UNIT 8

Evidence for Evolution

Many species develop unique features that help them survive.

Image Credits: ©WaterFrame/Getty Images

FIGURE 1: Over the course of 20 generations, some green anoles have developed stickier feet that allow them to survive better in habitats invaded by the brown anole.

The territory of the green anole, a native species in the southeastern United States, is being invaded by brown anoles originally from Cuba and the Bahamas. The anoles compete with each other for food. Both green and brown anoles will eat the eggs of the other species. A population of green anoles in Florida developed stickier feet to help them climb higher in vegetation. The physical change along with the change in habitat preference allows these green anoles to escape egg predation from brown anoles and competition for food associated with the presence of the brown anole.

Predict How do species change over time to adjust to varying conditions?

DRIVING QUESTIONS

As you move through the unit, gather evidence to help you answer the following questions. In your Evidence Notebook, record what you already know about these topics and any questions you have about them.

1. How do we know living things have changed over time?
2. What are the mechanisms of natural selection, and how do they lead to changes in species over time?
3. How can environmental changes impact traits in a population?

UNIT PROJECT

Investigating the Evolution of Eyes

Eyes are complex organs. Simple eyes allow organisms to sense light while complex eyes, like those in humans, allow organisms to see images. Explore how small changes over time can lead to the development of unique features, such as eyes. How can you explain the evolution of eyes?

Go online to download the Unit Project Worksheet to help plan your project.

8.1

Lines of Evidence for Evolution

Geological evidence indicates that Earth is billions of years old.

CAN YOU EXPLAIN IT?

FIGURE 1: Modern birds and long-extinct dinosaurs share some characteristics.

a Modern chicken

b *Archaeopteryx* fossil

Gather Evidence As you explore the lesson, gather evidence related to common ancestry and how living things change over time.

Figure 1 shows a modern chicken and the fossilized remains of a dinosaur that lived about 150 million years ago. This dinosaur species, named *Archaeopteryx*, was discovered in the 1860s. It was about the size of a chicken, and like all modern birds, it had feathered wings and a fused collarbone. But it also had many reptilian characteristics, including clawed toes, a long tail, and teeth.

In the 1990s, scientists discovered theropod fossils with feathers. Theropods were dinosaurs that walked on two legs, such as *Tyrannosaurus rex*. They first appeared over 200 million years ago during the Triassic period. This important discovery showed that feathers did not originate as an adaptation for flight. These theropods were covered with feathers, but they did not have wings. They were running animals. This means that feathers originally had another function in theropods.

Predict Do you think chickens and other birds could be descendants of dinosaurs? What evidence would you need to support such a claim?

Molecular and Genetic Evidence

How could a chicken be related to dinosaur ancestors? Evolution is the process of biological change by which descendants come to differ from their ancestors. Multiple lines of evidence support the idea that evolution has occurred. This evidence comes from fields such as molecular biology, developmental biology, and paleontology, just to name a few. All of this evidence helps to strengthen our understanding of evolution.

Hands-On Activity

Piecing Together Evidence

In this activity, you will receive pieces of "evidence" about a picture in order to make observations, inferences, and predictions about it.

PROCEDURE

1. Using the three strips that your teacher has provided, write down all observations and inferences that you can make about this picture.
2. Record observations, inferences, and a prediction for each remaining strip of "evidence" that you receive from your teacher.

MATERIALS

- picture cut into strips

ANALYZE

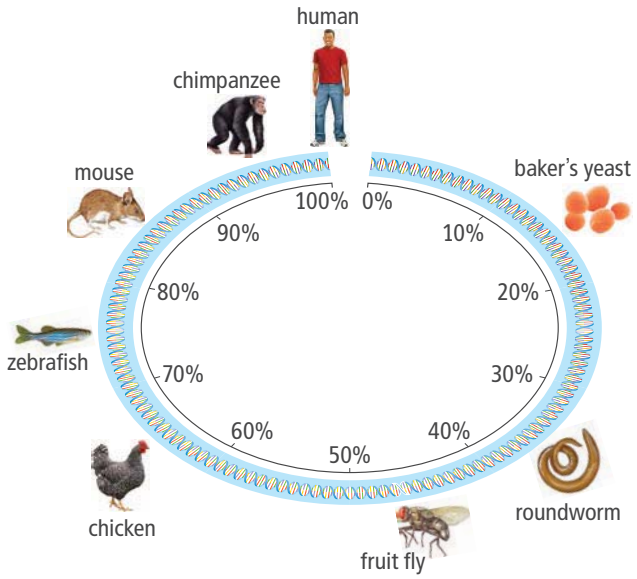
1. What type of evidence might evolutionary biologists find that would let them see the big picture of a species' evolutionary past?

Molecular Similarities

All living things on Earth share DNA as their genetic code. We all have the same four basic nucleotides that make up our genome. Through DNA sequencing technology, scientists can compare the genetic codes of different species. In general, the more related two species are, the more similar their DNA will be. The differences in the nucleotide sequences in the genomes of various species are smaller than you might think. For example, your genome is about 88 percent identical to that of a mouse. That may not be too surprising considering mice are mammals, too. However, this might come as a bit of a surprise: Did you know that your DNA is about 47 percent identical to that of a fruit fly?

Analyze How do patterns in DNA support the claim that living things share a common ancestor?

FIGURE 2: Many of our genes are shared by other organisms.



Explore Online

Hands-On Activity

Predicting Evolutionary Relationships Analyze similarities in a protein common to bacteria and eukaryotes. Then use the results of your analysis to draw conclusions about similarities among species.

Sequences of DNA nucleotides known as pseudogenes also provide evidence of evolution. Pseudogenes are genes that no longer function but are still carried along with functional DNA. They can also change as they are passed on through generations, so they provide another way to determine evolutionary relationships.

Similarities among cell types across organisms can also be revealed by comparing their proteins. A unique set of proteins is found in specific types of cells, such as liver or muscle cells. Computers are used to search databases of protein sequences and look for homologous, or similar, sequences in different species. Cells from different species that have the same proteins most likely come from a common ancestor. For example, the proteins of light-sensitive cells in the brain-like structure of an ancient marine worm closely resemble those of cells found in the vertebrate eye. Vertebrates are animals with a backbone. Invertebrates, like arthropods and worms, have no backbone. This resemblance in proteins shows a shared ancestry between worms and vertebrates. It also shows that the cells of the vertebrate eye originally came from cells in the brain.

Engineering

FIGURE 3: Scientists often study model organisms such as the zebrafish to learn more about human disease.

Using Model Organisms to Study Human Diseases

Because we share common ancestry with other species, many human genes also exist in other organisms such as zebrafish, fruit flies, and mice. This fact, along with their rapid life cycles, makes these organisms ideal models for the study of shared genes. Zebrafish have 70 percent of the same genes as humans, and they have bodies that are almost as transparent as embryos. This feature allows for a better view of what is happening inside of their bodies. Zebrafish can also regenerate their spinal cords after injury, which makes them a promising model organism for studies on spinal cord injuries.

Zebrafish have been used as a model organism for research on many human diseases, including muscle, kidney, heart, and nervous system disorders. Scientists use genetic manipulation techniques to induce mutations in the fish. By experimenting with mutant, or variant, forms of genes in this model organism, scientists can make predictions about how similar genes will function in humans. For example, a strain of mutant zebrafish called *breakdance* has been used for studies on arrhythmia, or abnormal heart rhythm, in humans.

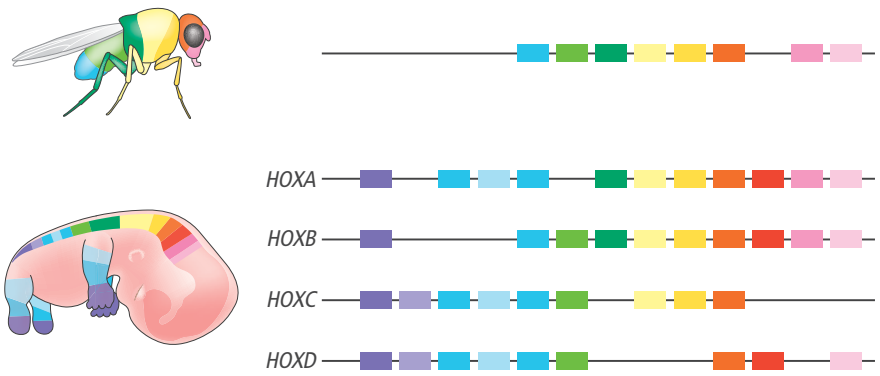
In addition to sharing much of our genetic material, zebrafish also have eyes that are similar to the human eye in many ways. Several zebrafish mutants have been identified that display eye defects and visual impairment. These mutants have helped scientists better understand how different genes are involved in eye disorders. For example, two mutant strains called *grumpy* and *sleepy* have been vital in the study of certain disorders that affect the optic nerve.

Analyze Make a list of criteria and constraints a researcher would need to consider when choosing a model organism for a human disease study. Include factors related to the organism's development and life cycle, the genetic basis of the disease being studied, and any ethical considerations.

Homeobox Genes and Body Plan Expression

As an animal develops, its genes guide the formation of organs and the arrangement of body parts. If we have much of our DNA in common with other organisms, such as mice or birds, why then does a bird's body plan look so different from our own? From a very early stage, certain types of homeobox genes, called *Hox* genes, help to guide the process that results in the development of an organism's characteristic body plan. The process begins by instructing embryonic cells where in the body they will be located—head, midsection, or tail. From there the genes define the location and number of eyes and limbs, the location of the gut, the development of a wing instead of a leg, and so forth. If a mutation arises in these genes, drastic changes can occur in the body plan of the animal. Scientists think that random mutations in these genes over time account for the incredible diversity of body types seen today.

FIGURE 4: Differences in fruit fly and human body plans arise from variations in *Hox* genes.



Analyze When do duplication mutations usually occur? In which type of cells would these mutations have to occur to be passed down from parents to offspring?

Collaborate Analyze the model of *Hox* genes in fruit flies and humans. Write your answers to the questions below, and then discuss your answers with a partner.

1. What patterns do you see in the similarities and differences between *Hox* genes in humans and in fruit flies?
2. How do your observations support the claim that humans and fruit flies share a common ancestor?

Vertebrates have multiple sets of the same *Hox* genes that insects and other arthropods have. For example, the *Hox* genes that direct the organization of the vertebrate body plan are actually just different versions of the *Hox* gene that directs the body plan in fruit flies and other insects. The difference suggests that over time, mutations have caused the original *Hox* gene to be copied repeatedly, forming a series of similar genes along a chromosome. Mutations in these genes are typically duplications, and with each duplication, the developing organism may show slightly different traits.

Explain *Archaeopteryx* is seen by some experts as a link between reptiles and birds. What types of cellular or molecular evidence might a scientist study in order to determine the evolutionary relationship between the chicken and modern reptiles?

Developmental and Anatomical Evidence

At a very early stage, and before homeobox genes begin to make differences in body form, many seemingly different animals show striking similarities. As a general rule, organisms that resemble each other in their development are more closely related than others with different patterns of development. Even after an embryo begins to take on its adult form, many organisms share anatomical features with each other. Scientists use developmental and anatomical features to make inferences about evolutionary relationships among species.

