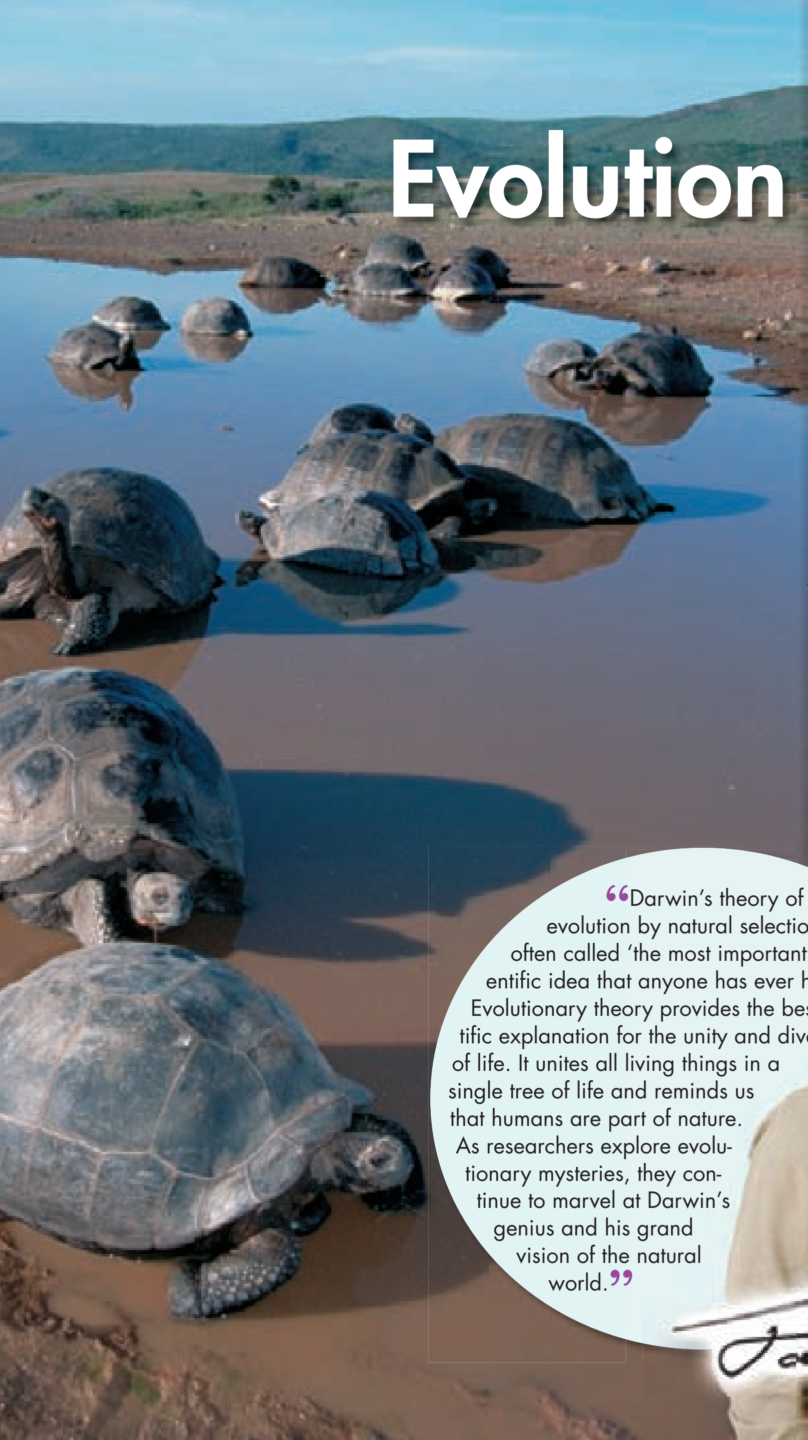


Evolution

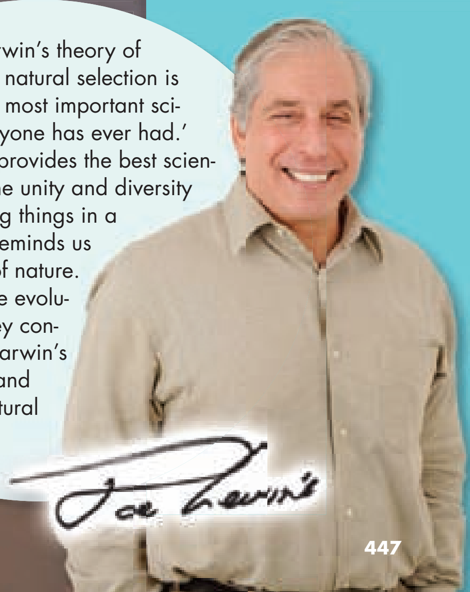
UNIT 5

Chapters

INTRODUCE the **Big ideas**

- **Evolution**
- **Unity and Diversity of Life**

"Darwin's theory of evolution by natural selection is often called 'the most important scientific idea that anyone has ever had.' Evolutionary theory provides the best scientific explanation for the unity and diversity of life. It unites all living things in a single tree of life and reminds us that humans are part of nature. As researchers explore evolutionary mysteries, they continue to marvel at Darwin's genius and his grand vision of the natural world."



16 Darwin's Theory of Evolution

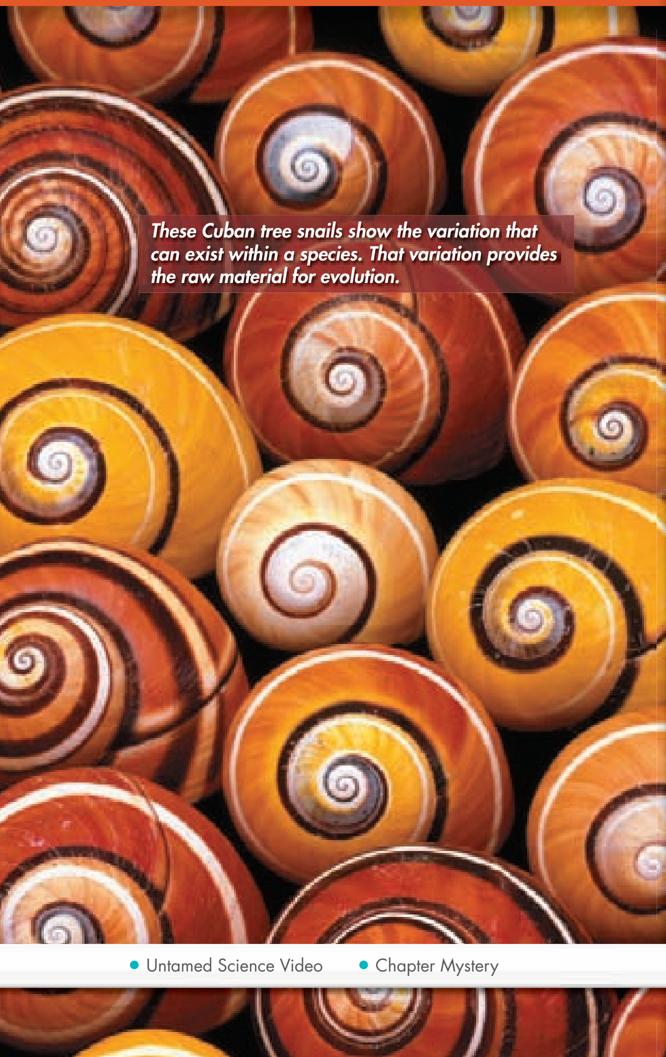
Big idea

Evolution

Q: What is natural selection?

BIOLOGY.com Search Chapter 16 GO • Flash Cards

INSIDE:



These Cuban tree snails show the variation that can exist within a species. That variation provides the raw material for evolution.

- Untamed Science Video
- Chapter Mystery

CHAPTER MYSTERY

SUCH VARIED HONEYCREEPERS

The misty rain forests on the Hawaiian island of Kauai are home to birds found nowhere else on Earth. Hiking at dawn, you hear them before you see them. Their songs fill the air with beautiful music. Then you spot a brilliant red bird with black wings called an 'i'iwi. As you watch, it uses its long, curved beak to probe for nectar deep in the flowers of 'ohi'a trees.

The 'i'iwi is just one of a number of species of Hawaiian honeycreepers, all of which are related to finches. Various honeycreeper species feed on nectar, insects, seeds, or fruits. Many Hawaiian honeycreepers, however, feed only on the seeds or nectar of unique Hawaiian plants.

How did all these birds get to Hawaii? How did some of them come to have such specialized diets? As you read the chapter, look for clues that help explain the number and diversity of Hawaiian honeycreepers. Then, solve the mystery.

Never Stop Exploring Your World. Finding the solution to the honeycreepers mystery is only the beginning. Take a video field trip to Hawaii with the ecogeeks of Untamed Science to see where the mystery leads.

