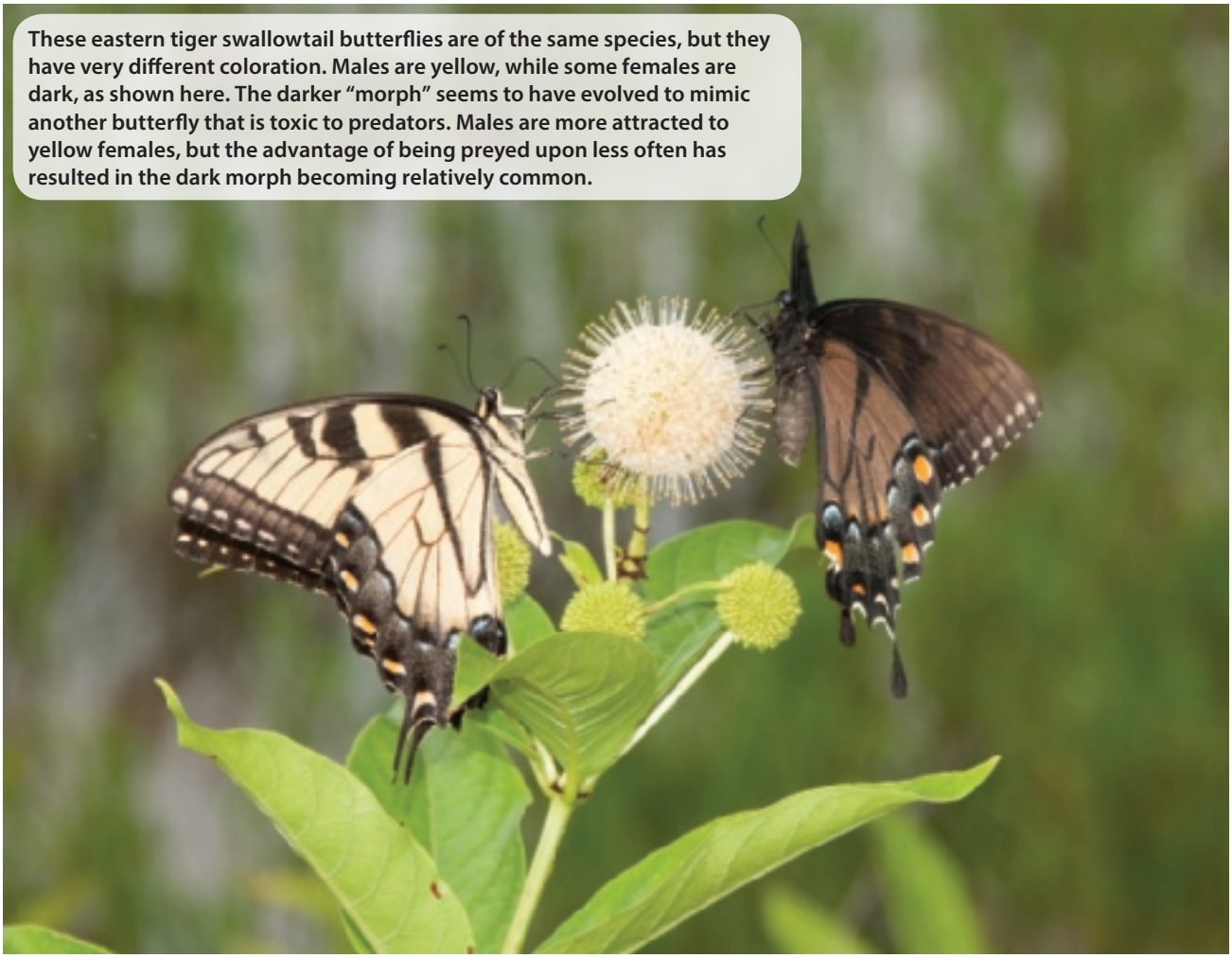
Even within a species, there can be incredible variation in traits. Some of that variation is the result of how the parents' genes are doled out to the offspring. Some of it is due to environmental factors, including temperature and substances that turn genes on or off. And some of it is due to how genes can become common across different populations.



These nudibranchs belong to the same species, *Goniobrachus geometricus*, but they display very different colors. Their coloration can help them blend in among corals, or it can serve as a warning to would-be predators that eating them would be a bad idea.



These Himalayan rabbits have different colors and sizes because of environmental temperature on the expression of genes. The smaller, darker rabbit was exposed to cold at birth, resulting in darker fur and smaller size.



These eastern tiger swallowtail butterflies are of the same species, but they have very different coloration. Males are yellow, while some females are dark, as shown here. The darker "morph" seems to have evolved to mimic another butterfly that is toxic to predators. Males are more attracted to yellow females, but the advantage of being preyed upon less often has resulted in the dark morph becoming relatively common.





On the south side of the Grand Canyon lives Abert's squirrel, *Sciurus aberti*. On the north side lives the Kaibab squirrel, *Sciurus aberti kaibabensis*. The third part of the Kaibab squirrel's scientific name indicates that it is considered a subspecies, or a very closely related type of the same species. Climate change and the separating effect of the canyon led to populations of the ancestral Abert's squirrel becoming isolated from each other. Over time, differences evolved. The two subspecies can still interbreed, which means they are not classified as separate species.

Convergence

When two things that aren't related are similar, this is called **convergence**. In evolution, very similar traits can appear in species that are not closely related. This can be observed between species that exist in the present day and between today's species and long-extinct species.

Vocabulary

convergence, n. independent evolution of similar traits across unrelated species



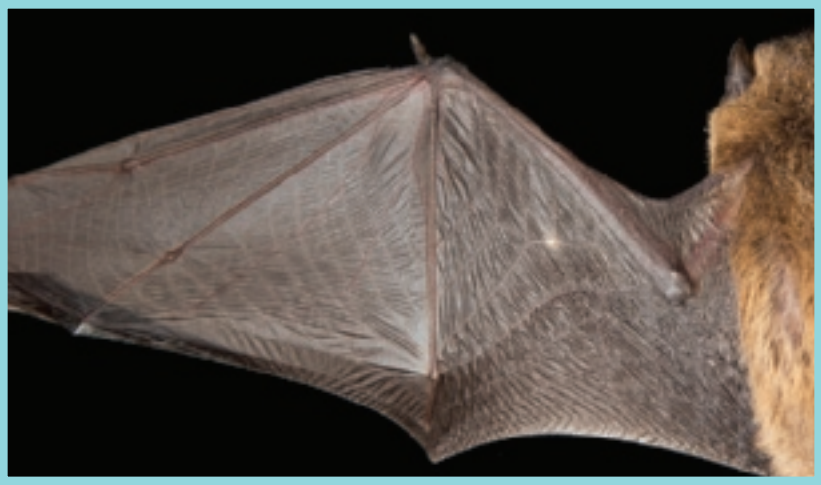
Ichthyosaurs were reptiles that lived hundreds of millions of years ago. They had skeletons made of bone and had caudal (tail) fins and dorsal fins like those of many modern sharks. But they were air breathers, not fish.