Developmental Similarities

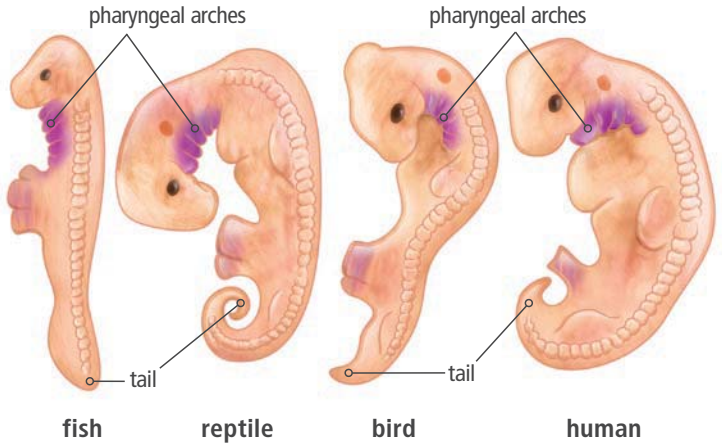
Language Arts Connection

Evolutionary developmental biology is a field of science that compares developmental processes in different organisms. Use library and Internet resources to research some of the latest advances in this field. Choose a study to focus on and make an informational guide to explain how this research has added to our knowledge of development and evolution. Discuss the evidence used to support the researchers' claims and explain how it supports their conclusions.

Invertebrates have an initial larval stage in which many organisms look quite similar, suggesting an evolutionary connectedness. At an early stage, some of these animals look exactly the same to the untrained eye. For example, barnacles and crabs show striking similarities as larvae even though as adults they take on very different body forms and behaviors. Barnacles become stationary animals, attaching to solid structures or larger animals. They must rely on their food to come to them. Crabs, on the other hand, use their legs to move around and capture food.

All vertebrates have three basic body features as embryos—a tail, limb buds, and pharyngeal arches. Note these common features in all four vertebrate embryos shown in Figure 5. Human embryos have a tail and pharyngeal arches, just as fish do. Homeobox genes direct the future development of these structures. Structures that once appeared very similar eventually differentiate in both structure and function. For example, pharyngeal arches become gills in adult fish. In mammals, however, pharyngeal arches develop into ear and throat structures. Biologists use shared developmental patterns as evidence of common ancestry.

FIGURE 5: All vertebrates go through a stage of development with common features.

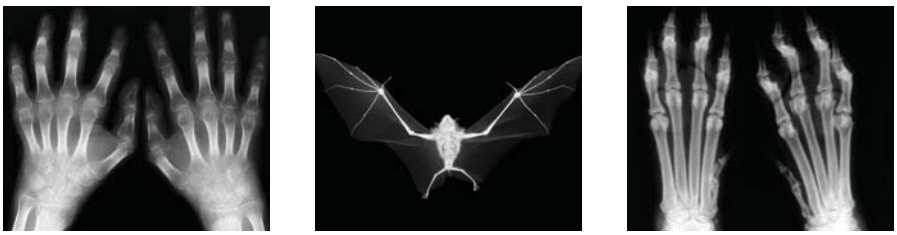


Analyze What similarities do the vertebrate embryos in Figure 5 share? How does this pattern of similarities help support common ancestry?

Anatomical Evidence

Homologous structures are features found in different organisms that share structural similarities but may have very different functions. Their appearance across different species offers strong evidence for common descent. It would be unlikely for many species to have such similar anatomy if each species evolved independently. For example, all four-limbed vertebrates, or tetrapods, share homologous bones in their forelimbs. Figure 6 compares the forelimbs of humans, bats, and dogs. In all of these animals, the forelimbs have several bones that are very similar to each other in appearance despite their different functions.

FIGURE 6: Homologous structures are different in detail but similar to each other in structure and relative location.



a Human hands **b** Bat wings **c** Dog feet

Gather Evidence What patterns do you notice in these structures in terms of similarities? How do the similarities support common ancestry?

Analogous Structures

Homologous structures such as the bat wing and human hand are based on the same underlying body plan, but have diverged into distinct structures because of their use. We do not use our arms and hands the same way that a bat uses its wing. In contrast, analogous structures are structures that perform a similar function but are not similar in origin. Think about the wings of a parrot and those of a dragonfly. Both bird and insect wings have similar shapes and structures because they are both used for flight. However, wings develop differently in birds and insects, and they are made of different tissues. For example, bird wings have bones. In contrast, insect wings do not have bones, only membranes. The similar function of wings in birds and flying insects evolved separately.

FIGURE 7: Bird wings and dragonfly wings are examples of analogous structures.

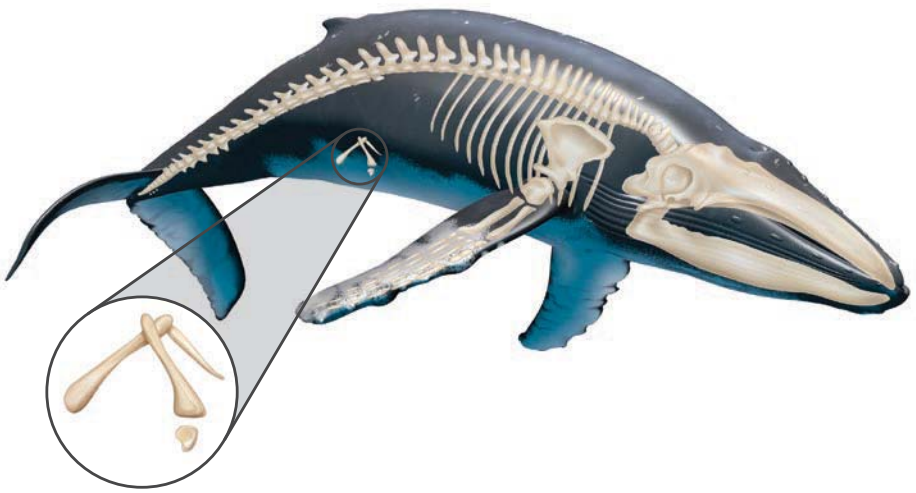
a Parrot wings **b** Dragonfly wings

Explain What is the difference between homologous and analogous structures? Which type of structure indicates common ancestry? Explain your answer.

Vestigial Structures

Anatomical comparisons can shed light on evolutionary relationships between species. Common body structures can become more similar or less similar over time. But what about structures which seem to serve no function at all? Early scientists had trouble explaining why flightless birds have wings or why humans have a tail bone. What we now know is that these vestigial structures are remnants of once-important structures that gradually have lost all or most of their function over time. Vestigial structures provide clues to an organism's evolutionary past. Consider the traces of pelvic bones present in the humpback whale shown in Figure 8. The pelvis normally sits near leg bones, such as the femur in humans.

FIGURE 8: Many whale species have vestigial pelvic and leg bones.



Analyze How does the evidence in Figure 8 support the idea that whales evolved from land mammals?

An example of a vestigial structure in humans is the arrector pili muscle, which makes your hair stand up when you are cold or scared. Goose bumps are caused by this muscle contracting and pulling the hair upward. This process normally creates air pockets to trap air and insulate the body. It also helps animals fluff up their fur to frighten off possible attackers. Humans still have this response, because we share a common ancestor with other mammals. However, we do not have enough hair for the response to serve its original function.

Explain What similarities in anatomical structures provide evidence of a link between the chicken and the *Archaeopteryx*? What additional evidence would help support the claim that these organisms share a common ancestor?

Geological and Fossil Evidence

Scientists study clues left behind in ancient rocks and discover traces of organisms that have long been extinct. Fossils are an important piece of evidence used to determine the evolutionary history of a species.

Geological Evidence

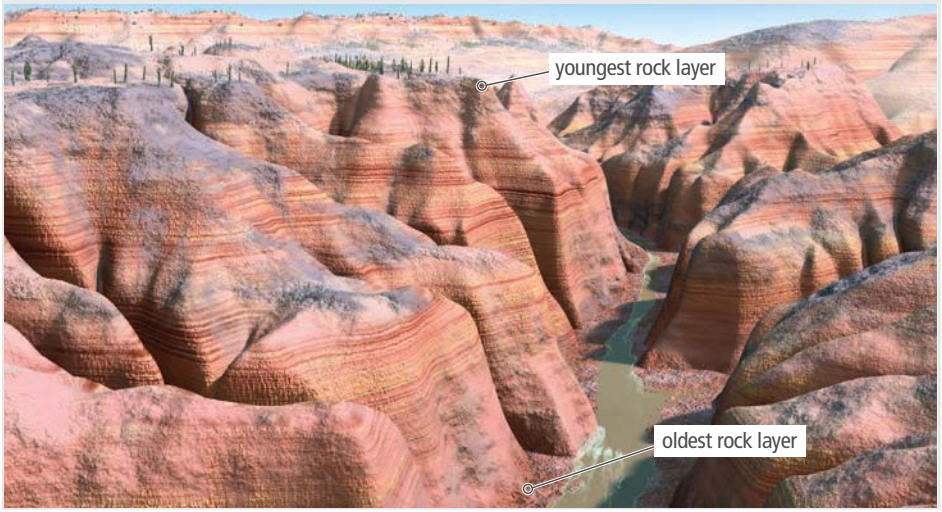
The age of Earth was a key issue in the early debates over evolution in the early 19th century. The common view was that Earth was created about 6,000 years earlier, and that since that time, neither Earth nor the species that lived on it had changed.

Georges Cuvier, a French zoologist of the late 1700s, did not think that species could change. However, his observations of fossil remains convinced him that species could go extinct. He found that fossils in the deepest layers of rock were quite different from those in the upper layers, which were formed by more recent deposits of sediment. He supported the theory of catastrophism which states that natural disasters such as floods and volcanic eruptions have happened often during Earth's long history. These events shaped landforms and caused species to become extinct in the process.

In the late 1700s, the Scottish geologist James Hutton proposed that the changes he saw in landforms resulted from slow changes over a long period of time, a principle that became known as gradualism. He argued that the layering of soil or the canyons formed by rivers cutting through rock did not result from large-scale events. He thought, rather, that they resulted from slow processes that had happened in the past.

One of the leading supporters of the argument for an ancient Earth was the British geologist Charles Lyell. In *Principles of Geology*, published in the 1830s, Lyell expanded Hutton's theory of gradualism into the theory of uniformitarianism. This theory states that the geologic processes that shape Earth are uniform, or remain the same, through time. Uniformitarianism combines Hutton's idea of gradual change over time with Lyell's observations that such changes have occurred at a constant rate and are ongoing. Uniformitarianism soon replaced catastrophism as the favored theory of geologic change.

FIGURE 9: This model shows evidence of slow, gradual change over time.



Explain Why are the concepts that Earth undergoes change and is billions of years old important for evolutionary theory?

Cause and Effect

Explain How do the geological features shown in Figure 9 support the claim that slow, gradual changes add up over long periods of time to cause great change?