UntamedScience™

16.1 Darwin's Voyage of Discovery

Key Questions

🔑 *What was Charles Darwin's contribution to science?*

🔑 *What three patterns of biodiversity did Darwin note?*

Vocabulary

evolution
fossil

Taking Notes

Preview Visuals Before you read, look at **Figure 16–1.** Briefly summarize the route the *Beagle* took.

BUILD Vocabulary

RELATED WORD FORMS In biology, the noun **evolution** means "the process by which organisms have changed over time." The verb *evolve* means "to change over time."

THINK ABOUT IT If you'd met young Charles Darwin, you probably wouldn't have guessed that his ideas would change the way we look at the world. As a boy, Darwin wasn't a star student. He preferred bird-watching and reading for pleasure to studying. His father once complained, "You will be a disgrace to yourself and all your family." Yet Charles would one day come up with one of the most important scientific theories of all time—becoming far from the disgrace his father feared he would be.

Darwin's Epic Journey

🔑 *What was Charles Darwin's contribution to science?*

Charles Darwin was born in England on February 12, 1809—the same day as Abraham Lincoln. He grew up at a time when the scientific view of the natural world was shifting dramatically. Geologists were suggesting that Earth was ancient and had changed over time. Biologists were suggesting that life on Earth had also changed. The process of change over time is called **evolution.** 🔑 **Darwin developed a scientific theory of biological evolution that explains how modern organisms evolved over long periods of time through descent from common ancestors.**

Darwin's journey began in 1831, when he was invited to sail on the HMS *Beagle*'s five-year voyage along the route shown in **Figure 16–1.** The captain and his crew would be mapping the coastline of South America. Darwin planned to collect specimens of plants and animals. No one knew it, but this would be one of the most important scientific voyages in history. Why? Because the *Beagle* trip led Darwin to develop what has been called the single best idea anyone has ever had.

If you think evolution is just about explaining life's ancient history, you might wonder why it's so important. But Darwin's work offers vital insights into today's world by showing how the living world is constantly changing. That perspective helps us understand modern phenomena like drug-resistant bacteria and newly emerging diseases like avian flu.

In Your Notebook *Using what you know about ecology, explain how the ideas of a changing Earth and evolving life forms might be related.*

Observations Aboard the *Beagle*

What three patterns of biodiversity did Darwin note?

A collector of bugs and shells in his youth, Darwin had always been fascinated by biological diversity. On his voyage, the variety and number of different organisms he encountered dazzled him. In a single day's trip into the Brazilian forest, he collected 68 species of beetles, and he wasn't particularly looking for beetles!

Darwin filled his notebooks with observations about the characteristics and habitats of the different species he saw. But Darwin wasn't content just to describe biological diversity. He wanted to explain it in a scientific way. He kept his eyes and mind open to larger patterns into which his observations might fit. As he traveled, Darwin noticed three distinctive patterns of biological diversity: (1) Species vary globally, (2) species vary locally, and (3) species vary over time.

Species Vary Globally Darwin visited a wide range of habitats on the continents of South America, Australia, and Africa and recorded his observations. For example, Darwin found flightless, ground-dwelling birds called rheas living in the grasslands of South America. Rheas look and act a lot like ostriches. Yet rheas live only in South America, and ostriches live only in Africa. When Darwin visited Australia's grasslands, he found another large flightless bird, the emu. **Darwin noticed that different, yet ecologically similar, animal species inhabited separated, but ecologically similar, habitats around the globe.**

Darwin also noticed that rabbits and other species living in European grasslands were missing from the grasslands of South America and Australia. What's more, Australia's grasslands were home to kangaroos and other animals that were found nowhere else. What did these patterns of geographic distribution mean? Why did different flightless birds live in similar grasslands across South America, Australia, and Africa, but not in the Northern Hemisphere? Why weren't there rabbits in Australian habitats that seemed ideal for them? And why didn't kangaroos live in England?

Quick Lab
GUIDED INQUIRY

Darwin's Voyage

1. Using a world map and **Figure 16–1,** count the number of lines of 10° latitude the *Beagle* crossed.
2. Using the biome map from Chapter 4 as a reference, identify three different biomes Darwin visited on his voyage.

Analyze and Conclude

1. Infer How did the geography of Darwin's voyage give him far greater exposure to species variability than his fellow scientists back home had?