The long tom is a kind of needlefish. Its long, toothed jaws are very similar to those of ichthyosaurs, but the long tom is a fish, and it did not exist at the time of the ichthyosaurs and other giant reptiles.



Though it's known as a fish, the great white shark and other sharks are not bony fishes like the long tom. The dorsal and caudal fins of the great white are very similar to those of the ichthyosaurs. The tail is very narrow and stiff in front of the caudal fin to give the shark a lot of thrust. Even though the shark and the ichthyosaur are not closely related, they have similar structures because they lived in and needed to move through the same environment.



Bats are mammals whose finger bones evolved to form the frame for wings. The wing itself consists mostly of thin, stretched skin.



Bird wings are supported by long arm bones, but they consist mostly of feathers.



Thousands of different insect species have wings.



Flying fish used their pectoral fins, which have evolved to function as wings, to briefly glide through the air after leaping from the ocean's surface to escape predators.

Evo-Devo

Evolutionary developmental biology is called evo-devo for short. It compares the development of embryos across different groups of organisms to make inferences about evolutionary relationships.

Fish		
Salamander		
Turtle		
Chicken		
Human		

Connection

What do the different types of organisms appear to have in common in the earliest part of their development? How do the types of organisms diverge as they develop? What common characteristics do they retain?













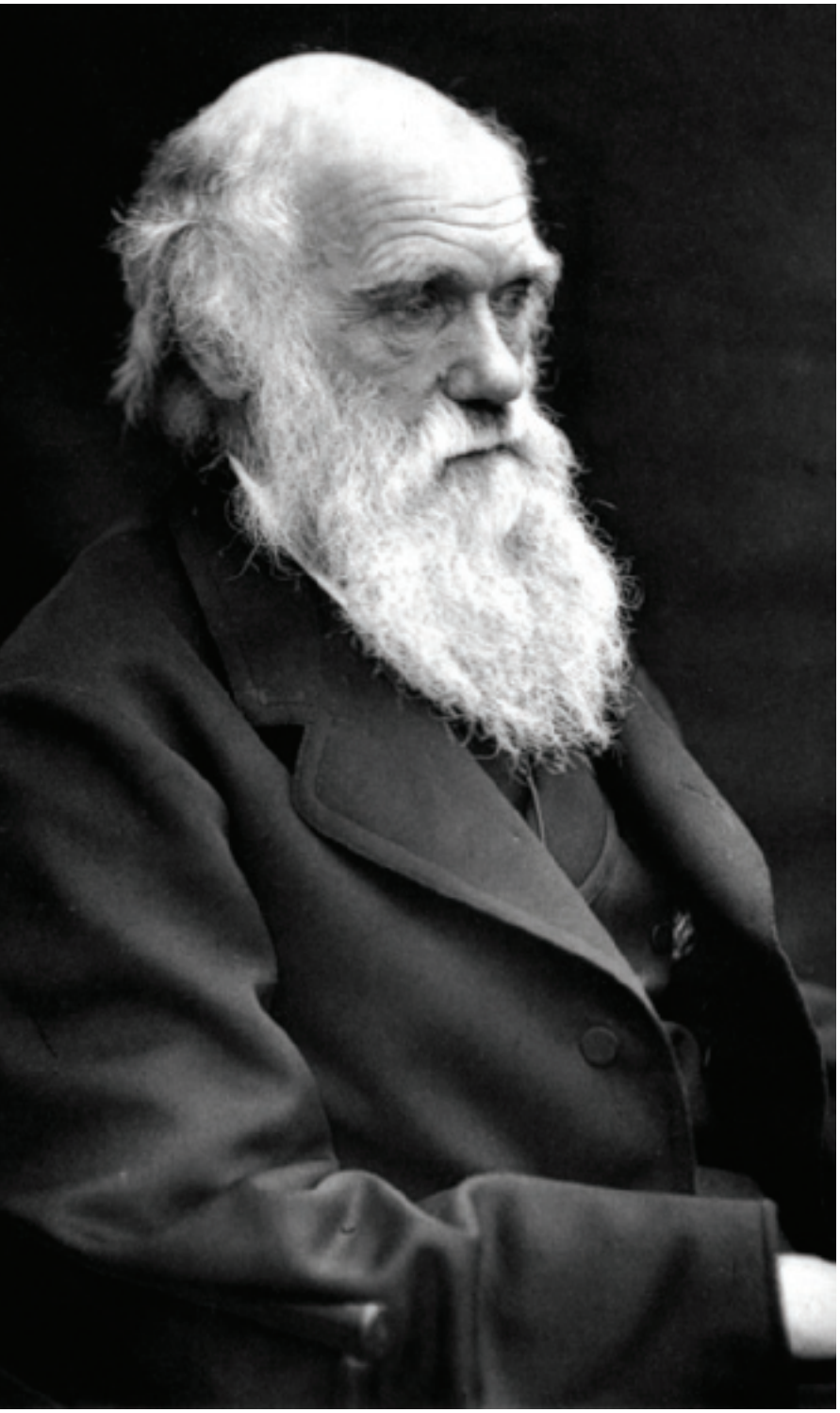








The Most Famous Writer Seldom Read

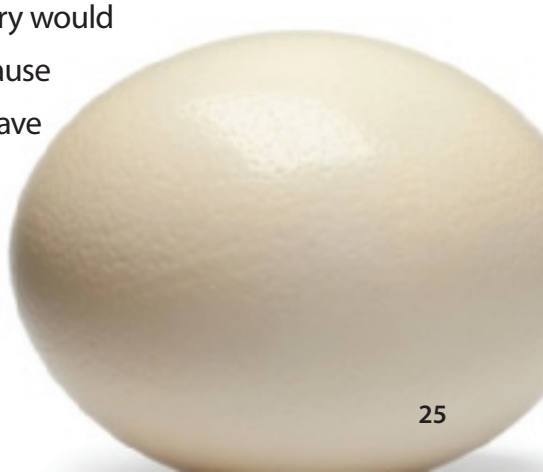


Charles Darwin's name is inseparably tied to the terms *evolution* and *natural selection*. Though Darwin's association with the idea of evolution by natural selection is common knowledge, it's safe to say that most people in the present day haven't directly read his most famous publication. Darwin's book, known in short as *On the Origin of Species,* was first printed by the publisher John Murray in London in 1859. The full title is *On the Origin of Species by Means of Natural Selection, or Preservation of Favoured Races in the Struggle for Life*. The saying "survival of the fittest" is our modern shorthand for the title phrase "*Preservation of Favoured Races in the Struggle for Life*." Take a look at some of the writing straight from Darwin's pen. On the left are a few passages from Chapter 3 of Darwin's famous work. The notes to the right expand on what Darwin meant.