Fossil Evidence

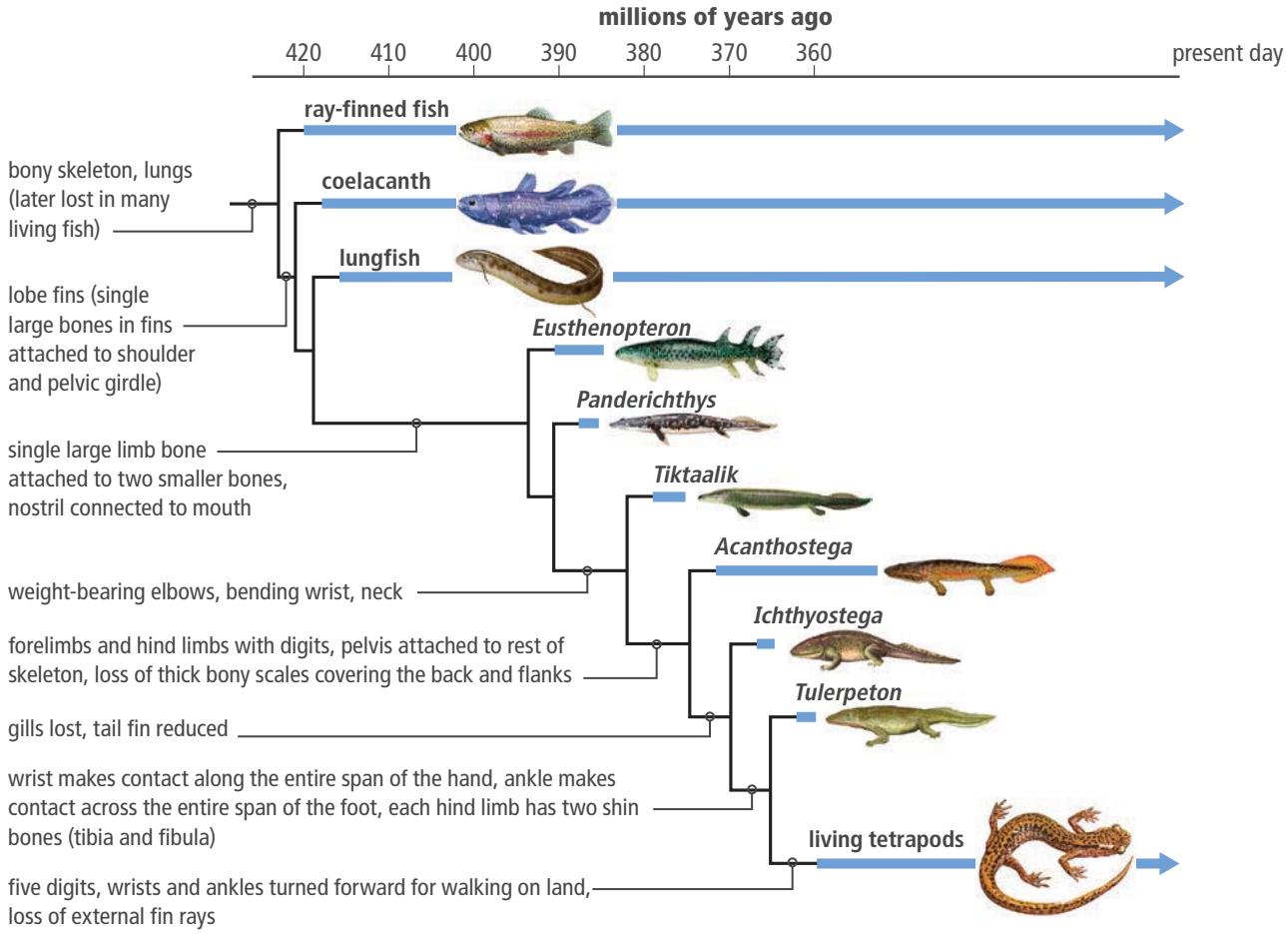
A fossil is the preserved remains of an organism, or the trace evidence of an organism's existence in the past. Most fossils form in sedimentary rock, which is made by many layers of sediment, or small rock particles. The best environments for any type of fossilization include wetlands, bogs, and areas where sediment is continuously deposited, such as river mouths, lakebeds, and flood plains.

Layers of rock form gradually over long periods of time, with more recent layers typically on top of older layers. Fossils that differ from each other slightly and are embedded in different layers of rock provide evidence for gradual change in species over time. The conditions needed for an organism's body to fossilize are rarely met. An organism's remains may be eaten by scavengers, it may decompose before it has time to fossilize, or it may simply be wiped away by erosion. Because of this, the fossil record will always be incomplete.

Scientists have been able to fill in some of these gaps by finding fossils of transitional species. These "missing links" demonstrate the evolution of traits within groups as well as the common ancestors between groups. For example, *Tiktaalik roseae* is a transitional species between fish and tetrapods. Figure 10 shows where *Tiktaalik* fills in the gap in the evolutionary history of fish and tetrapods.

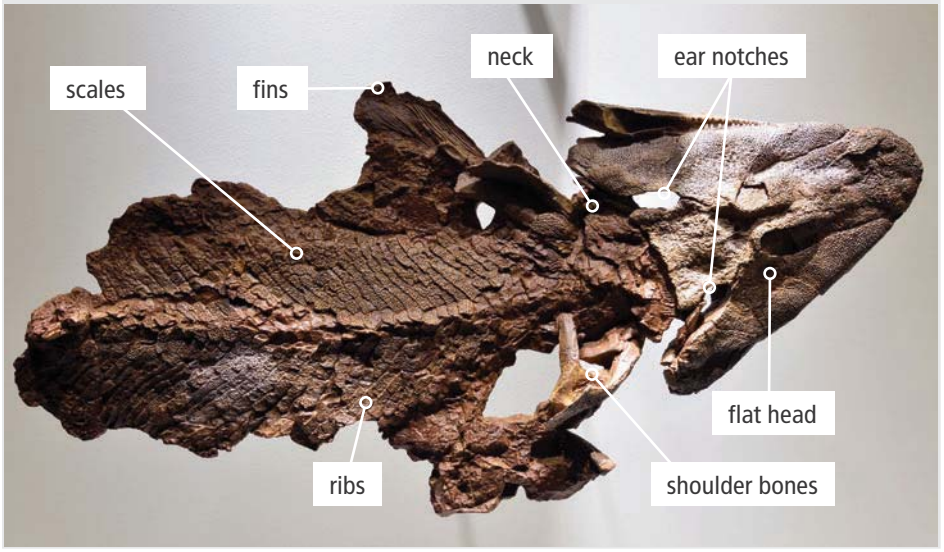
Collaborate With a partner, create a chart to explain how the traits described in Figure 10 would have helped the ancestors of living tetrapods adapt to walking on land.

FIGURE 10: This diagram shows the evolutionary relationships between ancient fishes and modern-day tetrapods.



Source: Zimmer, Carl, *The Tangled Bank*, Roberts & Company, 2009, as quoted by "The origin of tetrapods." Understanding Evolution http://evolution.berkeley.edu/evolibrary/article/evograms_04.

FIGURE 11: Fossil remains of *Tiktaalik,* a transitional species that lived about 370 million years ago, has both fish and tetrapod characteristics.



Analyze How do the presence of gills and lungs, as well as a bone structure that is homologous to that of tetrapods, support the idea that *Tiktaalik* fills in the gap between aquatic and land-dwelling species?

As you can see in Figure 11, *Tiktaalik* has both fish and tetrapod qualities. It has fins and scales like a fish. It also has the beginnings of limbs, including digits, proto-wrists, elbows, and shoulders, along with a functional neck and ribs similar to that of a tetrapod. Its discovery in 2004 helped to fill in the gap in the fossil record between early fish and the first land-dwelling species that evolved about 25 million years later. But that's not all it does. The structure of a recently discovered pelvic bone from *Tiktaalik* suggests that this creature used its hind legs in a more significant way than previously thought. The finding contradicts the previously held idea that primitive land animals used only their front legs to drag themselves across an ancient beach.

By studying the fossils found in individual rock layers, scientists can determine the approximate age of each fossil. Then by comparing one fossil to another, or examining fossils from different geographic areas, scientists can determine details about the environment in which each species lived.

Closer examinations of fossils and comparisons to living species can indicate anatomical and physiological similarities. Through analysis of the fossil record, we can begin to put together a clearer picture of a species' evolutionary history.

FIGURE 12: *Archaeopteryx* and modern-day bird skulls share common characteristics.

a *Archaeopteryx* skull replica

b Chicken skull

Explain Look at the *Archaeopteryx* and chicken skulls. What are the similarities, and what are the differences? How does the fossil evidence support the idea that birds share a common ancestor with dinosaurs?

Data Analysis

Radiometric Dating

Scientists can determine the age of a fossil through the process of radiometric dating. This technique uses calculations that are based on a radioisotope's steady rate of decay. Isotopes are atoms of the same element that have different numbers of neutrons. For example, all carbon atoms have six protons, but the number of neutrons may vary. The most common carbon isotope has six neutrons in its nucleus. Because the atomic mass of an atom is equal to the sum of protons and neutrons in its nucleus, this isotope is known as carbon-12, or ^{12}C. In the isotope carbon-14, or ^{14}C, there are still six protons but eight neutrons, which add up to 14.

Many elements have multiple isotopes, most of which are stable. However, some isotopes are unstable, or radioactive. This means that they give off radiation as they decay or break down over time. Decay rates differ widely and are known for each isotope. Figure 13 lists a few radioactive isotopes that are used in radiometric dating.

FIGURE 13: Isotopes Used in Radiometric Dating

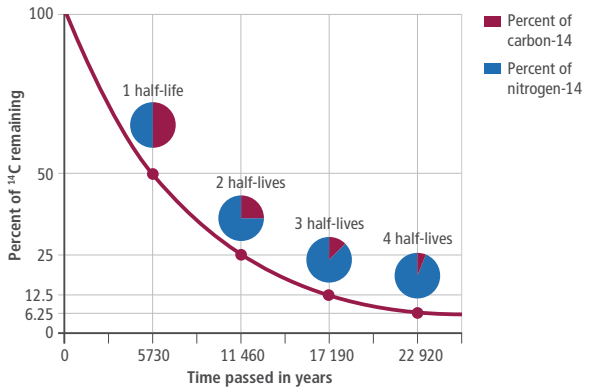
Isotope (parent)	Product (daughter)	Half-life (years)
rubidium-87	strontium-87	48.8 billion
uranium-238	lead-206	4.5 billion
potassium-40	argon-40	1.3 billion
carbon-14	nitrogen-14	5730

This decay of any radioisotope happens at a known, constant rate and is expressed as the isotope's half-life. A *half-life* is the amount of time it takes for half of the original mass of the isotope to decay into the product, or daughter isotope. By measuring the amount of parent isotope remaining along with the amount of daughter isotope remaining, you can calculate a ratio. This is known as the decay-product ratio.

The isotope ^{14}C is commonly used to date recent remains. Organisms absorb carbon through eating and breathing, so ^{14}C is constantly being resupplied. When an organism dies, its intake of carbon stops, but the decay of ^{14}C continues.

