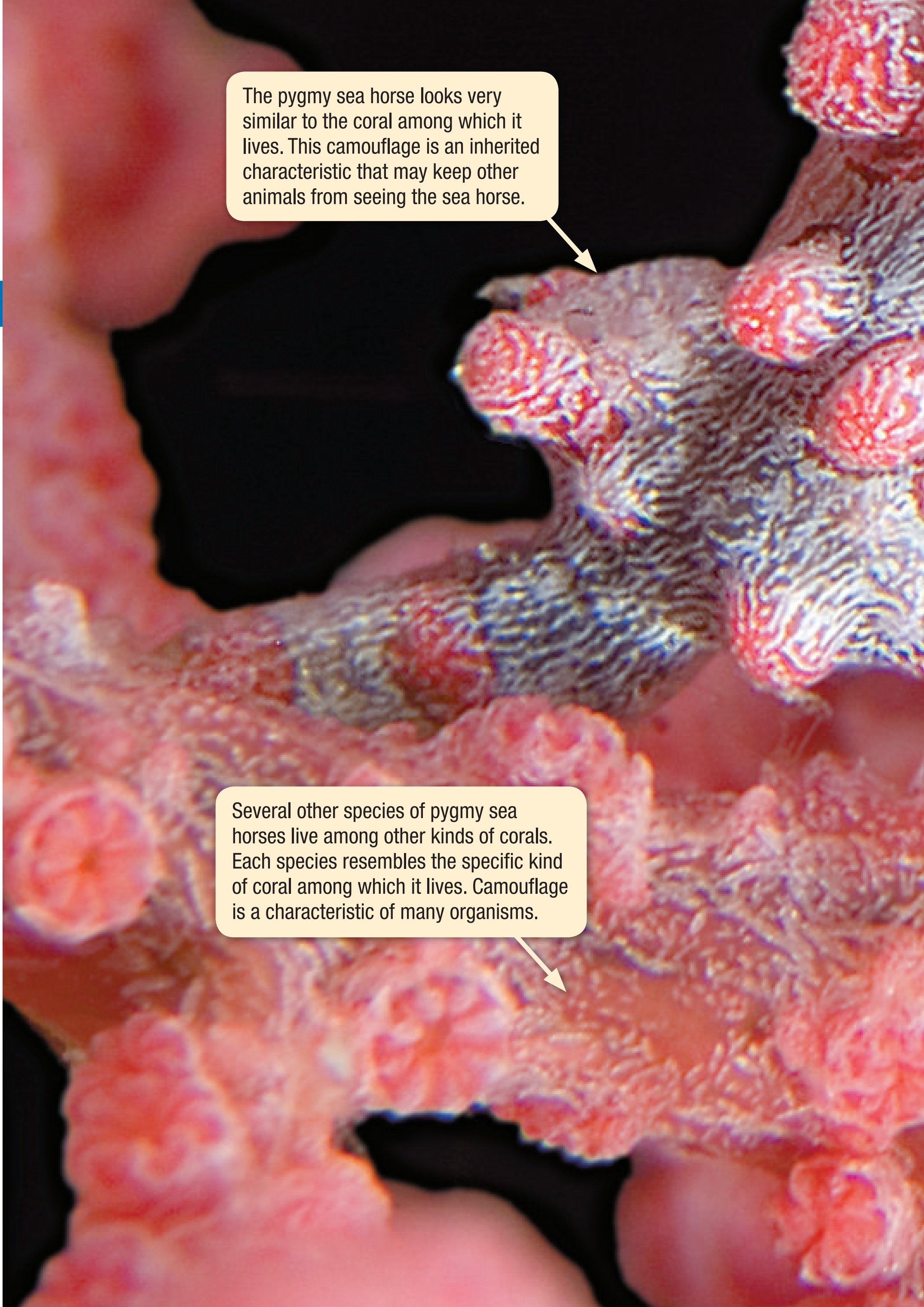
Chapter 16 Evolutionary Theory

Preview

Why It Matters

Modern evolutionary theory provides strong and detailed explanations for many aspects of biology, such as anatomy and behavior.



This pygmy sea horse is smaller than your fingernail. It lives exclusively among certain kinds of coral in coral reefs of the western Pacific Ocean.

Section 1

Developing a Theory

Key Ideas	Key Terms	Why It Matters
❯ Why is evolutionary theory associated with Charles Darwin? ❯ How was Darwin influenced by his personal experiences? ❯ How was Darwin influenced by the ideas of others?	evolution artificial selection	Many aspects of biology are best explained by evolutionary theory.

Recall that in biology, **evolution** is the process by which species may change over time. The idea that life evolves is not new. Yet for centuries, scientists lacked clear evidence that evolution happens. They also lacked a strong theory to explain how evolution happens. In 1859, Charles Darwin pulled together these missing pieces. Darwin, shown in **Figure 1,** was an English naturalist who studied the diversity of life and proposed a broad explanation for it.

A Theory to Explain Change over Time

Recall that in science, a *theory* is a broad explanation that has been scientifically tested and supported. ❯ **Modern evolutionary theory began when Darwin presented evidence that evolution happens and offered an explanation of how evolution happens.** Like most scientific theories, evolutionary theory keeps developing and expanding. Many scientists since Darwin have tested and added to his ideas. Most of Darwin's ideas, including his main theory, remain scientifically supported.

❯ **Reading Check** *What does* evolution *mean in biology? (See the Appendix for answers to Reading Checks.)*

evolution the process of change by which new species develop from preexisting species over time

Figure 1 Charles Darwin took many years to publish his theory of evolution by natural selection. Many of his ideas were first inspired by his 1831 global voyage on a ship called the *Beagle*.

Darwin's Ideas from Experience

In Darwin's time, most people did not think that living things had changed over time. In fact, many doubted that Earth itself had ever changed. But Darwin saw evidence of gradual change. **Darwin's experiences provided him with evidence of evolution at work.**

READING TOOLBOX

Key-Term Fold On the back half of your key-term fold, under each flap, write your own definition for the key terms in this section.

The Voyage of the *Beagle* Darwin's first evidence was gathered during a global voyage on a ship called the *Beagle*. As part of his work as a naturalist, Darwin collected natural objects from each place that he visited. For example, in South America, he collected fossils of giant, extinct armadillos. Darwin noticed that these fossils were similar, but not identical, to the living armadillos in the area.