The only difference between organisms which annually produce eggs or seeds by the thousand, and those which produce extremely few, is, that the slow-breeders would require a few more years to people, under favourable conditions, a whole district, let it be ever so large. The condor lays a couple of eggs and the ostrich a score, and yet in the same country the condor may be the more numerous of the two: the Fulmar petrel lays but one egg, yet it is believed to be the most numerous bird in the world… A large number of eggs is of some importance to those species, which depend on a rapidly fluctuating amount of food, for it allows them rapidly to increase in number. But the real importance of a large number of eggs or seeds is to make up for much destruction at some period of life; and this period in the great majority of cases is an early one. If an animal can in any way protect its own eggs or young, a small number may be produced, and yet the average stock be fully kept up; but if many eggs or young are destroyed, many must be produced, or the species will become extinct. It would suffice to keep up the full number of a tree, which lived on an average for a thousand years, if a single seed were produced once in a thousand years, supposing that this seed were never destroyed, and could be ensured to germinate in a fitting place. So that in all cases, the average number of any animal or plant depends only indirectly on the number of its eggs or seeds.

One of Darwin's key observations was that different species produce very different numbers of offspring but that both approaches to reproduction work in the sense of keeping a population going and passing on traits of the parents. Some organisms produce huge numbers of offspring, while others produce very few. Those that produce many also tend to lose many of those offspring. Darwin cites two birds. The condor lays few eggs, yet it is more abundant than the ostrich, which lays more eggs. Why? The condor's eggs receive more care, so the young condors are more likely to develop and reach adulthood. The ostrich takes a "strength in numbers" approach that also works because there are so many offspring that losing some to predators does not stop the parents from adding some surviving offspring to the population.

The amount of death that occurs in any given generation of offspring sets the stage for traits that increase an individual's chance of survival to be passed on to the next generation more than the traits of the offspring that don't reach adulthood. If all organisms survived the different stages of life and died of old age, Darwin's theory would not work because traits would have no effect on chances of survival.



If during the long course of ages and under varying conditions of life, organic beings vary at all in the several parts of their organisation, and . . . variations useful to any organic being do occur, assuredly individuals thus characterised will have the best chance of being preserved in the struggle for life; and from the strong principle of inheritance they will tend to produce offspring similarly characterised. This principle of preservation, I have called, for the sake of brevity, Natural Selection. Natural selection, on the principle of qualities being inherited at corresponding ages, can modify the egg, seed, or young, as easily as the adult. Amongst many animals, sexual selection will give its aid to ordinary selection, by assuring to the most vigorous and best adapted males the greatest number of offspring. Sexual selection will also give characters useful to the males alone, in their struggles with other males.

Natural selection, also, leads to divergence of character; for more living beings can be supported on the same area the more they diverge in structure, habits, and constitution, of which we see proof by looking at the inhabitants of any small spot or at naturalised productions. Therefore during the modification of the descendants of any one species, and during the incessant struggle of all species to increase in numbers, the more diversified these descendants become, the better will be their chance of succeeding in the battle of life.

Darwin's groundbreaking insight was how variation leads to advantaged individuals who then produce advantaged offspring. Even though he did not know how "qualities being inherited" actually worked, he knew that something allows traits to be passed on and that traits that improved an organism's ability to survive the "struggle for life" would be more likely to be passed on than the traits of organisms that did not survive.

Darwin also recognized that natural selection accounts for the diversity of life, including the diversity within a species. Diversity also leads to an improved chance that the species—some of its members, even if just a few—will survive even in dire circumstances.



Darwinian Dictionary

adaptation, n. an inherited trait that improves an organism's fitness for survival

Clarification: Individuals don't really adapt; species do. Individuals only survive or do not survive. The concept of adaptation doesn't mean that an individual plant or animal changes its traits to perform better in (to adapt to) its environment. It means that individuals that are genetically lucky enough to have the better traits in an environment are better off. And thus, they're the ones that can reproduce and pass their traits on to the next generation. Over time, the better traits of fortunate ancestors are common in the population, so a species overall is better adapted to the environment.

natural selection, n. the survival and reproductive success of organisms with qualities best suited to their environment

Clarification: A more apt name for natural selection could be "genetic good luck within the environmental conditions in a place and time." Nothing actively gets rid of disadvantageous traits. The unfortunate individuals with such traits just don't reproduce and pass them on as much.

evolution, n. changes in the genetic structure of populations over time

Clarification: The concept of evolution doesn't imply that living things transform into different species. Instead, each population passes on tiny differences that, over many generations, make the descendants notably different from the long-ago ancestors. And the concept of evolution doesn't imply that humans descended *from* apes. It theorizes, from evidence, that humans and apes are descendants of the same common ancestors.



Artificial Selection







Natural selection has shaped life for millions of years. It's a result of a population of a species affected by changes in the environment, in which particular individuals either thrive or do not. Humans have also acted as agents of selection. They have shaped certain species (and varieties within species) through selective breeding, for example. In these cases, species evolve, not by natural selection, but by artificial selection.



Here's an example . . .



The cats that people have as pets initially came into human lives in a kind of symbiotic relationship and did not involve selective breeding at all. Five thousand years ago, humans were forming settlements and getting serious about farming. Farming and then storing grain represented a source of free food for rodents, which, in turn, attracted cats. Archaeological and biological evidence from China shows that compounds in farmed grain eaten by rodents were ending up in cats. This is fairly direct evidence of cats being allowed to live among humans to act as rodent hunters if not pets. Presumably, one thing led to another, and bonds of trust and eventually affection formed between humans and cats.





DNA studies suggest that most of the 600 million domestic cats now kept as pets throughout the world can be traced to a wild cat species that lived in parts of Asia and Africa. The wide variety of domestic cat breeds today is the result of selective breeding that occurred only in the last 150 years. More than forty breeds are now recognized by cat breeding associations.