Radiometric Dating

FIGURE 14: Carbon-14 Decay



The half-life of ^{14}C is roughly 5700 years, which means that after 5700 years, half of the ^{14}C in a fossil will have decayed into ^{14}N, its decay product. The other half remains as ^{14}C. After 11,400 years, or two half-lives, 75 percent of the ^{14}C will have decayed. One quarter of the original ^{14}C remains.

The predictability of radiometric dating gives scientists a reliable tool to calculate the age of almost any fossil or rock sample. The oldest known rocks have been dated using radioisotopes. These were small crystals discovered in Australia that were calculated to be about 4.4 billion years old. Advances in the technology have made the process so precise that the margin of error is reported to be less than one percent.

Use the figures to answer the following questions.

1. If a rock contains 75 percent of the decay product, how many half-lives have passed?
2. If you measured the age of a fossil using ^{14}C dating and determined its age to be about 17,000 years old, how much of the rock should be made of ^{14}N?
3. If you are examining rock layers that are suspected to be about 20 million years old, which radioactive isotope would you use? Explain your answer.

CAREER: EVOLUTIONARY BIOLOGIST | WHALE EVOLUTION | Go online to choose one of these other paths.

Lesson Self-Check

CAN YOU EXPLAIN IT?

FIGURE 15: Modern birds such as chickens are thought to have descended from the same ancestor as feathered dinosaurs such as *Archaeopteryx*.

a Modern chicken

b *Archaeopteryx* fossil

Archaeopteryx has been called both the first bird and a 'feathered dinosaur.' Either way, it shares features of both birds and dinosaurs. First discovered around 1860, it has been studied vigorously for over a century, although only 12 very detailed and well-preserved fossils have been found in that time. The evolutionary history of modern birds may never be completely understood, but *Archaeopteryx* helps to fill in the gaps of this evolutionary timeline.

Explain What evolutionary evidence supports the conclusion that chickens and other modern birds are descendants of dinosaurs? Refer to the notes in your Evidence Notebook and write a short explanatory text that cites specific evidence from this lesson about lines of evidence for evolution to support your claim, and explain your reasoning.

The fossil record gives a rich history of the changing diversity of life on our planet. Anatomical details such as homologous and vestigial structures help to link species together. By examining the earliest developmental stages of organisms, we can see shared features among different species, such as a similarity in appearance between barnacle and crab larvae and similar developmental patterns in vertebrate embryos.

In addition, molecular and genetic evidence such as DNA and amino acid sequences provide evidence that can be used to determine the evolutionary relationships among different species. Taken together, these forms of evidence, put forth by different branches of science, overwhelmingly support the concept that living things change over time, yet are all descendants from a common ancestor.

CHECKPOINTS

Check Your Understanding

1. By examining the fin of a primitive fish, scientists have found similarities in bone structure to that of modern-day reptiles, birds, and mammals. What type of evidence does this describe?

a. vestigial structures
b. embryonic structures
c. analogous structures
d. homologous structures

2. *Astyanax mexicanus* is a species of tetra fish that dwells in bodies of water deep inside caves. Even though they cannot see, these fish still have small, nonworking eyes. Their eyes are examples of which type of structures?

a. embryonic
b. vestigial
c. homologous
d. analogous

3. The idea that present geologic processes are the key to the past is a tenet of which geologic theory?

a. gradualism
b. catastrophism
c. uniformitarianism
d. metamorphism

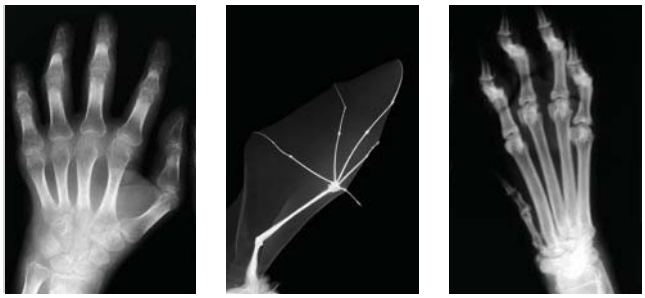
4. As embryos, all vertebrates have which of the following structures? Select all correct answers.

a. pharyngeal arches
b. limb buds
c. tail
d. lungs

5. The similarity in homologous structures between different species is evidence that they

a. share a common ancestor.
b. are members of the same genus.
c. use the similar structures in the same way.
d. evolved from each other.

FIGURE 16: Anatomical Structures



6. Which of the following statements correctly describes the evidence shown by the structures in Figure 16?

a. The bat and the dog share analogous bone structures in their forelimbs.
b. Only the human and the bat share homologous bone structures in their forelimbs.
c. The human and the bat share analogous bone structures in their forelimbs.
d. All three species share homologous structures in their forelimbs.

7. How are genes and proteins similar to homologous structures when determining evolutionary relationships among species?

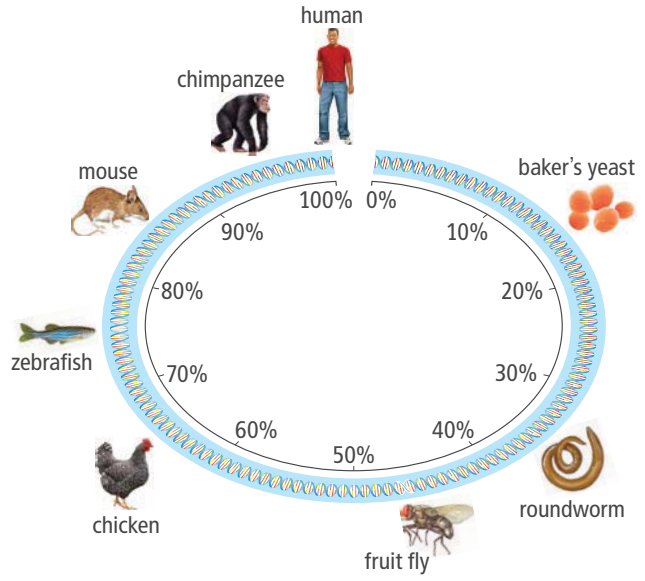
8. The hummingbird is more closely related to a lizard than it is to a dragonfly. How can you explain why two species that look similar are not necessarily that closely related?

9. How can the location of a fossil reveal its age? Explain your answer.

10. Paleontology is the study of fossils or extinct species. Explain how this field is important to the study of evolutionary biology.

11. You have discovered the fossil remains of three organisms. One is mammalian, one is reptilian, and the third has both mammalian and reptilian characteristics. What techniques could you apply to determine possible relationships among these organisms?

FIGURE 17: Shared DNA



Use Figure 17 to answer Questions 12 and 13.

12. Humans share the most DNA with which of the following species of animal?

a. zebrafish

b. fruit fly

c. roundworm

d. chimpanzee

13. Which organism do you think would be the best choice to use as a model organism in human health studies? Explain your answer.

MAKE YOUR OWN STUDY GUIDE

In your Evidence Notebook, design a study guide that supports the main idea from this lesson:

Multiple lines of evidence support common ancestry and evolution.

Remember to include the following information in your study guide:

- Use examples that model main ideas.
- Record explanations for the phenomena you investigated.
- Use evidence to support your explanations. Your support can include drawings, data, graphs, laboratory conclusions, and other evidence recorded throughout the lesson.

Consider how evidence from various fields of science can be used to support the idea of evolution and common ancestry. Remember that the same processes that formed fossil remains millions of years ago are still at work today.

8.2

Theory of Natural Selection

When camouflaged, an animal such as this crocodilefish can be almost impossible to spot.

CAN YOU EXPLAIN IT?

FIGURE 1: The orchid mantis *(Hymenopus coronatus)* resembles a flower in shape, but some scientists think it attracts insects for another reason.

With its brilliant colors and petal-shaped legs, the orchid mantis resembles the flower it is named for. This species' habitat consists of pink and white flowers in bushes and trees. Its diet is made up mainly of flying insects. You might think that the orchid mantis catches its prey by camouflaging itself as a flower. However, researchers have found that when it was placed beside the most common flower in its habitat, the orchid mantis attracted insects more often than the flower.

Predict How do you think the orchid mantis developed the traits that make it so attractive to insects?

Gather Evidence
As you explore the lesson, gather evidence for how natural selection results in species that are adapted to their environment.

Hands-On Activity

Modeling Natural Selection: Owls and Field Mice

We know from molecular, anatomical, and fossil evidence that species have changed over time. This change is called evolution. But how does evolution actually occur in nature? In this lab, you will model one mechanism of evolution called natural selection. You will represent the predator, an owl in search of field mice. Your group will "consume" all the field mice that you can easily see until only 25 percent of the population remains. These surviving field mice will then reproduce. As with the orchid mantises, the mice will pass on an important trait for survival to their offspring. You will continue the process for several generations of mice, with some being consumed and others surviving to pass on the traits that made them successful.

PREDICT

How does a population change as a result of natural selection?

PROCEDURE

1. Spread out the fabric habitat given to you on the tabletop.
2. Count out 20 pieces of paper of each of the five different colors for a total of 100 pieces. This will be your initial population of field mice.
3. One person should spread the pieces out randomly over the entire fabric habitat, making sure that none of the pieces cover the others. The remaining members of the group should not watch this process.
4. The other members of the group are now owls. They should pick up 75 pieces (field mice) as they see them, one by one, until a total of 25 of the field mice remain in the habitat. Be sure to count carefully.
5. Carefully shake off the habitat to remove the surviving mice (a total of 25).
6. Group the survivors by color and record the numbers in your data table. See Figure 3 for an example data table.
7. Next assume that each survivor has three offspring. Place three additional pieces of the same color with each survivor. Record the number of each color in the table. Note that there should again be 100 total pieces.
8. Mix up the new set of pieces and have a different person spread them over the habitat.
9. Repeat the entire process (Steps 3 to 8) two more times, making a total of three generations of field mice being preyed upon.

Analyze Explain how you will model predation in this activity.

FIGURE 2: Barn owls are predators. They feed mostly on small mammals, such as mice, voles, and shrews.

MATERIALS

- construction paper, five colors
- piece of fabric

DATA TABLE

FIGURE 3: Effect of Predation on Field Mice Populations Over Time

	Color 1	Color 2	Color 3	Color 4	Color 5
Number at start	20	20	20	20	20
Number after first predation					
Number after first reproduction					
(Add rows for two more generations.) ⬇					

ANALYSIS

1. Graph your data. What patterns can you identify in the data?
2. Which traits appear to be the most beneficial for survival in this environment? Explain your answer.
3. Explain why the number of some mouse varieties increased over time while others decreased.
4. How do you think the data would have changed if the experiment were continued until a total of five generations of field mice were preyed upon?

FIGURE 4: Mice can reproduce rapidly. The large number of offspring must compete with one another for resources.

Mice can reproduce rapidly. In fact, their population could increase exponentially if given enough resources and few predators. However, the greater the population, the more individuals must compete for resources such as food, water, and mates. In addition, mice must escape predators to survive long enough to pass on their traits. Any traits that help them survive and pass on their genes are considered beneficial in this environment. Natural selection is a mechanism by which individuals that have inherited beneficial adaptations show differential reproductive success.