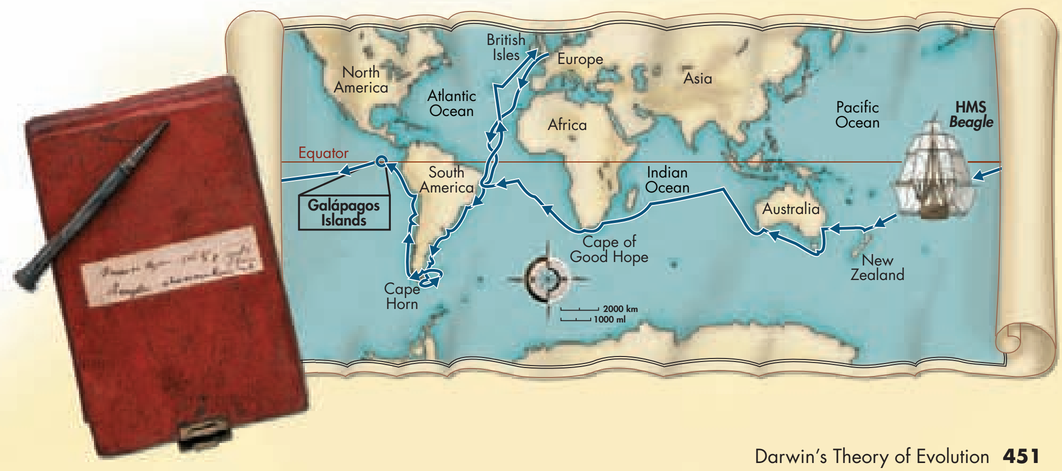
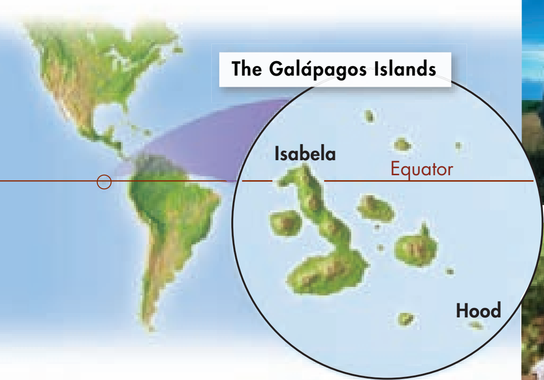


FIGURE 16–1 Darwin's Voyage On a five-year voyage aboard the *Beagle,* Charles Darwin visited several continents and many remote islands. **Draw Conclusions** ***Why is it significant that many of the stops the* Beagle *made were in tropical regions?***



Isabela Island Tortoise
Tortoises from Isabela Island have dome-shaped shells and short necks. Vegetation on this island is abundant and close to the ground.

Hood Island Tortoise
The shells of Hood Island tortoises are curved and open around their long necks and legs. This enables them to reach the island's sparse, high vegetation.

FIGURE 16–2 Tortoise Diversity
Among tortoises in the Galápagos Islands, shell shape corresponds to different habitats. Isabela Island has high peaks, is rainy, and has abundant vegetation. Hood Island, in contrast, is flat, dry, and has sparse vegetation.

Species Vary Locally There were other puzzles, too. For example, Darwin found two species of rheas living in South America. One lived in Argentina's grasslands and the other in the colder, harsher grass and scrubland to the south. **Darwin noticed that different, yet related, animal species often occupied different habitats within a local area.**

Other examples of local variation came from the Galápagos Islands, about 1000 km off the Pacific coast of South America. These islands are close to one another, yet they have different ecological conditions. Several islands were home to distinct forms of giant land tortoises. Darwin saw differences among the tortoises but didn't think much about them. In fact, like other travelers, Darwin ate several tortoises and tossed their remains overboard without studying them closely! Then Darwin learned from the islands' governor that the tortoises' shells varied in predictable ways from one island to another, as shown in **Figure 16–2.** Someone who knew the animals well could identify which island an individual tortoise came from, just by looking at its shell.

Darwin also observed that different islands had different varieties of mockingbirds, all which resembled mockingbirds that Darwin had seen in South America. Darwin also noticed several types of small brown birds on the islands with beaks of different shapes. He thought that some were wrens, some were warblers, and some were blackbirds. He didn't consider these smaller birds to be unusual or important—at first.

MYSTERY CLUE

Like the small brown birds on the Galápagos, Hawaiian honeycreepers live on islands with slightly different habitats. How might these varied habitats have affected the evolution of honeycreeper species?