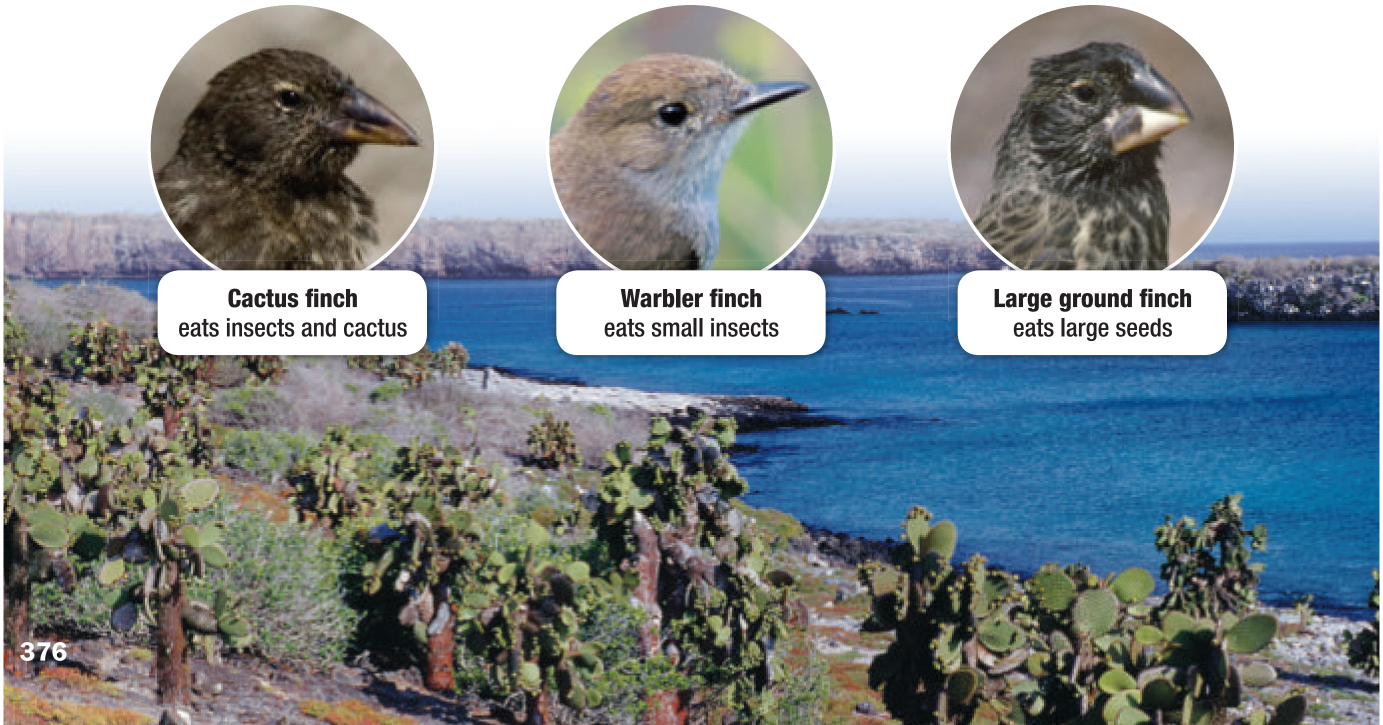
Darwin also visited the Galápagos Islands in the Pacific Ocean. There, he collected several different species of birds called *finches*. Each of the finches are very similar, but differences can be seen in the size and shape of the bill (or beak), such as those shown in **Figure 2.** Each finch has a bill that seems suited to the finch's usual food.

Darwin noticed that many of the islands' plants and animals were similar, but not identical, to the plants and animals he saw in South America. Later, Darwin proposed that the Galápagos species had descended from species that came from South America. For example, he suggested that all of the finch species descended from one ancestral finch species that migrated from South America. Then, the descendant finches were modified over time as different groups survived by eating different types of food. Darwin called such change *descent with modification*. This idea was a key part of his theory.

artificial selection the human practice of breeding animals or plants that have certain desired traits

Years of Reflection After returning from his voyage at the age of 27, Darwin spent years studying his data. He also continued studying many sciences. As he studied, his confidence grew stronger that evolution must happen. But Darwin did not report his ideas about evolution until much later. Instead, he took time to gather more data and to form a strong explanation for how evolution happens.

Figure 2 Darwin eventually learned that all Galápagos finch species were similar to each other and to one particular South American finch. **What explanation did Darwin propose for this similarity?**



Breeding and Selection Darwin took interest in the practice of breeding, especially the breeding of exotic pigeons. He bred pigeons himself and studied the work of those who bred other kinds of animals and plants, such as dogs, orchids, and food crops. Eventually, Darwin gained a new insight: breeders take advantage of natural variation in traits within a species. If a trait can be inherited, breeders can produce more individuals that have the trait. Breeders simply select individuals that have desireable traits to be the parents of each new generation. Darwin called this process **artificial selection** because the selection is done by humans and not by natural causes.

Academic Vocabulary

insight a clear understanding of something

Reading Check *When did Darwin first see evidence of evolution?*

Why It Matters

Breeding

The power of artificial selection can be seen today in the amazing variety of pets, show animals, and agricultural food crops. For example, more than 400 breeds of dogs exist today, from tiny Chihuahuas to Great Danes. All of these breeds, including wolves, are considered part of the same species (*Canis lupus*) because most can interbreed.

Dog Diversity

People have lived with dogs—or the wolf ancestors of dogs—throughout history. Over time, people learned to selectively breed dogs by choosing certain individuals to become parents. People have selected dogs that have various kinds of physical and behavioral traits. So today, each breed of dog is known for its appearance as well as its degree of playfulness, friendliness, watchfulness, or cleverness. Some breeds are also known for certain quirks or problems.

Quick Project Visit a local pet store, and ask which breeds are most popular or most expensive. Ask why.

Hands-On

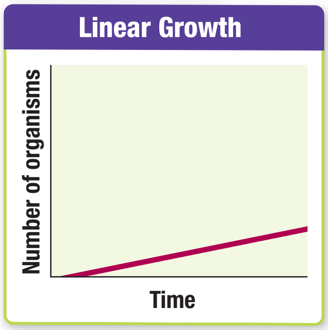
QuickLab 15 min

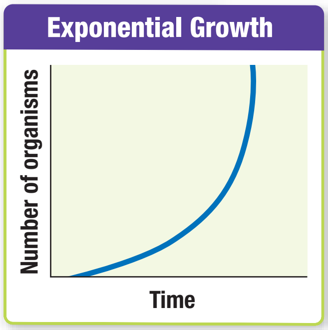
Two Kinds of Growth

Can you visualize the difference between linear growth and exponential growth?