If the environment were to change, the traits that are beneficial could also change. If the grass in a field were to change colors due to a change in weather, different traits would be "selected for." This does not mean that nature actually "chooses" traits. It simply means that some traits are passed down more often than others because organisms with those traits are better able to survive and reproduce more than others in their population.

Explain Answer these questions about the concepts explored in this activity.

1. Name an animal that uses camouflage to avoid predators. What habitat is it most likely to survive in? What are some other traits that could help an animal survive in the presence of predators?
2. What kinds of resources might field mice compete for? What types of traits would give a field mouse a competitive advantage over other members of its own species?

Developing the Theory of Natural Selection

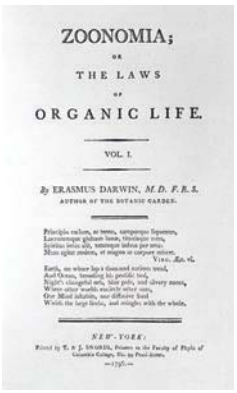
Charles Darwin was one of the most famous people to consider the question of how living things evolve; however, the concept of evolution had been discussed for more than 100 years when Darwin proposed his theory of evolution.

Early Ideas About Evolution

Early scientists observed relationships among organisms and how they seemed to be well adapted for specific environments. Darwin built upon the work of these scientists to develop a theory for how evolution occurs. A theory is an explanation based on evidence that has been repeatedly confirmed through experimentation or observation. Today, we have a wide body of evidence that supports Darwin's theory of evolution.

FIGURE 5: Ideas about evolution have developed over time.

1735 *Systema Naturae* Carolus Linnaeus proposed a new system of organization for plants, animals, and minerals based upon their similarities.



1794-1796 *Zoonomia* Darwin's grandfather, Erasmus Darwin, considered how organisms could evolve through mechanisms such as competition.

1809 *Philosophie Zoologique* Jean-Baptiste Lamarck presented evolution as occurring due to environmental change over long periods of time.

1749 *Histoire Naturelle* Georges-Louis Leclerc, Comte de Buffon, discussed important ideas about relationships among organisms, sources of biological variation, and the possibility of evolution.

1798 An Essay on the Principle of Population Thomas Malthus argued that the increasing human population would challenge the world's ability to supply enough food for everyone.

1830 *Principles of Geology* Charles Lyell proposed the theory of uniformitarianism. This theory states that both gradual and catastrophic geological changes have occurred at a constant rate on Earth and are ongoing.

Analyze How does the information in Figure 5 support the idea that theories change and develop over time as new evidence is discovered?

Darwin's Voyage

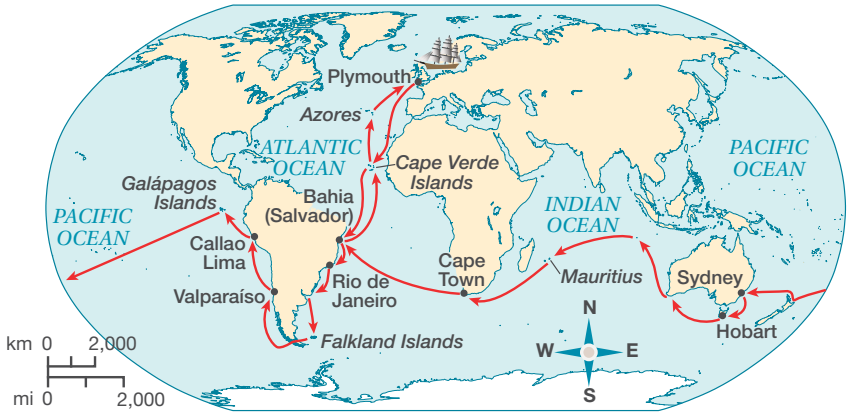
FIGURE 6: Charles Darwin

In 1831, the ship HMS *Beagle* set sail from England on a five-year journey to map the coast of South America and the Pacific islands. The ship captain saw it as an opportunity to collect specimens and study natural history. An invitation was extended to Charles Darwin, a recent graduate from the University of Cambridge. To prepare for the trip, Darwin collected scientific tools, as well as books, one of which was Lyell's *Principles of Geology*, which he read along his travels.

The first stop occurred at the Cape Verde Islands, where Darwin noticed a band of seashells on a cliff high above the shoreline. Darwin was curious about how the shells ended up there. During the following year, the young naturalist explored the rain forest to collect specimens of plants, animals, and rocks. As he worked, Darwin kept a diary, recording each new observation. This approach allowed him to do comparative studies, such as noting the differences between fossils found on a later stop in the Falkland Islands and those found on the coast of South America. Darwin also noted geological phenomena that made him wonder how environments changed.

FIGURE 7: Darwin's Journey on the HMS *Beagle*

Explore Online



Near the end of his journey, the *Beagle* arrived in the Galápagos Islands. At this stop, Darwin would make some of his most widely known observations, which are still studied today. Darwin noted that the species found on one island looked different from those on nearby islands and on the mainland. He was struck by the variation of traits among similar species. Some traits seemed well suited to the animals' environments and diets.

FIGURE 8: Galápagos tortoises (*Geochelone elephantopus*) had variations in their traits that seemed to match their environment.

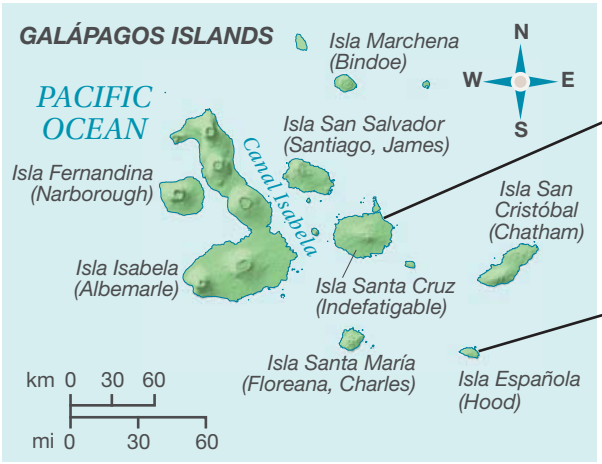
a The high shell edge of saddle-backed tortoises allow them to stretch their long necks.

b Domed tortoises have a short neck and short legs.

Predict Which variety of tortoise (saddle-backed or domed) would most likely live in an environment with mosses and short plants? Which would most likely live in an area with tall plants? Explain your answer.

Among all of Darwin's observations, the most well known are those of the Galápagos finches. These small birds, sometimes known as "Darwin's finches," are closely related, but with significant differences. These observations led Darwin to infer that species must somehow be able to adapt to their surroundings. An adaptation is a feature that allows an organism to survive and reproduce in its environment. It was this analysis that eventually helped shape Darwin's theory about how organisms change over time.

FIGURE 9: Variation in Galapagos Finches



a Large cactus finch *(Geospiza conirostris)*

Species in the genus *Geospiza* have thick beaks and can feed on large, hard seeds that require strength for crushing.

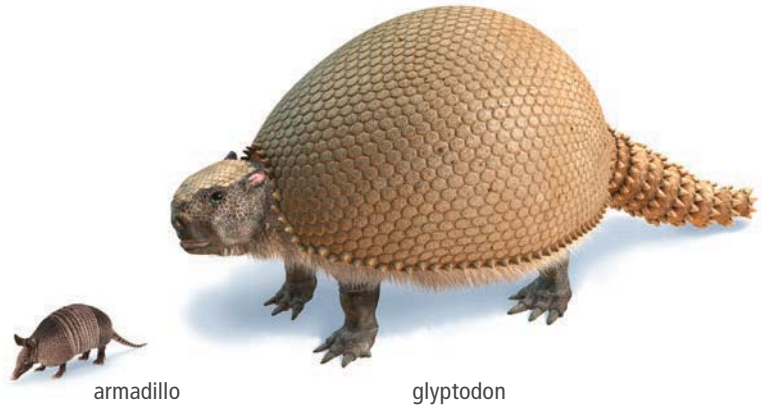
b Small tree finch *(Camarhynchus parvulus)*

Species in the genus *Camarynchus* have biting strength at the tips of their beaks, which is useful for tearing vegetation.

Analyze Use Figure 9 to answer these questions: How do these finches' adaptations help them survive and reproduce in their environment? What type of beak would you expect to see on a finch that eats insects? Explain your answer.

Several years before Darwin landed in the Galápagos, the *Beagle* anchored near Bahia Blanca in Argentina. While there, hunters brought back an armadillo. This was Darwin's introduction to this strange, armored animal. While on a fossil-hunting trip in the area, he found fossils of huge animals, including *Glyptodon*, a giant armadillo. The fact that these fossils looked like the living species suggested that modern animals might have some relationship to fossil forms. These fossils suggested that in order for such changes to occur, Earth must be much older than previously thought.

FIGURE 10: Darwin found fossils of *Glyptodon,* which resembles the modern armadillo.



armadillo glyptodon

Explain How do the *Glyptodon* fossils Darwin found in Argentina show that species have changed over time?

Predict Give three examples of geological processes that could cause fossils of organisms to be found in areas they did not historically inhabit.

During his voyage, Darwin also found fossil shells of marine organisms high up in the Andes Mountains. Darwin later experienced an earthquake during his voyage and observed the effects on the surrounding land. The land that had been underwater was moved above sea level. This experience explained what he saw in the Andes. Darwin's observations on his voyage supported Lyell's theory that daily geologic processes can add up to great change over a long period. Darwin later extended the ideas of an old Earth and slow, gradual change to the evolution of organisms. These observations led to the concept of evolutionary gradualism.

After his voyage, Darwin spent more than 20 years building on his research and knowledge of how evolution occurs. Although he had traveled the world, Darwin also found great insight in his home country of England. One important influence on Darwin's research was the work of farmers and breeders.

Artificial Selection

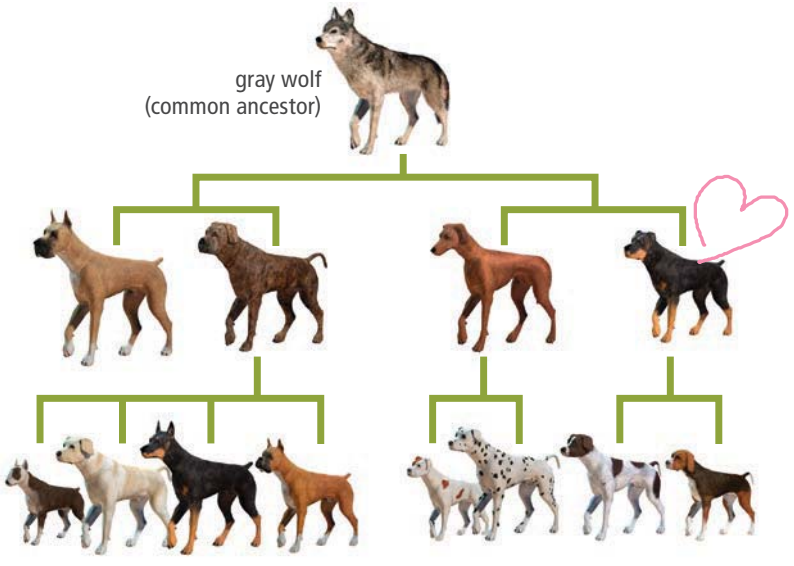
In England, Darwin observed a lot of variation in domesticated plants and animals. Farmers explained to him that, for example, some cows grew big and strong and produced a lot of milk. Others would be smaller and produce far less milk. The farmer would only breed those cows that were larger and that produced more milk. These productive traits were then passed on to the following generations. Through selection of certain traits, breeders could produce a great amount of diversity.