Artificial selection now goes beyond choosing parent animals to breed and involves inserting genes directly into the unfertilized eggs of organisms. If the eggs are fertilized, the resulting offspring can have a new gene that was taken from, say, a fluorescent jellyfish. This has been done in a number of species to make them fluoresce under ultraviolet light, or "glow in the dark."

The point of making glowing animals isn't amusement. It's done as a kind of tagging. The jellyfish gene for the green fluorescent protein (GFP) is added to a different organism's genome along with other genes intended to make more important changes for study. If the offspring fluoresces under a UV light, researchers know that the gene transfer worked. If the offspring doesn't glow, researchers know the gene transfer didn't work. This is much less expensive than running genetic tests on all of the treated animals.

A few animals have been modified to fluoresce just for the sake of appearance, though. Genetically engineered aquarium fish, for example, now glow in their tanks.



Young Scientists Podcast



Episode: Selective Breeding
(Begin transcript)
(Intro theme music)

Carmen: Hey, listeners. I'm Carmen. It's good to be back, and thanks for listening to the Young Scientists podcast. Today we have a very exciting guest here with us, Angelo Harmon, who is going to talk to us about something close to many of our hearts: dogs! Welcome to the pod, Angelo!

Angelo: Thanks so much, Carmen. I'm glad to be here.

Carmen: So, Angelo, you have a career as a dog show judge.

Angelo: That's right. I've been a dog show judge for over 20 years.

Carmen: You must know a lot about dogs! I thought it would be fun if you could talk about the different types of dogs you see in your shows and give us some interesting facts about them.

Angelo: Of course. You gave us a good starting point when you used the phrase "types of dogs." When people refer to types of dogs, what they're talking about are dogs' breeds. But keep in mind that all dogs are the same species.

Carmen: Can you tell us more about those two terms, *species* and *breed*?

Angelo: Sure. A species is a group of animals that have similar characteristics and are capable of mating to reproduce. For instance, frogs and horses can't mate because they are different species. However, all wolves belong to the same species, *Canis lupus* of the genus *Canis*. That's where the word *canine* comes from, by the way. Anyhow, different varieties of wolves can mate. So what does that have to do with dogs? Well, dogs are a domesticated subspecies of the wolf. And within this subspecies of dog, there are over 300 different breeds. As a dog show judge, my job is to spot the most exemplary individuals of a breed.

Carmen: I see. Sow how do breeds come about?

Angelo: Golden retrievers, standard poodles, Labradors, dachshunds . . . these are breeds. A breed is a group of animals within the same species that were selectively bred. When a dog is selectively bred, it means a breeder chose two parent dogs and mated them to produce offspring with the characteristics that the breeder

wanted. Selective breeding doesn't happen naturally. In the case of dogs, selective breeding from the wolf ancestor has produced everything from the mighty mastiff to the teacup Chihuahua. Mastiffs and Chihuahuas are of the same species, believe it or not; but they are dramatically different breeds.

Carmen: We've definitely gotten an amazing variety of dogs through selective breeding, each with their own wonderful traits. What are some of the advantages and disadvantages to selective breeding?

Angelo: In the dog show world, we classify dogs into different groups, like the Working Group, Sporting Group, Herding Group, and so forth. And within each group, we see different breeds of dogs that can specialize in different things. Some breeds make great guard dogs, others are fast runners, and some are great hunters. It's really incredible. Selective breeding has made it so that we can work with these animals, but they've also become lovable members of our families as pets.

Carmen: Variety is a good thing, right? Is there a downside to it, though?

Angelo: Well, there is, unfortunately. With selective breeding to emphasize certain characteristics comes certain health disadvantages.

Carmen: Can you give us some examples?

Angelo: Sure. Breeds like pugs and French bulldogs are more prone to breathing problems because of their flat muzzles. Great Danes, Irish wolfhounds, and other large dogs can have issues with their bones because their big size puts stress on their bodies. Dachshunds and toy dogs can have orthopedic problems because of their short legs. Show dogs obviously represent the finest of their breeds, but every now and then, with a very trained eye, we can spot a dog with some physical deformities.

Carmen: And the question we've all been waiting for: Do you have a favorite dog breed?

Angelo: [pauses] I really love them all. But I would have to say the greyhound. Their musculature, vision, and speed are super impressive and a very interesting contrast to their elegance and laid-back personalities. They also occur in dozens of fur colors and patterns. It makes me want to collect them! [laughter]

Carmen: Well, Angelo, it's been so interesting having you on the pod today! Thank you so much for coming on and talking to us about our best friends.

Angelo: Thanks so much for having me, Carmen. It's been a pleasure. Maybe this episode of your podcast will be voted "Best in Show"!

(Closing theme music)

(End transcript)

Pigotie Survival: A Classroom Game

Ms. Roman's class plays a classroom game called Pigotie Survival. The mythical pigotie birds of Zoweyland nest in trees near lake shorelines and feed on insects. Pigotie birds lay four eggs in a clutch. When they are just learning to fly, the pigotie chicks eat small insects off the sand below their nest. Pigotie birds mature in one year and have a life span of three years.

Chukkers hawks feed on fish in the shallow water. When convenient, they also pick off pigotie chicks feeding on the sandy beach. Once in a while, a Chukkers hawk will go after pigotie chicks in the nest.



Playing the Game:

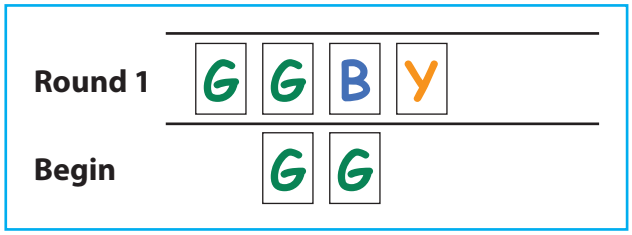
- Players secretly record their predictions of how many pigotie birds of different colors will make up the population in three years. *Then the game is on!*
- Die rolls determine outcomes for the pigote birds.
- Each round (three rolls of the die) represents one year in the pigotie population.
- Survival is tracked on a chart with a row for each round.
- Surviving birds form nesting pairs and produce offspring as follows:

Pairing	Chicks in nest
B + B	Four blue
B + G	Two blue, two green
B + Y	Four green
G + G	Two green, one blue, one yellow
G + Y	Two green, two yellow
Y + Y	Four yellow

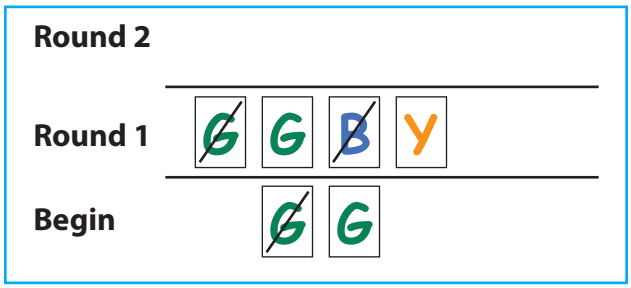
Roll Result	Action
1	Hawk strikes nest. Remove one offspring per nest.
2	Wildfire burns nest. Remove one offspring per nest.
3	Tsunami destroys nest. Remove one offspring per nest.
4	Camouflage failure on beach. Remove one green or blue chick per nest.
5	Camouflage failure on beach. Remove one green or blue chick per nest.
6	Remove one parent. Remove a chick if a parent is no longer available.