Procedure

1. Place **grains of rice** in the cups of an **egg carton** in the following sequence: Place one grain in the first cup. Place two grains in the second cup. Place three grains in the third cup. In each of the remaining cups, place *one more* grain of rice than in the cup before.
2. Use a line graph to graph the results of step 1.
3. Repeat step 1, but use the following sequence: Place one grain in the first cup, two in the second cup, and four in the third cup. In each remaining cup, place twice as many grains as placed in the cup before.
4. Use a line graph to graph the results of step 3.





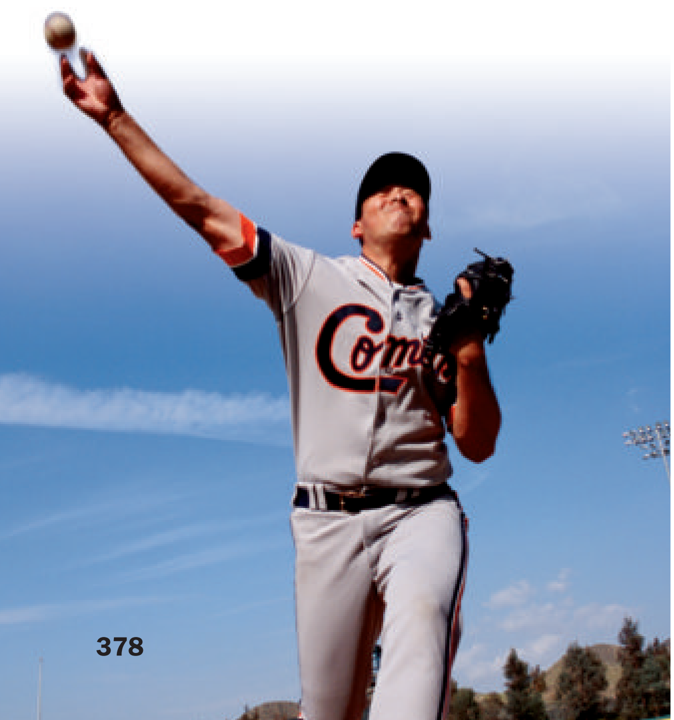
Analysis

1. **Match** your graphs to the graphs shown.
2. CRITICAL THINKING **Analyzing Terminology** Linear growth is also called *arithmetic growth,* and exponential growth is also called *geometric growth*. Propose an explanation for the use of these terms.

Darwin's Ideas from Others

In Darwin's time, most people—including scientists—believed that each species was created once and stayed the same forever. But this view could not explain fossils of organisms that no longer exist, such as dinosaurs. Some scientists tried to explain such observations by saying that species could die out but never change. Others, including Darwin's own grandfather, proposed various mechanisms to explain how species may change over time. **Darwin was influenced by ideas from the fields of natural history, economics, and geology.** The ideas of Lamarck, Malthus, Cuvier, and Lyell were especially important.

Figure 3 According to Lamarck's idea of inheritance, this baseball player's children would inherit strong arm muscles. **Why was this idea important to Darwin?**



Lamarckian Inheritance In 1809, the French scientist Jean Baptiste Lamarck proposed an explanation for how organisms may change over generations. Like Darwin and others, Lamarck noticed that each organism is usually well adapted to its environment. He proposed, as Darwin would later, that organisms change over time as they adapt to changing environments.

However, Lamarck had an incorrect idea about inheritance. He proposed that changes due to use or disuse of a character would be passed on to offspring. For example, he knew that a person's muscles may increase in size because of use or may decrease in size because of disuse, as shown in **Figure 3.** He believed that offspring inherited these kinds of changes. This idea was eventually disproved, but not in Darwin's time. Darwin once accepted this idea because it proposed a role for inheritance in evolution.

Population Growth Another key influence on Darwin's thinking about evolution was an essay by Thomas Malthus. In 1798, this English economist observed that human populations were increasing faster than the food supply. Malthus pointed out that food supplies were increasing *linearly*. More food was being produced each year, but the amount by which the food increased was the same each year. In contrast, the number of people was increasing *exponentially*. More people were added each year than were added the year before. Malthus noted that the number of humans could not keep increasing in this way, because many people would probably die from disease, war, or famine.

Darwin simply applied Malthus's idea to all populations. Recall that a *population* is all of the individuals of the same species that live in a specific place. Darwin saw that all kinds of organisms tend to produce more offspring than can survive. So, all populations must be limited by their environments.

Figure 4 Layers of rock contain evidence of changes occurring over millions of years in organisms and environments on Earth. Darwin realized that such evidence supported his ideas about evolution.

Geology and an Ancient Earth In Darwin's time, scientists had become interested in the study of rocks and landforms, and thus began the science of *geology*. In particular, scientists such as Georges Cuvier, James Hutton, and Charles Lyell studied fossils and rock layers, such as those shown in **Figure 4.** Cuvier argued that fossils in rock layers showed differences in species over time and that many species from the past differed from those of the present. But Cuvier did not see species as changing gradually over time. He thought that changes in the past must have occurred suddenly.

Hutton and Lyell, on the other hand, thought that geologic processes—such as those that wear away mountains and form new rocks and fossils—work gradually and constantly. Lyell carefully and thoroughly presented his ideas in a book, which Darwin read. Lyell's ideas fit well with Darwin's observations and showed that Earth's history was long enough for species to have evolved gradually.

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Topic: Charles Darwin
Code: HX80262

Reading Check ***What belief did Darwin and Lamarck share?***

Section 1 Review

KEY IDEAS

1. **Describe** Darwin's relationship to modern evolutionary theory.
2. **Identify** personal experiences that contributed to Darwin's thinking about evolution.
3. **Identify** other scientists that influenced Darwin's thinking.

CRITICAL THINKING

4. **Applying Process Concepts** Darwin observed that artificial selection can produce specific traits. Suppose a farmer has a corn crop in which each ear of corn has some yellow kernels and some white kernels. Describe how the farmer could produce a variety of corn that has all white kernels.

METHODS OF SCIENCE

5. **Scientific Testing** According to Lamarck's idea of inheritance, an individual that developed an improved trait within its lifetime, especially through repeated use, could pass that trait on to its offspring. Propose a way to test the accuracy of this idea.

Section 2 Applying Darwin's Ideas

Key Ideas	Key Terms	Why It Matters
What does Darwin's theory predict? Why are Darwin's ideas now widely accepted? What were the strengths and weaknesses of Darwin's ideas?	natural selection adaptation fossil homologous structures	The principles of evolution are used daily in medicine, biology, and other areas of modern life to understand, predict, and develop advancements in each area.