The farmers and breeders were not causing one cow to be more productive than another. Rather, they were controlling which cows would be used to breed offspring. The process of changing a species by breeding it for certain traits is called artificial selection. In this process, humans make use of the genetic variation in plants and animals by acting as the selective agent. Humans determine which traits are favorable and then breed individuals that show those traits.

Humans have been using artificial selection to select for desirable traits in plants and animals for thousands of years. Virtually all of the fruits and vegetables we eat have been greatly altered from their wild forms through the process of artificial selection.

Collaborate Discuss this question with a partner: How is artificial selection different than genetic engineering?

FIGURE 11: Domesticated dogs evolved through artificial selection. The common ancestor for domesticated dogs was the gray wolf.



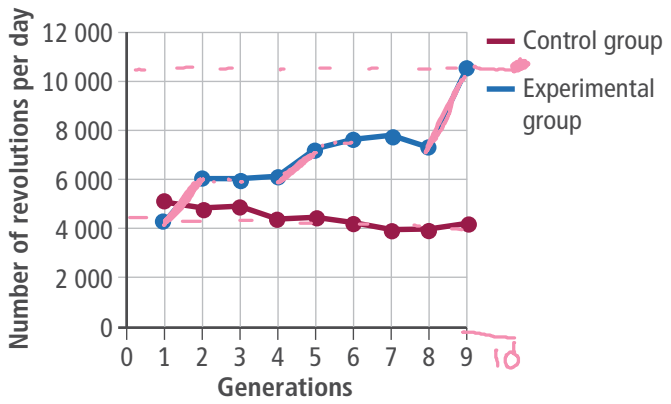
Although Darwin had no knowledge of genetics, he observed that, with human intervention, certain individuals could be selected to produce offspring with desirable traits. When selected and allowed to breed, these individuals would pass their traits onto their offspring. In order for artificial selection to occur, the trait must be heritable. Heritability is the ability of a trait to be passed down from one generation to the next.

Darwin related what he learned about breeding to his ideas on adaptation. In artificial selection, individuals with desired traits are bred over generations, but only if the traits are advantageous to breeders. However, breeders also might select against features that are not desirable or "useful." During artificial selection, humans act as the selective agent. In nature, however, the environment generates the selective pressure that determines if a trait is passed on or not.

Cause and Effect

Selection of Exercise Ability

FIGURE 12: In artificial selection, humans can make use of genetic variation by acting as the selective agent.



Source: Swallow et.al, *Behavior Genetics*, 28:3.

Scientists used mice to study whether exercise ability can improve in animals over several generations. In this experiment, mice were artificially selected for increased wheel-running behavior. The mice that were able to do the most wheel running were selected to breed the next generation. The control group represents generations of mice that were allowed to breed randomly.

Analyze Answer these questions about the data in the graph:

1. What is the difference in results between the mice in the control group and the mice in the experimental group?
2. Use the trend in the data to make a prediction about the number of revolutions on the wheel per day for mice in Generation 10 of the experimental group.

Darwin applied this thinking to develop his theory of evolution by natural selection. In nature, the environment is the selective agent. Similar to artificial selection, in natural selection the characteristics are selected only if they give an advantage to individuals in the environment as it is right now. Furthermore, Darwin realized that desirable traits would only emerge gradually in a population. He knew that it sometimes took many generations for breeders to produce the varieties he had observed.

Explain Make a graphic organizer to summarize Darwin's findings and illustrate how each observation relates to the processes that lead to changes in species.

Principles of Natural Selection

Charles Darwin was not the only person to develop a theory to explain how evolution may take place. An English naturalist named Alfred Russel Wallace independently developed a theory very similar to Darwin's. Both Darwin and Wallace had studied the huge diversity of plants and animals in the tropics, and both had studied the fossil record. They also were both influenced by the work of Thomas Malthus and his principles of economics.

Malthus had published a book in 1798 in which he discussed how increasing human populations would challenge the world's ability to produce enough food for everyone. Both Darwin and Wallace applied Malthus's ideas to the pressures experienced by plants and animals as populations increased. They noted that no species dominated the world, because some resource limited their ability to reproduce and survive. In an environment where resources are limited, individuals must compete for them. Those organisms that compete successfully go on to reproduce and pass on their traits.

Predict Why were Darwin and Wallace's ideas presented to other scientists before they were published?

In 1858, the ideas of Darwin and Wallace were presented to an important group of scientists in London. The next year, Darwin published his ideas in the book *On the Origin of Species by Means of Natural Selection*. The theory of natural selection explains how evolution can occur. Natural selection is a mechanism by which individuals that have inherited beneficial adaptations show differential reproductive success. This theory is built on the premise that more individuals are produced in each generation than can survive in any environment where resources are not infinite.

Genetic Variation

Darwin's theory of evolution by natural selection was based on observed patterns among plants and animals he and others studied. What he did not understand was how these changes occurred. About six years after the publication of *The Origin of Species*, a little-known monk named Gregor Mendel published his research on genetics and the basic principles of heredity.

FIGURE 14: Variation in coat color can be seen in jaguars and their offspring.

Mendel's work showed that traits are passed down from parents to offspring and that traits are inherited independently of one another. We now know that traits are coded for by genes and that alleles are different variations of the same gene. Variation in the alleles between individual organisms within a population is called genetic variation. Genetic variation is the basis for natural selection.

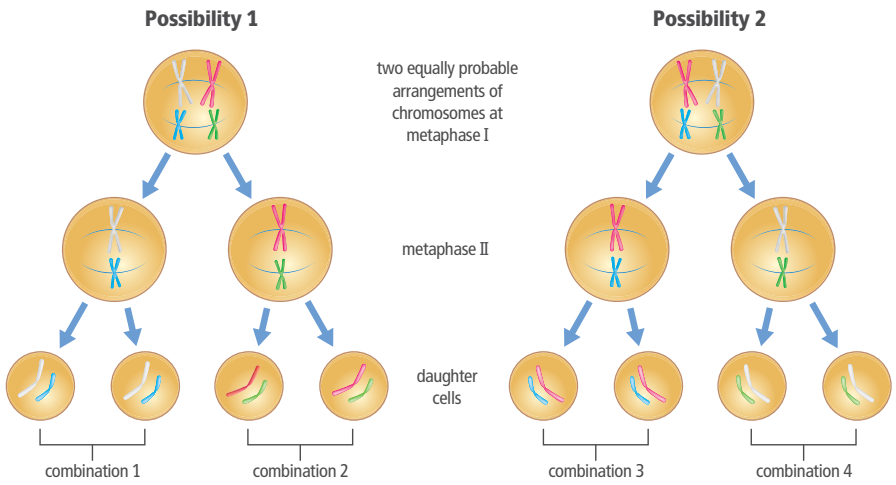
For example, the jaguar cub in Figure 14 inherited a combination of alleles that resulted in it having a different color than its mother. Therefore, there is variation in coat color in the jaguar population, and some variations may prove more beneficial than others in a given environment.

Collaborate In the owl and field mouse simulation, how did you model both variation in traits and parents passing down traits to offspring? Write your answer and discuss it with a partner.

Genetic variation is increased by sexual reproduction and meiosis. In sexual reproduction, the offspring receives two forms of each gene, one from each parent. Genes are segregated during the formation of gametes. If the genes are not linked, they will segregate separately, or undergo independent assortment. As genes are lined up and shuffled in different ways during meiosis, various combinations of genetic material are generated. As a result, sexually reproducing organisms exhibit variety in their traits. For example, Figure 15 shows the variation that can be seen in color patterns on Asian beetles. It is this type of variation that natural selection acts on. Crossing over during meiosis also allows for new combinations of genetic material. This generates an even higher number of possible combinations of genes.

FIGURE 15: Sexual reproduction increases genetic variation.

FIGURE 16: Chromosomes separate independently during meiosis. As a result, gametes have many different combinations of genes.



Heritable mutations also increase genetic variation. Damage to DNA is often caught at checkpoints in the cell cycle. The cell cannot proceed through the cell cycle until the damage is repaired or the cell self-destructs. However, sometimes the checkpoint fails, and cells with mutations proceed with replications. If a mutation is heritable, or passed on to an organism's offspring, it can increase genetic diversity within a population.

Model Explain how you could have modeled a new trait arising from a mutation in the owl and mouse simulation.

Keep in mind that natural selection acts on phenotypes, or physical traits, rather than on the genetic material itself. New alleles are not made by natural selection—they occur by genetic mutation. In addition, these mutations must be heritable, or passed down to offspring. Only mutations that occur in sex cells are passed on to offspring.

Overproduction

It was the work of Thomas Malthus that inspired many of Darwin's ideas about modification by natural selection. In his work, Malthus pointed out the potential of human populations to grow exponentially if there was a constant birth rate and ideal conditions. Such conditions would include unlimited resources and an absence of predators or disease. However, populations do not grow in an unchecked way. As Malthus pointed out, human populations are limited by many factors, such as disease, war, and limited resources.

FIGURE 17: Malthus predicted that population growth would outpace food production, causing a "Malthusian catastrophe."

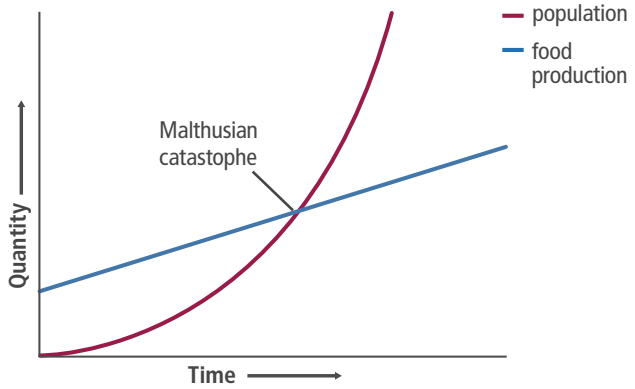


FIGURE 18: Individuals compete for resources such as food.

Predict The birds in Figure 18 are competing for a piece of food. What are some traits that might allow a bird to outcompete other birds for food?

Competition

Darwin noted that more offspring are born than can survive and that, without limits, any one species might overrun Earth. However, environments place limits on population growth, where some individuals are more successful at survival than others. Those individuals that survive better and produce more offspring will have their traits passed on to subsequent generations.

Building on Malthus's ideas that there were limits to human population growth, Darwin reasoned that a similar struggle for resources took place in nature. The challenge is for each individual to be better at obtaining available resources, such as food, water, and shelter.