To Begin: Round 1 begins with two green parents. For two green parents, the resulting clutch yields

- two green chicks,
- one blue chick, and
- one yellow chick.



Round 1: Chris rolls the die three times, resulting in a 1, a 5, and a 6.
Chris removes a green chick, a blue chick, and a green parent. One green parent, one green chick, and one yellow chick survive.



Round 2: It's a new year with a new batch of chicks! Before the die roll again, the nests must be repopulated.

- Every two remaining pigotie birds starts a nest.
- When an odd number of pigotie birds remains, a green parent is added to fill out the mating pairs for the round.

Round 3								
Round 2	G	G	B	Y	G	G	Y	Y
Round 1	~~G~~	G	~~B~~	Y				
Begin		~~G~~	G					

Chris's turn ended with one yellow and two green pigotie birds.

The green + green pairing results in a nest of one blue, two green, and one yellow chicks.

The green + yellow pairing results in a nest of two green and two yellow chicks.

Both nests are added to the Round 2 row of the chart. Now there are three nests.

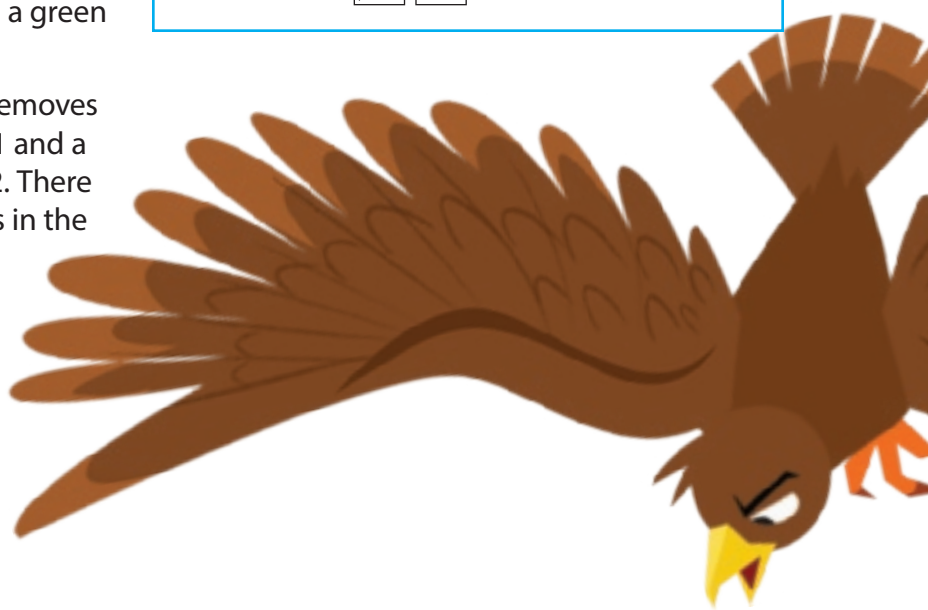
Devin rolls the die three times, resulting in a 2, a 5, and a 5.

Because of the 2 (Remove one offspring per nest), Devin removes a green chick from Round 1, a green chick from Round 2 Nest 1, and a yellow chick from Round 2 Nest 2.

Because of the first 5 rolled (Remove one green or blue chick per nest), Devin removes a blue pigotie bird from the Round 1 nest and a green pigotie bird from both Round 2 nests.

Because of the second 5 rolled, Devin removes a blue pigotie bird from Round 2 Nest 1 and a green pigotie bird from Round 2 Nest 2. There are no more green or blue pigotie birds in the Round 1 nest to remove.

Round 3								
Round 2	~~G~~	~~G~~	~~B~~	Y	~~G~~	~~G~~	Y	~~Y~~
Round 1	~~G~~	~~G~~	~~B~~	Y				
Begin		~~G~~	G					



Round 3: It's another new year and time for a new batch of chicks! Since this is the third year, the round begins with removal of any remaining parents from the start of game.

Then it's time to repopulate the nest. There are effectively two breeding pairs surviving, all yellow. This results in eight yellow chicks in the new Round 3 nests.

Kiya rolls the die to determine what will happen to the pigotie bird population.

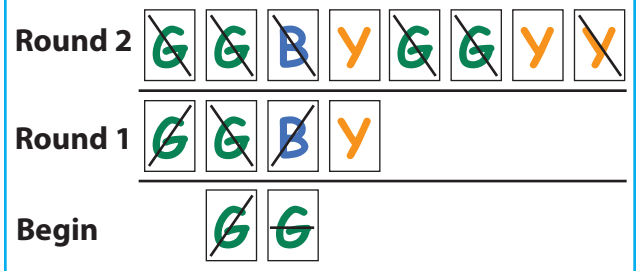
After her roll, it's time to see whose prediction most closely matches the pigotie bird population after three years.



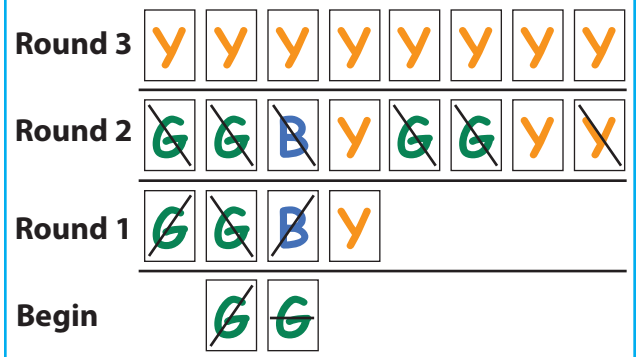




Round 3



Round 4



Connection

The survival of every species depends on enough individual members surviving to produce offspring for future generations. Specific traits can be passed from one generation to the next. These traits may increase, decrease, or have no effect on the probability of survival. A probability is the likelihood of something happening.