Darwin applied Malthus's idea to all species. Every living thing has the potential to produce many offspring, but not all of those offspring are likely to survive and reproduce.

Evolution by Natural Selection

Darwin formed a key idea: Individuals that have traits that better suit their environment are more likely to survive. For example, the insect in **Figure 5** is less likely to be seen (and eaten) than a brightly colored insect is. Furthermore, individuals that have certain traits tend to produce more offspring than others do. These differences are part of **natural selection.** Darwin proposed that natural selection is a cause of evolution. In this context, *evolution* is a change in the inherited characteristics of a population from one generation to the next.

Steps of Darwin's Theory Darwin's explanation is often called the *theory of evolution by natural selection.* **Darwin's theory predicts that over time, the number of individuals that carry advantageous traits will increase in a population.** As shown in **Figure 6,** this theory can be summarized in the following four logical steps:

Step 1 Overproduction Every population is capable of producing more offspring than can possibly survive.

Step 2 Variation Variation exists within every population. Much of this variation is in the form of inherited traits.

Step 3 Selection In a given environment, having a particular trait can make individuals more or less likely to survive and have successful offspring. So, some individuals leave more offspring than others do.

Step 4 Adaptation Over time, those traits that improve survival and reproduction will become more common.

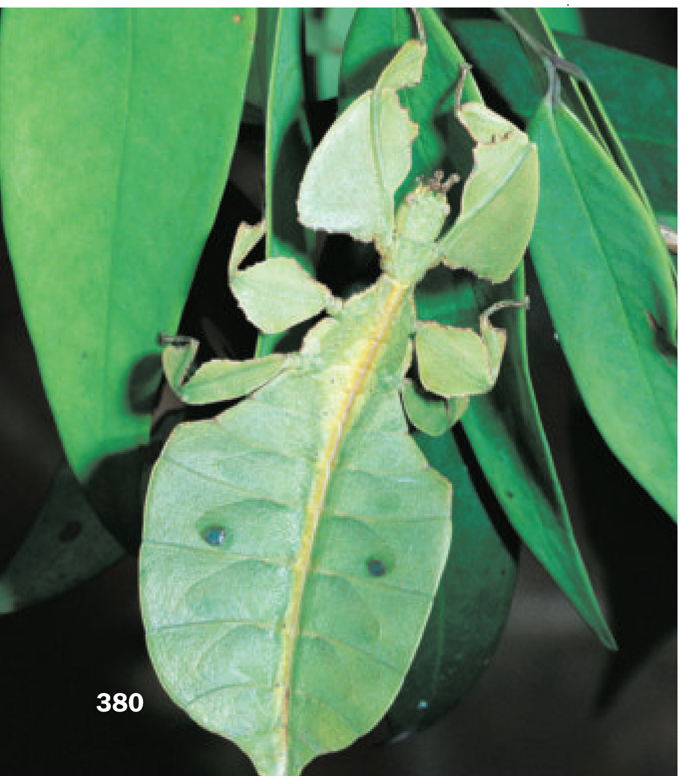

Figure 5 This insect is well adapted to its environment. **How does Darwin's theory help explain this observation?**

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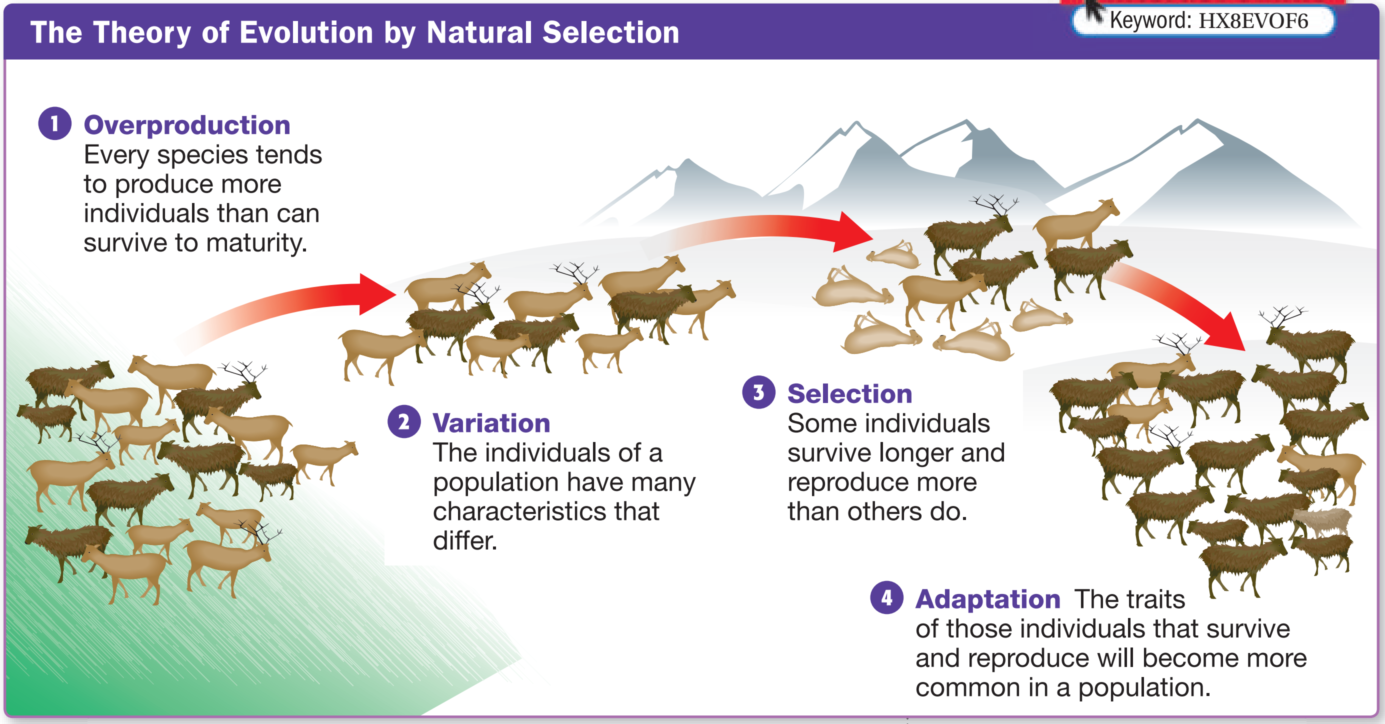


Figure 6 Darwin proposed a logical process by which evolution may occur. **Can this process act on individuals?**

Selection and Adaptation Darwin's theory explains why living things vary in form yet seem to match their environment. Each habitat presents unique challenges and opportunities to survive and reproduce. So, each species evolves because of the "selection" of those individuals that survive the challenges or make best use of the opportunities. Put another way, each species becomes *adapted* to its environment as a result of living in it over time. An **adaptation** is an inherited trait that is present in a population because the trait helps individuals survive and reproduce in a given environment.