Adaptation

Sometimes, a certain variation allows an individual to survive better than other individuals it competes against in its environment. More successful individuals are "naturally selected" to live longer and to produce more offspring that share those adaptations. Over time, natural selection will result in species with adaptations that are well suited for survival and reproduction in an environment. More individuals will have the trait in every following generation, as long as the environmental conditions continue to remain beneficial for that trait.

A well-studied example of natural selection in jaguars is shown in Figure 19. About 11,000 years ago, many species faced extinction. Large cats, including jaguars, faced a shortage of food due to the changing climate of that time. Fewer mammals were available to eat, so the jaguars had to eat other animals, such as reptiles. The jaguar population showed variations of jaw and tooth size that became important for survival.

FIGURE 19: Natural selection has led to changes in the jaguar species over time.

a Like many other species, jaguars can produce more offspring than can be supported by the environment. Some jaguars may be born with slightly larger jaws and teeth (skull 1) due to natural variation in the population.

b Jaguars with large jaws and teeth are able to eat armored animals, such as shelled reptiles. These jaguars are more likely to survive and to have more offspring than jaguars that can eat only mammals.

Explain Why did larger jaws and teeth become more common in the jaguar species over time? How do the four principles of natural selection explain these changes?

In biology, the term fitness is a measure of the ability of an organism to survive and produce more offspring relative to other members of the population in a given environment. An individual with high fitness is well adapted to its environment. After the change in climate, jaguars that had larger teeth and jaws had a higher fitness than other jaguars in the population. Jaguars that ate less did not necessarily all die or stop producing altogether; they just reproduced a little less.

It is important to note that fitness does not simply mean being the biggest and strongest individual. For example, being small is beneficial for some types of male spiders. Their lower body weight makes it easier for these males to cast a strand of silk into the air and be carried by the wind to a new location. As a result, these males have more opportunities to find mates and pass on their genes.

Understanding Natural Selection

In order to fully understand the theory of natural selection, it is important to consider how changes in the environment can influence fitness. It also is useful to examine some of the common misconceptions about how natural selection occurs.

Changing Environments

As an environment changes, different traits will become beneficial. Ecologists Peter and Rosemary Grant observed an example of natural selection acting on existing traits within a population of medium ground finches on one of the Galápagos Islands. A drought in 1977 reduced the number of the small, soft seeds that the finches preferred. However, there were still plenty of large, tough-shelled seeds.

The two graphs in Figure 20 represent the number of birds with each size of beak. In 1976, a total of 751 birds were measured. The distribution of beak size is shown in the histogram on the left. After the drought, the Grants again measured the beak sizes of the 1978 survivors. There were 90 birds measured to construct the histogram on the right. The Grants noticed that the distribution of beak sizes changed after the drought affected the types of available food in the environment.

Cause and Effect

Natural selection causes populations to adapt over time. The main principles of natural selection are:

Genetic Variation There is natural variation in the population.

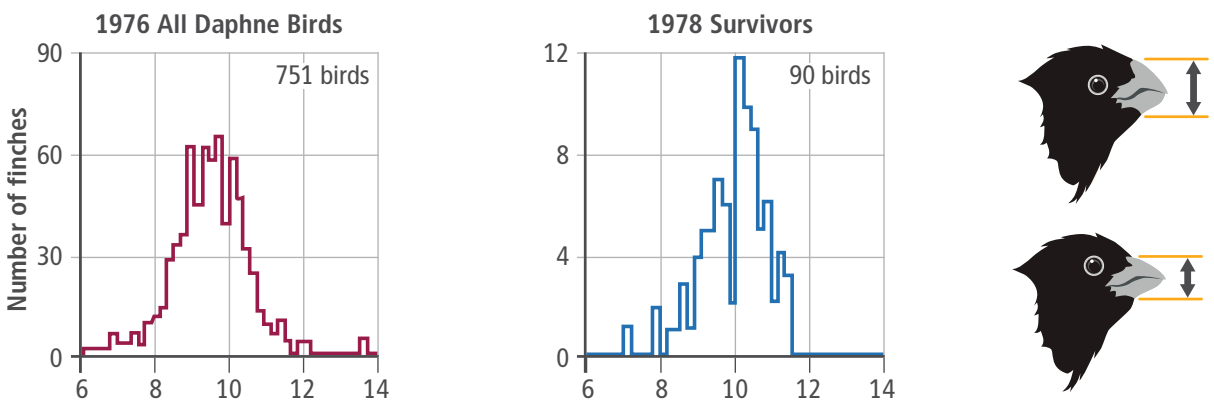
Overproduction More offspring are produced than can survive.

Competition Individuals must compete for resources, and some will outcompete others.

Adaptation Over time, beneficial traits become more common in the population, as individuals with those traits survive better and reproduce more often.

Analyze How did the distribution of beak sizes change after the 1977 drought? Explain how changes in the environment and the process of natural selection resulted in these changes.

FIGURE 20: The data in these graphs shows finch beak size before and after a drought.



The numbers of large-beaked finches on this Galápagos island kept rising until 1984, when the supply of large seeds went down after an unusually wet period. These conditions favored production of small, soft seeds, and small-beaked birds were now better adapted for the environment. With evolution, a trait that is an advantage today may be a disadvantage in the future.

Misconceptions About Natural Selection

It is tempting to assume that any feature on an organism must be the ideal trait for that organism's environment. However, not all traits are adaptations. For example, humans have a tail bone, but this anatomical feature is not the result of natural selection in humans. A feature such as this may have resulted from natural selection for a previous function, but it now serves no specific function. This trait is heritable, so it is passed down from person to person, but it no longer serves its original purpose.

FIGURE 21: This cartoon depicts a misconception about natural selection.

Explain The cartoon in Figure 21 depicts a cat who has developed a can opener for a hand. How does this cartoon demonstrate a misunderstanding of the theory of natural selection?

It also is important to keep in mind that natural selection does not produce individuals which are perfectly suited to their environment. This is partly because organisms have combinations of traits that result from complex sets of tradeoffs. For example, having large horns may help an organism fight successfully for mates, but they may make it difficult for the animal to escape predators as effectively as it could with lighter horns. Therefore, it would be difficult for selective pressures to produce "ideal" traits, because a trait that is ideal for one purpose may be less than ideal in other contexts.

Another reason natural selection does not produce ideal traits is that natural selection acts only on traits that already exist. Genetic variation within a population is what allows for the environment to "select" for certain traits. New alleles are not made by natural selection—they occur by genetic mutations.

Many mutations have harmful results and therefore are not likely to produce a trait that is beneficial in a given environment. However, some mutations lead to traits that might be advantageous to certain individuals. A mutation could change an organism's DNA in a way that leads to the production of a new type of protein. If this results in a trait that increases an organism's fitness, this trait would be selected for. Therefore, new traits can occur, but they are not created through natural selection.

Analyze You may have heard someone use the phrase "We'll have to adapt" to describe the way people adjust to their surroundings. Explain why this phrase could lead to misconceptions about natural selection.

Another common misconception about natural selection is that individuals can adapt to their environment. Natural selection leads to changes in populations, not in individual organisms. Evolution is a change in the proportion of alleles in a population over many generations. Therefore, individuals do not adapt to their environment over the course of one lifetime. Adaptations occur in populations, and those adaptations evolve over time through the process of natural selection. This process may take millions of years, or it may occur very quickly, as it does in single-celled organisms, such as bacteria.

Model Think back to the owls and field mice simulation. Were the four main principles of natural selection modeled accurately? How could you improve this model to reflect the principles of natural selection more effectively?

Guided Research

Natural Selection Today

The battle is on against bedbugs—those nasty little critters that invade your home and can give you painful, itchy bites. These pests were nearly vanquished from Earth in the 1940s by the use of the pesticide DDT, but now they are back. And those that survived the onslaught of DDT have developed a resistance to pesticides.

The DNA of bedbugs tells an interesting story about change and adaptations for survival. At one time, bedbugs fed on bats as much as they fed on humans. Although bats and humans live completely different lifestyles, that was not always the case.

Bedbugs started out as cave dwellers, feeding on bats. Early humans made homes in caves and became a new food source for the bedbugs. But technology changed everything, and soon humans were building houses. Humans also sleep at night, and bats nod off during the day. So, bedbugs that fed on bats and bedbugs that fed on humans began to diversify.

The bats that followed humans from caves to houses had to change their sleep schedule. Even as bats began to move into barns and bat houses, they brought their own brand of bedbug with them, and evidence suggests that the populations of bedbugs never mixed.

Evidence further suggests that the two groups continue to diverge. For example, the bedbugs that maintained their feeding relationship with humans now carry a genetic variation that makes them resistant to pesticides. This is not the case for the bat-feeding bedbugs.

Researchers are now studying bedbugs to learn how they develop resistance to pesticides. Several genes have been identified that may be related to this phenomenon. Many of these genes give rise to proteins in the insect's exoskeleton. This makes sense, because bedbugs are exposed to pesticides through contact with their exoskeleton.

For now, humans will have to rely on bedbug-sniffing dogs and a variety of pesticides, many of which lose their effectiveness as these pests continue to adapt by developing resistances to them.

FIGURE 22: Bedbugs show evidence of recent evolution. New traits include a thick, waxy exoskeleton that repels pesticides and a more efficient process for making its natural chemical defenses.

Language Arts Connection

Research another species whose evolution interests scientists. Gather evidence to explain how this species' traits have changed, why these traits are beneficial, and how this species might continue to change in the future. Be sure to cite specific textual evidence to support your claims. Finally, present your findings in the form of an essay, slideshow, or poster. Include a list of sources in the format specified by your instructor.

Evidence is anything that helps in forming a conclusion or judgment. When drawing evidence from informational texts, ask yourself these questions:

- Are the facts verifiable—that is, can they be proven true?
- Are the opinions from an expert or experts on the topic?
- Is the evidence relevant to the topic?
- Is there enough evidence to answer all reasonable questions?

GENETIC DIVERSITY IN FLORIDA PANTHERS | MODELING NATURAL SELECTION | BIOMECHANICS OF STAG BEETLE JAWS

Go online to choose one of these other paths.

Lesson Self-Check

CAN YOU EXPLAIN IT?

FIGURE 23: The orchid mantis *(Hymenopus coronatus)* resembles a flower in shape. But it attracts flies for another reason. Its color appears to be more important than its shape.

Recall the orchid mantis, the insect that resembles the flower after which it is named. It is easy to assume that the insect has high fitness because it looks like a flower. In fact, researchers have found that when placed beside the most common flower in its habitat, the orchid mantis attracts insects more often than the flower.

Why would insects be more attracted to the mantis than a flower? Apparently, it has more to do with the mantis's bright color than its flowerlike shape. Many insects have brains that are more attuned to color than to complex shapes. If an insect sees a color it thinks is a nectar-bearing flower, it flies in to investigate. That is when the orchid mantis makes its move—it captures the insect with lightning-fast speed.

Explain Refer to the notes in your Evidence Notebook and use what you have learned about natural selection to make a claim for how this trait could have evolved over time. Include a discussion of each of the principles of natural selection and how they led to the adaptations we see in modern-day orchid mantises.