Settling a Friendly Debate

Dr. Morgan Shiloh <M.Shiloh@Homeville.edu>

Professor of Biology

Homeville College

Dear Dr. Shiloh,

Thank you for taking time to read my email. I go to Foster Junior High School here in Homeville, and a friend and I are having a debate. We hope you can settle our friendly argument. First of all, I'm not even sure whether you are the right person to ask. Our question is about evolution, so as a biologist, you seemed like a logical person to contact. On the other hand, maybe I should be writing to a paleontologist? Anyway, we did some internet searches and came up dry. Then we took our question to our science teacher. Ms. Roman encouraged us to follow through and reach out directly to an expert, so I'm hoping that's you!

So here's the debate. My friend Rene lives out on the edge of town where there are lots of wooded areas to explore. We hike the trails sometimes. Last week we spotted several lizards that seem larger than the ones we've seen in previous years. Rene is sure the lizards are evolving to be larger. Rene's theory is that the birds in the woods eat the lizards, so the lizards are adapting by growing larger so they'll become too big for the birds to threaten.

I said that evolution doesn't work like that. First, a group of lizards can't just decide they want to be bigger to fight off birds and then grow that way. Secondly, changes to species don't happen quickly enough that we could see, say, a size difference in a whole species of lizard from one summer to the next. I think maybe we are seeing the larger lizards that have survived to maturity, but that's not an adaptation.

Can you settle our debate? Are we witnessing the evolution of a species of lizard into a larger species? Does evolution of species ever happen quickly enough to be directly witnessed?

With thanks and sincerely yours,

Taylor Drake

Dear Taylor,

To start, kudos to you and Rene for two things—first *for noticing nature*, and second for asking questions about things you've observed. The best way to settle an argument is to learn about a topic with an open mind and then dig into the evidence. So, I'm happy to share some information with you about changes in presently living populations. Evolution by natural selection (and thereby, speciation) is generally a loooong process of genetic change. In a few rare cases, though, elements of it happen on a timescale that we're able to observe.

Taylor, you are correct in noting that organisms do not decide that they need to adapt and then physically transform. Through mutations and other processes, species are undergoing minuscule changes all the time, but individuals don't have a say in the matter. In fact, most species spontaneously change steadily enough across generations that the species as a whole rarely lasts more than a few million years before it goes extinct or changes so much that it is considered a new species. It's a random process in which characteristics that happen to be beneficial in the environment get passed on.

It would take systematic research into your specific population of lizards to know what's going on with their sizes; still, it's not fair to automatically say that Rene is 100% wrong about increments of evolution being observable. Rapid changes, over just a few generations, are observable in small populations over short periods (from tens to hundreds of years). However, those don't tend to "stick" and spread through an entire species. Here's an example. When brown anole lizards invaded the Florida habitats of green anoles, the green lizards adapted over about 20 generations, in just 15 years after the brown lizard invasion. Green lizards with larger, stickier toe pads could climb to higher branches to avoid the competition. The high-climbing green lizards with larger toe pads survived to breed more than their smaller-toed kin, which meant increasingly more offspring with those bigger, stickier toes. (I've included a picture of the green *Anolis carolinensis* for you here.)

Generally speaking, though, research across a broad range of species suggests that it takes about a million years for an entirely new species to branch away from an ancestor species.



We could make a summer project out of systematically collecting data on the lizards you and Rene observed. If you are interested in doing that, get back in touch with me, and I'll help you design an investigation.

Best regards,
Morgan Shiloh, PhD
Department of Biology

Extra Bones? Nope!

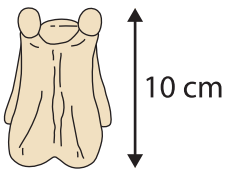
In the early 1800s, a French naturalist named Jean-Baptiste Lamarck suggested that changes to an organism during its lifetime could be inherited by future generations. For example, when giraffes stretched to reach the uppermost leaves on trees, their necks would lengthen a bit. Then, when the giraffes had young, the offspring would inherit the lengthened necks. By the 1930s, most scientists acknowledged that patterns of inheritance are based on interactions among dominant and recessive genes—not on interactions of individual organisms with their environment.

So, how did the tallest land mammal get its height? You might think that giraffes' ancestors, through mutations, acquired more neck bones. But a giraffe has seven cervical vertebrae in its neck, as do most other mammals, including you.

In 2015, a team of scientists compared the neck bones of living giraffes with those of their fossilized ancestors. How many neck vertebrae did the giraffes' ancestors have? Yep, seven.

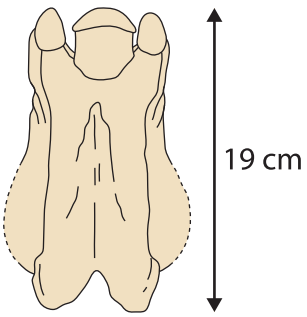
Then the team took a close look at the structure of those bones. They took measurements and compared the ratio of the length to the width of the third bone, and it became clear how giraffes got their long necks.

The scientists concluded that, over millions of years, the bones that support the neck changed in shape. The fossil record doesn't show a simple linear progression, but it does show that older giraffe-like species had shorter vertebrae while more recent species had vertebrae that were elongated. For about 5 million years, the vertebrae nearest the head had elongated but not the bones closer to the animals' backs. More recently, about 2 million years ago, fossils show giraffe ancestors whose vertebrae nearest the back were also elongated. Eventually, giraffe-like animals had elongated vertebrae along their entire necks.