In sum, Darwin's theory explains evolution as a gradual process of adaptation. Note that Darwin's theory refers to *populations* and *species*—not *individuals*—as the units that evolve. Also, keep in mind that a species is a group of populations that that can interbreed.

Publication of the Theory In 1844, Darwin finally wrote an outline of his ideas about evolution and natural selection. But he showed it only to a few scientists that he knew well. He was afraid that his ideas would be controversial. Then in 1858, he received a letter from another young English naturalist named Alfred Russel Wallace. Wallace asked for Darwin's opinion on a new theory—a theory much like Darwin's! Because of this similarity, Darwin and Wallace jointly presented their ideas to a group of scientists. Darwin was finally motivated to publish a full book of his ideas within the next year.

Darwin's book *On the Origin of Species by Means of Natural Selection* presented evidence that evolution happens and offered a logical explanation of how it happens. Biologists began to accept that evolution occurs and that natural selection helps explain it.

Reading Check ***Is natural selection the same thing as evolution?***

READING TOOLBOX

Hypothesis or Theory? Why isn't Darwin's explanation simply called *the theory of evolution*? Why isn't it called a *hypothesis*?

natural selection the process by which individuals that are better adapted to their environment survive and reproduce more successfully than less well adapted individuals do

adaptation a trait that improves an organism's ability to survive and reproduce; the process of becoming adapted

fossil the trace or remains of an organism that lived long ago, most commonly preserved in sedimentary rock

What Darwin Explained

Darwin's book was more than an explanation of his theory. It also included a thorough presentation of the evidence that living species evolved from organisms that lived in the past. Darwin had studied much of the data that was available in his time. **Darwin presented a unifying explanation for data from multiple fields of science.** Today, these sciences include geology, geography, ecology, developmental biology, anatomy, genetics, and biochemistry. Scientists continue to draw upon the power of Darwin's explanations.

ACADEMIC VOCABULARY

infer to derive by reasoning

The Fossil Record Have you ever looked at a series of historical maps of a city? You can infer that buildings and streets have been added, changed, or destroyed over time. Similarly, you can infer past events by looking at **fossils,** traces of organisms that lived in the past. All fossils known to science make up the *fossil record*.

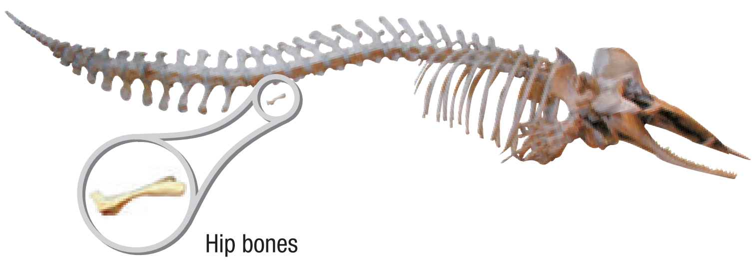
Sometimes, comparing fossils and living beings reveals a pattern of gradual change from the past to the present. Darwin noticed these patterns, but he was aware of many gaps in the patterns. For example, Darwin suggested that whales might have evolved from a mammal that lived on land. But at the time, no known fossils were "in between" a land mammal and a whale.

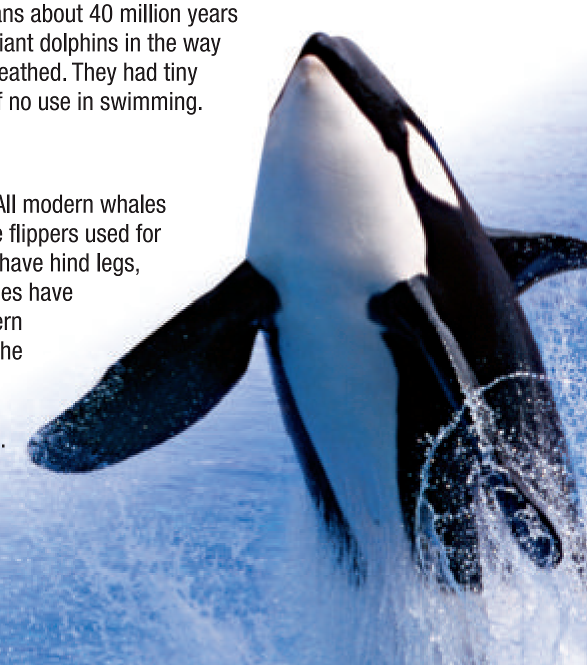
Figure 7 Darwin once hypothesized that modern whales evolved from ancient, four-legged, land-dwelling, meat-eating mammals. Over the years since, scientists have collected a series of fossil skeletons that support this hypothesis.

1 ***Pakicetus* (PAK uh SEE tuhs)** Scientists think that whales evolved from land-dwelling mammals such as those in the genus *Pakicetus*. The fossil skeleton of a pakicetid is shown here. These mammals lived about 50 million years ago, walked or ran on four legs, and ate meat.

2 ***Ambulocetus* (AM byoo loh SEE tuhs)** Mammals of this genus lived in coastal waters about 49 million years ago. These mammals could swim by kicking their legs and using their tail for balance. They could also use their short legs to waddle on land. They breathed air through their mouth.

3 ***Dorudon* (DOHR oo DAHN)** Mammals of this genus lived in the oceans about 40 million years ago. They resembled giant dolphins in the way that they swam and breathed. They had tiny hind limbs that were of no use in swimming.





4 **Modern Whales** All modern whales have forelimbs that are flippers used for swimming. No whales have hind legs, but some toothed whales have tiny hipbones. All modern whales must come to the surface of the water to breathe through a hole at the top of their head.

Rhea (South America)

Ostrich (Africa)

Emu (Australia)

Figure 8 Three unique bird species are shown here. Each of these is similar in size, shape, eating habits, and habitat. However, each species seems to have first appeared on a separate continent. **What does this pattern suggest about evolution?**

Darwin predicted that *intermediate forms* between groups of species might be found. And indeed, many new fossils have been found, such as those shown in **Figure 7.** But the conditions that create fossils are rare, so we will never find fossils of every species that ever lived. The fossil record will grow but will never be complete.