1. State your claim.
2. Use evidence to support your claim.
3. Explain how the evidence you cited supports the claim you are making.

CHECKPOINTS

Check Your Understanding

1. Which two processes that occur during the formation of gametes contribute to increasing diversity within a population's gene pool?
   - **a.** independent assortment
   - **b.** cell signaling
   - **c.** transformation
   - **d.** crossing over
   - **e.** segregation of alleles

2. If the climate were to change in an environment, it is more likely that some individuals within a population will survive if _____
   - **a.** the individuals reproduce sexually.
   - **b.** the individuals are genetically identical.
   - **c.** there is genetic variation within the population.
   - **d.** the individuals reproduce asexually.

3. The work of _____ most helped Charles Darwin understand how bands of seashells could be found in rock strata high above sea level.
   - **a.** Malthus
   - **b.** Lyell
   - **c.** Mendel
   - **d.** Leclerc

4. Which of the following are key elements of Darwin's theory of evolution by natural selection? Select all correct answers.
   - **a.** genetic variation
   - **b.** genetic engineering
   - **c.** fitness
   - **d.** adaptation
   - **e.** overproduction

5. Explain how mutations lead to genetic variation.

6. Construct an explanation as to how natural selection might produce an effect of the giraffe's neck length changing over time.

7. How did the work of farmers and breeders in England influence the work of Charles Darwin? Use examples to support your explanation.

8. What effect did Darwin's travels to the Galápagos Islands have on the development of his theory of natural selection?

9. Draw a timeline of events that influenced Darwin's work and the people whose work he built upon.

10. Develop a model that can be used to illustrate natural selection. Explain how your model demonstrates the four main principles of natural selection.

MAKE YOUR OWN STUDY GUIDE

In your Evidence Notebook, design a study guide that supports the main ideas from this lesson:

Many scientists had made observations and developed ideas about evolution, but it was Charles Darwin who developed the theory of evolution by natural selection.

Natural selection is a process in which overproduction, variation, and competition lead to the adaptation of populations over time.

Remember to include the following information in your study guide:

- Use examples that model main ideas.
- Record explanations for the phenomena you investigated.
- Use evidence to support your explanations. Your support can include drawings, data, graphs, laboratory conclusions, and other evidence recorded throughout the lesson.

Consider how the models you observed demonstrate the four main principles of natural selection.

Earth Science Connection

Biogeography Biogeography is the study of the geographical distribution of organisms and ecosystems over space and time. Similar to the way fossil evidence was used to support the idea that Earth's surface has changed over time due to continental drift, biogeography can be used to support the idea that species change over time due to evolution through natural selection. For example, what might be indicated by the fact that marsupials only exist in the Americas and Australia?

How does the geographical distribution of closely related species, and the distribution of similar but not related species, provide evidence for evolution? Use library and Internet resources to select a biogeographical example that provides a line of evidence for evolution. Then, create a conceptual model to represent your example and explain your model in a short story.

FIGURE 1: Female marsupials care for their undeveloped young outside of their bodies in special pouches until they reach independence.

Social Studies Connection

The Importance of Relationships As early humans evolved, so did their societies. Humans began as small groups of hunter-gatherers. Some societies have shifted from hunter-gatherer to agriculture to industrialization and finally to urban, post-industrial societies. Industrial and post-industrial societies may minimize relationships that are common in other societies. For example, electronic socializing has taken the place of other forms of communication, such as phone calls, letters, and in-person conversation.

Using library and Internet resources, research the social structures that are in place in hunter-gatherer, agricultural, industrial, and post-industrial human societies and how each structure emphasizes or minimizes the need for social relationships. What might explain a shift in social behavior in modern humans? Write a report that outlines your position on whether electronic socializing is impacting the quality of relationships in modern humans. Include background on the evolution or changing nature of relationships in human societies. Make sure you provide evidence that supports your claim.

FIGURE 2: Social networking may actually reduce social connections between peers.

Life Science Connection

Domesticating Foxes Researchers in Russia have been exploring the domestication of foxes for over 50 years. From the parent generation onward, only the least aggressive foxes have been allowed to breed. This experiment in domestication has significantly changed both the behavior and the appearance of the foxes over a relatively short time period.

Using library and Internet resources, research the Russian fox domestication experiment. Develop a scientific poster that outlines the purpose, methods, and outcomes of the fox domestication experiment, with a discussion about next steps and what the outcomes indicate about the mechanism for domestication in dogs.

FIGURE 3: Domesticated Fox

SYNTHESIZE THE UNIT

In your Evidence Notebook, make a concept map, graphic organizer, or outline using the Study Guides you made for each lesson in this unit. Be sure to use evidence to support your claims.

When synthesizing individual information, remember to follow these general steps:

- Find the central idea of each piece of information.
- Think about the relationships between the central ideas.
- Combine the ideas to come up with a new understanding.

DRIVING QUESTIONS

Look back to the Driving Questions from the opening section of this unit. In your Evidence Notebook, review and revise your previous answers to those questions. Use the evidence you gathered and other observations you made throughout the unit to support your claims.

PRACTICE AND REVIEW

1. DNA nucleotides are said to be universal because they are the same for all known organisms. What is this evidence of? Select all correct answers.

a. common ancestry
b. fossil record
c. evolution
d. natural selection

2. Which lines of evidence did Darwin use to explain the variety of finches on the Galapagos Islands? Select all correct answers.

a. DNA evidence
b. fossil evidence
c. geological evidence
d. anatomical evidence

3. How did fossils contribute to Darwin's ideas about changes in species over time?

a. Fossils supported Darwin's ideas about common ancestry and the relationship of living species to fossil species.
b. Fossils showed that all species are the result of gradual changes over time.
c. Fossils explained how species develop different traits.
d. Fossils showed how humans had been impacting the traits of organisms for thousands of years.

4. Natural selection acts on which of the following? Select all correct answers.

a. individuals
b. populations
c. genes
d. traits

5. Which statement best describes the relationship between natural selection and variation?

a. All variations are acted upon by natural selection.
b. Variations evolve during natural selection to make a species better adapted to its environment.
c. Natural selection acts on variations that are selected for or against based on the environment.
d. Natural selection creates variations that are selected for or against based on the environment.

6. Which factor is not required in order for natural selection to take place?

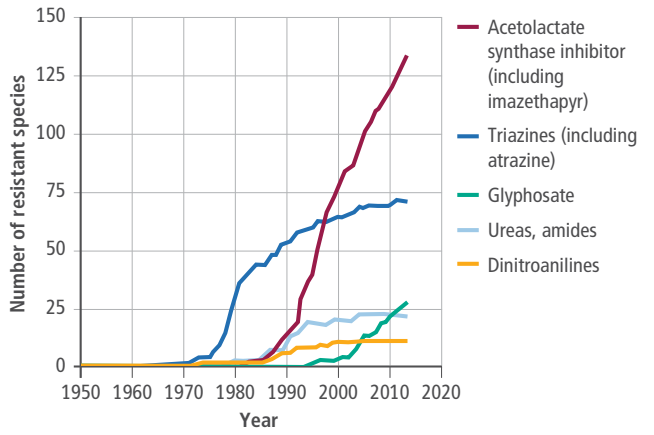
a. adaptation
b. competition
c. overproduction
d. sexual reproduction
e. variation

Use the following information and Figure 4 to answer questions 7–9.

Chemical herbicides are used in agricultural and landscape maintenance to kill unwanted vegetation, such as weeds. As the use of an herbicide becomes more common and widespread, weeds can evolve resistance to particular types of herbicide.

The Rise of Superweeds

FIGURE 4: The number of weed species resistant to herbicides has increased since 1970.



Source: Heap, Ian. "International Survey of Herbicide Resistant Weeds." as quoted in Gilbert, Natasha, (2013) "Case Studies: A hard look at GM crops," *Nature*, 497(7447).

7. Weeds first evolved resistance to which herbicide class?

- **a.** acetolactate synthase inhibitor
- **b.** dinitroanilines
- **c.** glyphosate
- **d.** triazines
- **e.** ureas, amides

8. What is most likely indicated by the fact that the number of species resistant to a class of herbicide does not decrease over time?

- **a.** Individual weeds evolve herbicide resistance and pass the trait to their offspring.
- **b.** The herbicide resistance trait is maintained in resistant populations.
- **c.** The weed populations frequently lose then evolve a resistance to herbicides again.
- **d.** Whenever one weed species loses herbicide resistance, one or more species gains resistance, leading to a net increase in resistant species.

9. Model a likely sequence of events that would lead to herbicide resistance in plants.

10. Use these terms to complete the statement below:

trait, evolution, DNA, genetic

Mitochondria and chloroplasts contain their own _____. The theory of endosymbiosis proposes that this _____ evidence may support the idea that mitochondria and chloroplasts were once free-living prokaryotes that were engulfed by larger prokaryotic host cells. The internalized prokaryotes might have provided nutrients and energy to the host cell, and, in turn, received protection and a stable environment in which to live. This endosymbiotic relationship may have led to the _____ of mitochondria and chloroplasts. These organelles would be an advantageous _____ selected for in populations.

11. Why is the fossil record an imperfect line of evidence for evolution?

UNIT PROJECT

Return to your unit project. Prepare your research and materials into a final presentation to share with the class. In your final presentation, evaluate the strength of your predictions, analysis, and conclusions about the evolution of eyes.

Remember these tips while evaluating:

- Look at the empirical evidence—evidence based on observations and data. Does your line of evidence support the idea that eyes have evolved over time?
- Consider if the explanation is logical. Does it contradict any evidence you have seen?
- Is there enough evidence to answer all reasonable questions? How might you develop tests for any additional questions?

Investigating Evolution in Unique Environments

FIGURE 5: These organisms were found in Movile Cave.

Movile Cave in Romania is closed to the public. In fact, fewer than 100 people have ever entered the cave. Those who have been inside returned with reports and images of translucent organisms, many without eyes, that have extra-long antenna and can breathe the toxic atmosphere. What do you think is happening in this cave, and what explains the unique appearance of these organisms?

1. ASK A QUESTION

With your team, make a list of questions you have about the organisms and the environment in Movile Cave. Identify the factors you will research to answer these questions.

2. CONDUCT RESEARCH

Investigate Movile Cave in Romania. What makes this cave unique, and what has contributed to the evolution of unique organisms within the cave?

3. DEVELOP A MODEL

Create a model that explains a likely sequence of events that led to the current organisms inhabiting Movile Cave.

4. CONSTRUCT AN EXPLANATION

Use your research and model to construct an explanation for how the organisms in Movile Cave changed and evolved over time. What traits were selected for and how are they advantageous in the environment?

5. COMMUNICATE

Present your research and your model as a multimedia presentation that explains how evolution and natural selection led to unique organisms in Movile Cave.

CHECK YOUR WORK

A complete presentation should include the following information:

- a set of questions about what caused the evolution of unique traits in organisms in Movile Cave
- an explanation supported by evidence that details how the organisms changed and evolved over time and the selective pressures that caused the changes
- a model to accompany your explanation that explains a likely sequence of events that led to the appearance and behavior of the current organisms inhabiting Movile Cave