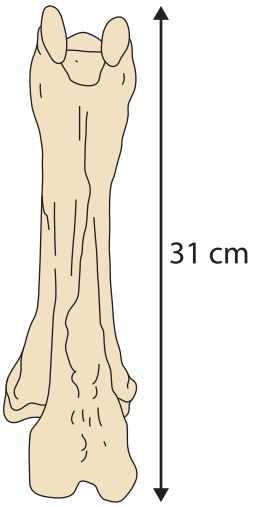
Prodremotherium elongatum

2:1 length to width



Samotherium major

Up to 4:1 length to width

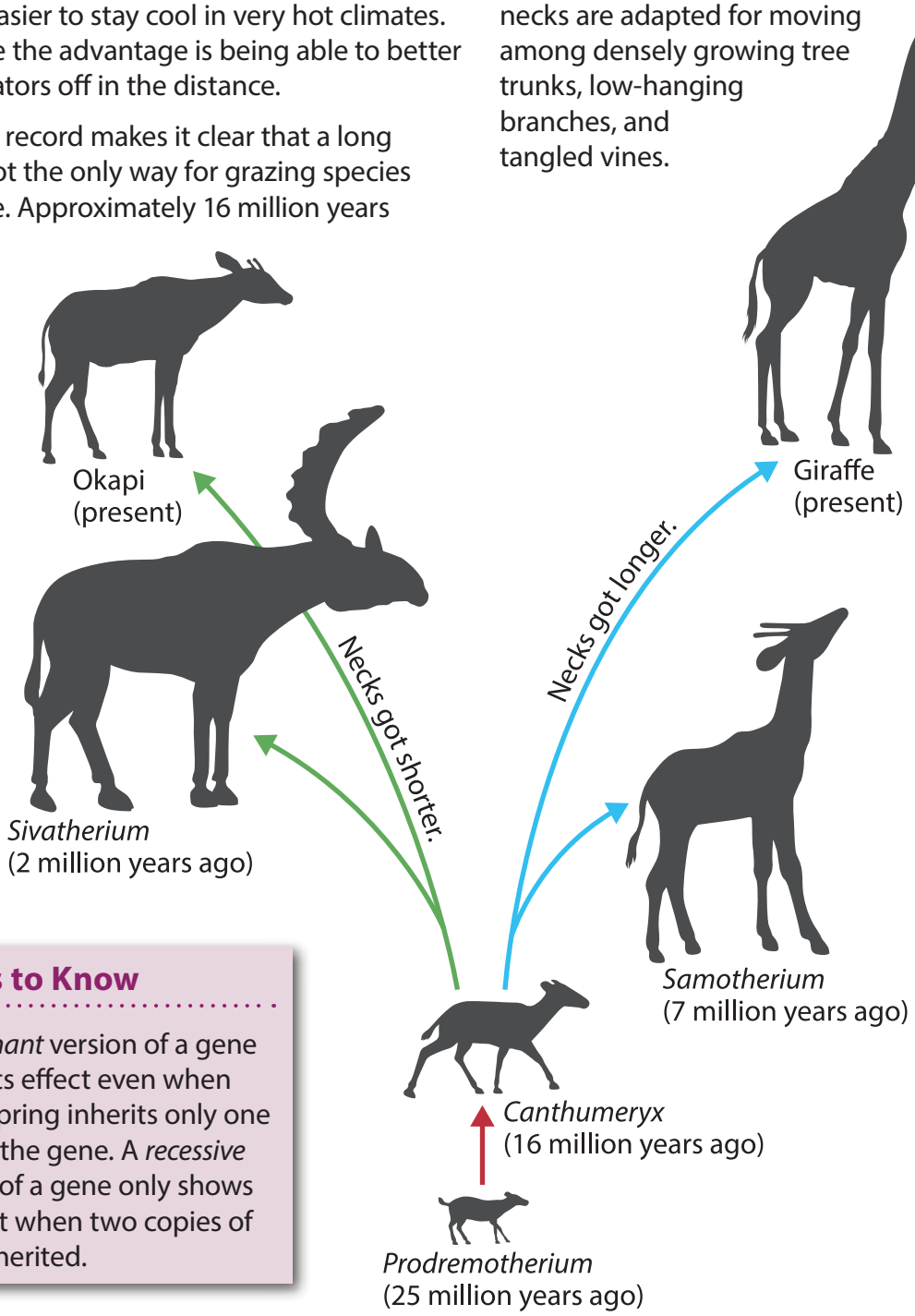


Giraffa camelopardalis

Up to 11:1 length to width

So, what's the competitive advantage of a long neck? The answer is still up in the air. Was Lamarck correct in saying that a long neck allowed a giraffe to reach tasty leaves at the tops of trees where other giraffes couldn't? Scientists are still not sure. Some have suggested that longer necks make the males better able to attract—and battle for—potential mates. Others hypothesize that longer necks make it easier to stay cool in very hot climates. Or maybe the advantage is being able to better see predators off in the distance.

The fossil record makes it clear that a long neck is not the only way for grazing species to survive. Approximately 16 million years ago, *Canthumeryx* was a smallish animal with a slightly elongated neck. This animal is the ancestor of two groups of living species, giraffes and okapis. One branch of the family tree evolved to have much longer necks, and the other shorter necks. Giraffes live on the savanna of Africa, a relatively open habitat of trees, shrubs, and grasses. Okapis live in a rain forest in central Africa, where their shorter necks are adapted for moving among densely growing tree trunks, low-hanging branches, and tangled vines.



Words to Know

A *dominant* version of a gene shows its effect even when the offspring inherits only one copy of the gene. A *recessive* version of a gene only shows its effect when two copies of it are inherited.

A Sheep Named Dolly

On a tropical island in *Jurassic Park*, cloned dinosaurs roam freely, and the tourists are confined for their own protection. In the film *Multiplicity*, a construction worker gets himself cloned so he can manage his life better. In *Star Wars: The Clone Wars* an army of clones battles for domination of a galaxy far, far away. Clearly, many movie and TV viewers are fascinated by the idea of cloning.

When an organism is cloned, an exact copy of its DNA is made. It can happen in nature, such as when identical twins develop. Scientists can also make clones. The first mammal cloned by a team of scientists, a sheep named Dolly, was born in 1997. The team proved that the DNA in the nucleus of adult animals' body cells, say a skin cell or a gland cell, can be copied in a laboratory to produce an offspring that will develop into an adult. Dolly's arrival surprised many other scientists, who did not think body cells could behave like a fertilized egg cell, dividing and forming all the different kinds of cells needed for a new individual.

The news about Dolly raced around the world, and within a few years other kinds of mammals were cloned, including pigs, cats, dogs, and horses. Immediately, people started asking if humans could be cloned. And more importantly they asked whether they *should* be cloned. The answers ranged from "never" to "I don't see why not."

"Could they?" is a question that biologists can answer. "Should they?" is a question for ethicists.

Consider whether there should be an exact genetic replica of yourself. Not a twin who is the same age, but a baby. Should animals that people eat be cloned? Should a favorite dog who is old and sick be cloned so that the owner has company when the older dog dies? And what about cloning a world-renowned scientist, artist, or musician at the end of their life?



Dolly lived for many years near the lab in Scotland where she was cloned.