Biogeography *Biogeography* is the study of the locations of organisms around the world. When traveling, Darwin and Wallace saw evolution at work when they compared organisms and environments. For example, Darwin saw the similarity of the three species of large birds in **Figure 8.** He found each bird in a similar grassland habitat but on a separate continent. This finding was evidence that similar environments shape the evolution of organisms in similar ways.

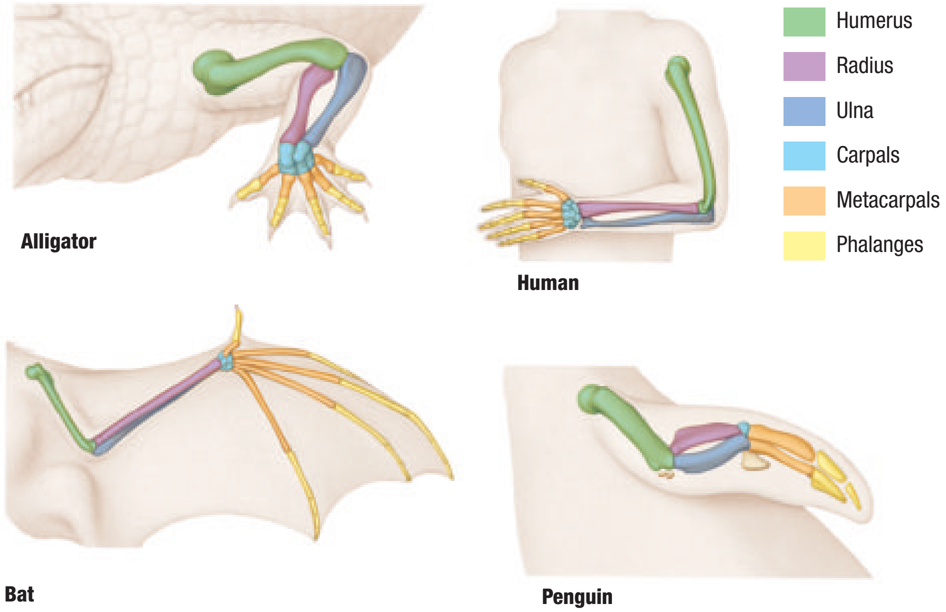
Sometimes, geography separates populations. For example, a group of organisms may become separated into two groups living on two different islands. Over time, the two groups may evolve in different patterns. Generally, geologists and biologists have found that the movement of landforms in Earth's past helps to explain patterns in the types and locations of both living and fossil organisms.

Developmental Biology The ancestry of organisms is also evident in the ways that multicellular organisms develop from embryos. The study of such development is called *embryology*. This study is interesting because embryos undergo many physical and genetic changes as they develop into mature forms.

Scientists may compare the embryonic development of species to look for similar patterns and structures. Such similarities most likely derive from an ancestor that the species have in common. For example, at some time during development, all vertebrate embryos have a tail. *Vertebrates* are animals that have backbones.

Reading Check ***Why is the fossil record incomplete?***

Figure 9 Although they look very different from one another on the outside, the forelimbs of most tetrapods (vertebrates that have four limbs) include a similar group of bones. **What hypothesis does this observation support?**



Anatomy Another place to observe the results of evolution is inside the bodies of living things. The bodily structure, or *anatomy,* of different species can be compared. Many internal similarities are best explained by evolution and are evidence of how things are related.

For example, the hypothesis that all vertebrates descended from a common ancestor is widely accepted. Observations of the anatomy of both fossil and living vertebrates support this hypothesis. When modern vertebrates are compared, the difference in the size, number, and shape of their bones is clear. Yet the basic pattern of bones is similar. In particular, the forelimbs of many vertebrates are composed of the same basic groups of bones, as **Figure 9** shows. This pattern of bones is thought to have originated in a common ancestor. So, the bones are examples of **homologous** structures, characteristics that are similar in two or more species and that have been inherited from a common ancestor of those species.

Biochemistry To explain the patterns of change seen in anatomy, scientists make testable predictions. For example, if species have changed over time, the genes that determine their characteristics should also have changed. Recall that genes can change by mutation and that such change can make new varieties appear. Then, natural selection may "select against" some varieties and so "favor" others.

Scientists have observed that genetic changes occur over time in all natural populations. A comparison of DNA or amino-acid sequences shows that some species are more genetically similar than others. These comparisons, like those in anatomy, are evidence of hereditary relationships among the species. For example, comparing one kind of protein among several species reveals the pattern shown in **Figure 10.** The relative amount of difference is consistent with hypotheses based on fossils and anatomy.

Reading Check ***What explains similarities in bone structure?***

Hemoglobin Comparison

Animal with hemoglobin	Amino acids that differ from human hemoglobin
Gorilla	1
Rhesus monkey	8
Mouse	27
Chicken	45
Frog	67
Lamprey	125

Figure 10 Scientists have compared the amino acids that make up hemoglobin proteins in several species. Organisms that have fewer differences are more likely to be closely related. **How does this pattern relate to genetic change?**

Evaluating Darwin's Ideas

Why was Darwin such an important scientist? **Darwin's work had three major strengths: evidence of evolution, a mechanism for evolution, and the recognition that variation is important.** Today, Darwin is given credit for starting a revolution in biology.

Strengths Darwin was *not* the first to come up with the idea that evolution happens, but he was the first to gather so much evidence about it. He described his most famous book as "one long argument" that evolution is possible. Before publishing, Darwin collected and organized many notes, observations, and examples, such as the illustration shown in **Figure 11.** So, one strength of Darwin's work is that it is supported by, and helps explain, so much data.

Darwin also presented a logical and testable mechanism that could account for the process of evolution. His theory of natural selection was well thought out and convincing to scientists of his time as well as today. It has since become a foundation of biology.

Finally, Darwin changed the way scientists thought about the diversity of life. Before Darwin, most scientists saw species as stable, unchanging things. They classified species based on average appearances and ignored variation. But Darwin showed that variation was everywhere and could serve as the starting point for evolution.

Weaknesses Darwin's explanations were incomplete in one major way: He knew very little about genetics. **Inherited variation was crucial to Darwin's theory of natural selection, yet his theory lacked a clear mechanism for inheritance.** At different times, Darwin proposed or accepted several ideas for such a mechanism, but none of them were correct. He thought about this problem for much of his life.

Darwin never knew it, but Gregor Mendel had begun to solve this problem. However, Mendel's findings about heredity were not widely published until 1900. Those findings opened the door to a new age in the study of evolution. Today, an understanding of genetics is essential to understanding evolution.

Reading Check ***What did Darwin do before publishing his ideas?***

Figure 11 This drawing of a rhea was printed in one of Darwin's books. Darwin collected and organized a large amount of data to help explain his ideas. **How else did Darwin support his main theory?**

homologous (hoh MAHL uh guhs) describes a character that is shared by a group of species because it is inherited from a common ancestor

Section 2 Review

KEY IDEAS

1. **Outline** Darwin's theory of evolution by natural selection. Be sure to include four logical steps.
2. **List** the kinds of data that Darwin helped explain.
3. **Compare** the strengths and weaknesses of Darwin's ideas.

CRITICAL THINKING

4. **Applying Information** Use the theory of natural selection to explain how the average running speed of a population of zebras might increase over time.
5. **Elaborating on Explanations** Describe how a single pair of seed-eating bird species could have arrived on an island and evolved into an insect-eating species. (Hint: Consider the food available.)

USING SCIENCE GRAPHICS

6. **Process Cartoon** Create your own version of **Figure 6** in the form of a four-panel cartoon. Choose a unique type of organism to represent the population undergoing natural selection. Also, depict a unique set of traits and limiting conditions for the population.

Section
3
Beyond Darwinian Theory

Key Ideas	Key Terms	Why It Matters
How has Darwin's theory been updated? At what scales can evolution be studied?	speciation	The study of evolution was new in Darwin's day, but it is essential to biology today.

Does modern evolutionary theory differ from Darwin's theory? Yes and no. Darwin observed and explained much about the large-scale patterns of biology, but some patterns have yet to be explained. He proposed a logical process (natural selection) for evolution, even though he could not explain evolution at the genetic level. Biology has made great progress since Darwin's time. Modern evolutionary theory relates patterns and processes at many levels.

Darwin's Theory Updated

Since Darwin's work was published, his theory has been thoroughly investigated. **Discoveries since Darwin's time, especially in genetics, have been added to his theory to explain the evolution of species.** Some parts of Darwin's theory have been modified, and new parts have been added. But mostly, Darwin's theory has been supported.

The first major advance beyond Darwin's ideas was the rediscovery, in 1900, of Mendel's *Laws of Heredity*. These ideas opened the door for a genetic explanation of evolution. By the 1940s, scientists began to weave Darwin's theory together with newer studies of fossils, anatomy, genetics, and more. This unification is called the *modern synthesis* of evolutionary theory.

In particular, biologists have learned that evolution can result from processes other than natural selection. For example, survival and reproduction can be limited by chance or by the way that genes work. In the modern view, any or all of these forces may combine with natural selection (as described by Darwin). This synthesis helps explain some of the patterns of evolution that were unexplained by natural selection alone.

Remaining Questions Some of the most important questions about evolution have been asked only recently. So, many questions are still being investigated, as shown in **Figure 12.** Modern biologists have tentative answers to the following questions:

- **Can an individual evolve?** Darwin correctly inferred that individuals do not evolve. They may respond to outside forces, but individuals do not pass on their responses as heritable traits. Rather, populations evolve when natural selection acts (indirectly) on genes.

Figure 12 Modern genetic science and Darwin's theory have been united. **How could this genetic scientist study evolution?**

Hands-On

QuickLab

15 min

Selection Model

In this lab, you will model the process of natural selection. Can you predict the outcome?

Procedure

1. Work with a partner. Spread out a **handful of small, colored candies** onto a **piece of cloth or paper that has a colorful design.** One person should act as "predator" of the candies while the other uses a **stop-watch** to monitor time and then records the results.
2. The "predator" should use **tweezers** to try to "capture" as many candies as possible within 10 s.
3. Record the results, and switch roles. Repeat 10 times.

Analysis

1. **Graph** the total number of each color of candy that was "captured." Use a bar graph.
2. CRITICAL THINKING **Evaluating Results** Explain why some colors were "captured" more often than others.
3. CRITICAL THINKING **Forming Hypotheses** Predict the outcome if the background is changed to solid red.

- **Is evolution the survival of the fittest?** Natural selection can act only on the heritable variation that exists in a population. Chance variations do not always provide the best adaptation for a given time and place. So, evolution does not always produce the "fittest" forms, just those that "fit" well enough to leave offspring.
- **Is evolution predictable?** Evolution sometimes results in larger or more-complex forms of life, but this result cannot be predicted. Many forms of life are simple yet successful. For example, bacteria have been abundant for billions of years. In contrast, some complex organisms, such as dinosaurs, have appeared, been successful for a time, and then almost completely disappeared. Mostly, scientists cannot predict the exact path that evolution will take.

speciation (SPEE shee AY shuhn) the formation of new species as a result of evolution

Studying Evolution at All Scales

› Because it affects every aspect of biology, scientists can study evolution at many scales. Generally, these scales range from microevolution to macroevolution, with speciation in between. Informally, *microevolution* refers to evolution as a change in the genes of populations, whereas *macroevolution* refers to the appearance of new species over time.

Speciation The link between microevolution and macroevolution is speciation. **Speciation,** the formation of new species, can be seen as a process of genetic change or as a pattern of change in the form of organisms. Recall that a *species* is a group of organisms that are closely related and that can mate to produce fertile offspring. So, speciation can begin with the separation of populations of the same species. For example, the two kinds of squirrels shown in **Figure 13** seem to be evolving from one species into two because of separation.

› Reading Check *At what scales can evolution be studied?*

Figure 13 These squirrels are closely related but are almost different enough to be unique species. Their populations are separated by the Grand Canyon.

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Topic: Evolution
Code: HX80546

Processes of Microevolution To study microevolution, we look at the processes by which inherited traits change over time in a population. Five major processes can affect the kinds of genes that will exist in a population from generation to generation. These processes are summarized below. Notice that natural selection is only one of the five. You will learn more about these processes soon.

- **Natural Selection** As you have learned, natural selection can cause an increase or decrease in certain alleles in a population.
- **Migration** *Migration* is the movement of individuals into, out of, or between populations. Migration can change the numbers and types of alleles in a population.
- **Mate Choice** If parents are paired up randomly in a population, a random assortment of traits will be passed on to the next generation. However, if parents are limited or selective in their choice of mates, a limited set of traits will be passed on.
- **Mutation** Mutation can change the numbers and types of alleles from one generation to the next. However, such changes are rare.
- **Genetic Drift** The random effects of everyday life can cause differences in the survival and reproduction of individuals. Because of these differences, some alleles may become more or less common in a population, especially in a small population.