In 2005, UNESCO (United Nations Educational, Scientific and Cultural Organization) called for a worldwide ban on human cloning. Several other organizations agree, including the WHO (World Health Organization). Most object to human cloning on the grounds that the practice will reduce human dignity. They said that a person should not be used as a means to an end. Other experts disagree and say that people have babies using all sorts of methods and for all sorts of reasons. They argue that the most important influence on the lives of children come from how they are brought up, rather than their genetics.

So, should scientists keep working on cloning technology with the aim to eventually clone humans? This is where ethical concerns collide with science. *Ethics* is an area of study that identifies humans values and right and wrong behavior and explores the purpose of living as a human. Following ethical principles makes an individual person feel good, but they also guide human communities to work well for their members and other communities.

Ethicists might ask, "What is the purpose of cloning?" Or, "Is it okay to make clones in a lab to better understand how living cells work?" Or, "Is cloning ethical if it helps people who have diabetes or heart disease?"

But what about using cloning to produce human babies? What if the process turns out to be unsafe and causes harm to the child? Will cloned people feel less an individual than other people?





If thinking about these questions is interesting to you, you might consider a career in bioethics, or ethics related to the life sciences. Bioethicists work in many settings. Most hospitals employ bioethicists, as do pharmaceutical companies, biotechnology companies, and government health agencies. Depending on where you work, you may give advice about how to make ethical decisions, represent patients when decisions are being made about their care, or help educate the public about controversies over medical procedures.

Some people have careers that combine bioethics with another field. Often medical doctors, social workers, nurses, lawyers, and college professors get additional education and training to be able to address bioethics in their work.



Bioethicists working in hospitals may work with patients to discuss their medical testing and treatment options.

Unique Humanity



Human beings and other animals are similar in many ways. Other animals do many of the things that humans do. For example, several other species care for their young for lengthy periods of time. Elephant young remain with their mothers for 16 years on average. Many other species use simple tools to solve problems and teach survival skills to the young in their communities. Other animals play for fun, just like humans do. If you have a pet, you've probably witnessed an animal at play.

So what is it that sets humans apart from all the other species? One way to answer that question has to do with the way we accumulate knowledge and pass it on to future generations. Humans are unique in our engagement in the purposeful practice of collecting and passing on knowledge. A mother chimpanzee will show her offspring how to use a stick to retrieve termites from a mound. But she doesn't record her instructions in a written language to teach other chimpanzees at a later time. She might figure out the best length stick to get the job done, but she doesn't pass on data to save other chimpanzees the time of their own termite-probing trial and error.

In contrast, human language and the ability to record it in writing have allowed humans to pass on what they know to future generations for thousands of years. The result is an astonishing accumulation of knowledge. And even though one person could never learn everything that humanity has now recorded, the knowledge is preserved. It is there for the taking for those who would seek it. You don't need to have witnessed the first flight of an airplane to know what happened at that event. You don't have to get sick eating toxic plants



to learn which vegetables are safe for human consumption. You don't have to reinvent how to make a pancake. If you put in the study time, you can become a surgeon skilled enough to operate on another person's failing heart. Because of humans' preservation of knowledge, you can know far more in your lifetime than you could if you only learned what a parent demonstrated for you or if you had to make every new discovery for yourself.

Human brains are unique in terms of the scale of their creativity, ability to plan for the future, and imagination. We are the only species to use the language of mathematics in complex engineering and in exploring the likelihood of things to happen. Our collective human species has made intellectual and technological leaps that set us far apart from all other animals. Humans are capable of species-changing problem-solving. Through the complicated enterprises of science and health care, we have increased our overall life span and the ability of people with impairments to survive and thrive. Through engineering and design, we have advanced abilities to feed, clothe, and shelter ourselves. These abilities soften the effects that natural environments would have on us.

All species but humans tend to produce as many offspring in their lifetimes as their bodies will biologically permit. Environmental factors determine how many survive. Ecosystems find equilibrium among populations—the balance of nature. In contrast, humans can protect an overwhelming majority of individuals and help them survive. Humans also have conscious awareness of breeding consequences and can decide when and whether to reproduce. We are the only species with this level of intellectual control of our own reproduction and, as an extension, of our populations. We are also the only species to have unlocked some of the secrets of how genes make us into what we are—and to have used that knowledge to make changes.

What do these developments mean for humans in the story of evolution? If all species are very gradually evolving through natural selection, are humans as well? We are the only organisms able to deliberately challenge the limitations of natural selection on our species. How we will use the power of our knowledge is the story that is unfolding before us. We can ask ourselves the question "What will we become?" and influence the answer.



Glossary

adaptation, n. an inherited trait that improves an organism's fitness for survival

artificial selection, n. steps taken by humans to perpetuate desired traits in plants and animals

bioethicist, n. a scholar who studies the ethical implications of biological research and applications

clone, n. an exact genetic copy of an organism

convergence, n. independent evolution of similar traits across unrelated species

dominant gene, n. a version of a gene that shows its effect even when the offspring inherits only one copy of the gene

embryo, n. a multicellular organism in the early stage of its development

evolution, n. changes in the genetic structure of populations over time

fossil record, n. the history of life on Earth according to fossils that have been found throughout time

gene, n. a unit of hereditary information that occupies a specific place on a chromosome

gene therapy, n. the use of genes to treat, prevent, or cure a disease or medical condition

homeostasis, n. a stable internal environment

isotope, n. each of multiple types of atoms of the same element that have the same number of protons but different numbers of neutrons in their nuclei

mass extinctions, n. events in Earth's past during which large percentages, usually about 75%, of species became extinct during short periods of geologic time

natural selection, n. the survival and reproductive success of organisms with qualities best suited to their environment

phylogenetic tree, n. a diagram that shows evolutionary relationships among types of living things

phylogeny, n. the evolutionary history of organisms (also *phylogenesis*)

probability, n. the likelihood of something happening

radiocarbon dating, n. a method for determining the age of an object by examining the ratio of carbon 12 to carbon 14 isotopes in its material

radiometric dating, n. a process for determining the age of materials by examining the decay of isotopes

random, adj. occurring or selected by no predetermined method or conscious decision

recessive gene, n. a version of a gene that only shows its effect when two copies of it are inherited

science literacy, n. the ability to read, hear, and comprehend information about scientific topics and demonstrate understanding in discussion and through writing

sedimentary rock, n. rock formed through the compaction and cementation of layers of sediment

skepticism, n. doubt about the truth of something

speciation, n. the formation of distinct new species as a result of biological evolution

species, n. a group of living organisms consisting of similar individuals capable of exchanging genes or interbreeding

taxa, n. plural of *taxon*, a group of related species

technology, n. the use of scientific knowledge to solve practical problems

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