ACADEMIC VOCABULARY

random without aim or plan; purposeless

Patterns of Macroevolution To study macroevolution, we look at the patterns in which new species evolve. We may study the direction, diversity, or speed of change. Patterns of change are seen when relationships between living and fossil species are modeled.

- **Convergent Evolution** If evolution is strongly directed by the environment, then species living in similar environments should evolve similar adaptations. Many examples of this pattern were observed by Darwin and can be seen today.
- **Coevolution** Organisms are part of one other's environment, so they can affect one another's evolution. Species that live in close contact often have clear adaptations to one another's existence, as shown in **Figure 14.**

Figure 14 This moth species and this orchid species have coevolved in a close relationship. The moth feeds exclusively on the orchid, and the orchid's pollen is spread by the moth.

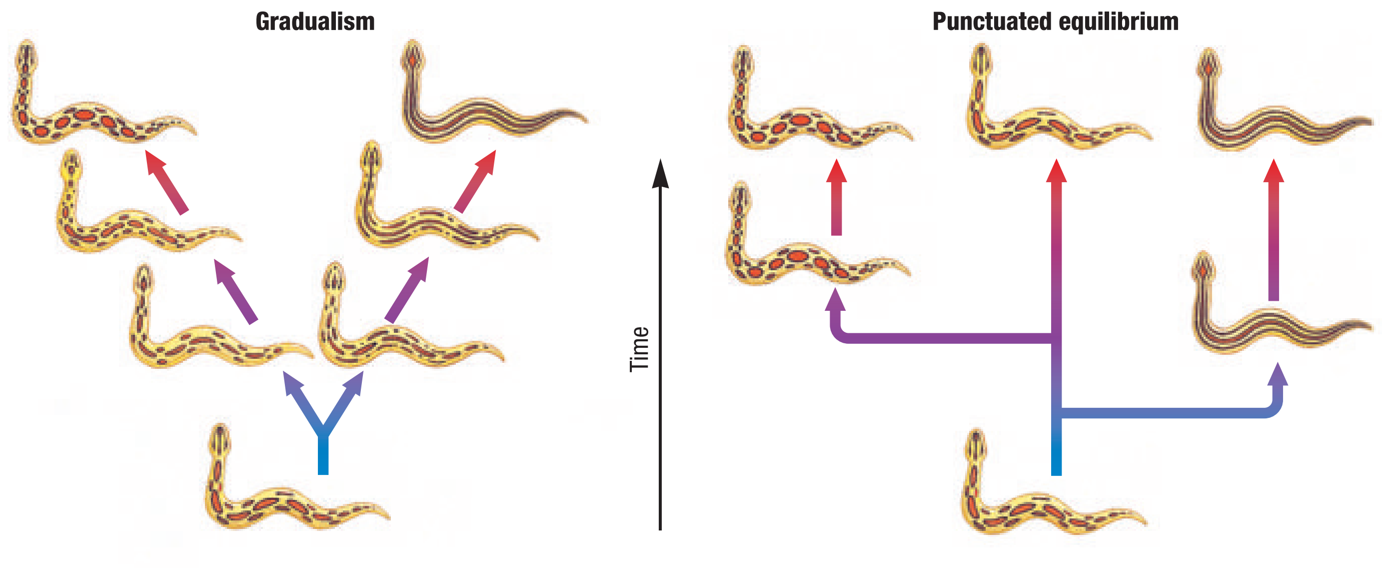

Figure 15 Two differing models of the pace of evolution have been proposed. **Do these models show microevolution or macroevolution?**

- **Adaptive Radiation** Over time, species may split into two or more lines of descendants, or *lineages*. As this splitting repeats, one species can give rise to many new species. The process tends to speed up when a new species enters an environment that contains few other species. In this case, the pattern is called *adaptive radiation*.
- **Extinction** If all members of a lineage die off or simply fail to reproduce, the lineage is said to be *extinct*. The fossil record shows that many lineages have arisen and radiated, but only a few of their descendants survived and evolved into the species present today.
- **Gradualism** In Darwin's day, the idea of slow, gradual change was new to geology as well as biology. Darwin had argued that large-scale changes, such as the formation of new species, must require many small changes to build up gradually over a long period of time. This model is called *gradualism* and is shown in **Figure 15.**
- **Punctuated Equilibrium** Some biologists argue that species do not always evolve gradually. Species may remain stable for long periods until environmental changes create new pressures. Then, many new species may "suddenly" appear. This model is called *punctuated equilibrium* and is shown in **Figure 15.**

READING TOOLBOX

Taking Notes Complete your notes summarizing the major concepts from this chapter. Be sure to include microevolution and macroevolution.

Section 3 Review

KEY IDEAS

1. **Describe** how Darwin's ideas have been updated. Be sure to mention the role of natural selection in modern evolutionary theory.
2. **List** the scales at which evolution can be studied, and list the patterns and processes studied.

CRITICAL THINKING

3. **Arguing Logically** A classmate states that because land animals evolved from fishes and then flying things evolved from walking things, we can predict that future life will evolve to travel in outer space. Write a logical argument against this statement. Be sure to support your argument with examples.

ALTERNATIVE ASSESSMENT

4. **Who's Who** Make a brochure or poster entitled "Who's Who of Evolutionary Theory." Use reference sources to find basic facts about major evolutionary scientists that lived during or after Darwin's lifetime.

Chapter 16 Summary

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SUPER SUMMARY
Keyword: HX8EVOS

Key Ideas

1 Developing a Theory

- Modern evolutionary theory began when Darwin presented evidence that evolution happens and offered an explanation of how evolution happens.
- Darwin's experiences provided him with evidence of evolution at work.
- Darwin was influenced by ideas from the fields of natural history, economics, and geology.

Key Terms

evolution (375)
artificial selection (377)

2 Applying Darwin's Ideas

- Darwin's theory of evolution by natural selection predicts that over time, the number of individuals that carry advantageous traits will increase in a population.
- Darwin presented a unifying explanation for data from multiple fields of science.
- The strengths of Darwin's work—evidence of evolution, a mechanism for evolution, and the recognition that variation is important—placed Darwin's ideas among the most important of our time. However, Darwin lacked a mechanism for inheritance.

Key Terms

natural selection (380)
adaptation (381)
fossil (382)
homologous structures (384)

3 Beyond Darwinian Theory

- Discoveries since Darwin's time, especially in genetics, have been added to his theory to explain the evolution of species.
- Because it affects every aspect of biology, scientists can study evolution at many scales. Generally, these scales range from microevolution to macroevolution, with speciation in between.

Key Terms

speciation (387)