Species Vary Over Time In addition to collecting specimens of living species, Darwin also collected **fossils,** which scientists already knew to be the preserved remains or traces of ancient organisms. Some fossils didn't look anything like living organisms, but others did.

Darwin noticed that some fossils of extinct animals were similar to living species. One set of fossils unearthed by Darwin belonged to the long-extinct glyptodont, a giant armored animal. Currently living in the same area was a similar animal, the armadillo. You can see in **Figure 16–3** that the armadillo appears to be a smaller version of the glyptodont. Darwin said of the organisms: "This wonderful relationship in the same continent between the dead and the living, will, I do not doubt, hereafter throw more light on the appearance of organic beings on our earth, and their disappearance from it, than any other class of facts." So, why had glyptodonts disappeared? And why did they resemble armadillos?

Putting the Pieces of the Puzzle Together On the voyage home, Darwin thought about the patterns he'd seen. The plant and animal specimens he sent to experts for identification set the scientific community buzzing. The Galápagos mocking-birds turned out to belong to three separate species found nowhere else! And the little brown birds that Darwin thought were wrens, warblers, and blackbirds were actually all species of finches! They, too, were found nowhere else, though they resembled a South American finch species. The same was true of Galápagos tortoises, marine iguanas, and many plants that Darwin collected on the islands.

Darwin was stunned by these discoveries. He began to wonder whether different Galápagos species might have evolved from South American ancestors. He spent years actively researching and filling notebooks with ideas about species and evolution. The evidence suggested that species are not fixed and that they could change by some natural process.

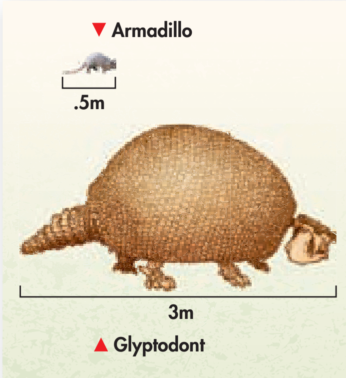


FIGURE 16–3 Related Organisms? Despite their obvious differences, Darwin wondered if the armadillo might be related to the ancient glyptodont. **Compare and Contrast** *What similarities and differences do you see between these two animals?*

16.1 Assessment

Review Key Concepts

1. a. Review What is evolution?

b. Apply Concepts What ideas were changing in the scientific community at the time of Darwin's travels? How might those new ideas have influenced Darwin?

2. a. Review What three kinds of variations among organisms did Darwin observe during the voyage of the *Beagle?*

b. Infer Darwin found fossils of many organisms that did not resemble any living species. How might this finding have affected his understanding of life's diversity?

Apply the Big idea

Interdependence in Nature

3. You have learned that both biotic and abiotic factors affect ecosystems. Give some examples of each, and explain how biotic and abiotic factors could have affected the tortoises that Darwin observed on the Galápagos Islands.

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16.2 Ideas That Shaped Darwin's Thinking

Key Questions

What did Hutton and Lyell conclude about Earth's history?

How did Lamarck propose that species evolve?

What was Malthus's view of population growth?

How is inherited variation used in artificial selection?

Vocabulary

artificial selection

Taking Notes

Outline Make an outline of this lesson using the green headings as main topics and the blue headings as subtopics. As you read, fill in details under each heading.

THINK ABOUT IT All scientists are influenced by the work of other scientists, and Darwin was no exception. The *Beagle*'s voyage came during one of the most exciting periods in the history of science. Geologists, studying the structure and history of Earth, were making new observations about the forces that shape our planet. Naturalists were investigating connections between organisms and their environments. These and other new ways of thinking about the natural world provided the foundation on which Darwin built his ideas.

An Ancient, Changing Earth

What did Hutton and Lyell conclude about Earth's history?

Many Europeans in Darwin's day believed Earth was only a few thousand years old, and that it hadn't changed much. By Darwin's time, however, the relatively new science of geology was providing evidence to support different ideas about Earth's history. Most famously, geologists James Hutton and Charles Lyell formed important hypotheses based on the work of other researchers and on evidence they uncovered themselves. **Hutton and Lyell concluded that Earth is extremely old and that the processes that changed Earth in the past are the same processes that operate in the present.** In 1785, Hutton presented his hypotheses about how geological processes have shaped the Earth. Lyell, who built on the work of Hutton and others, published the first volume of his great work, *Principles of Geology,* in 1830.

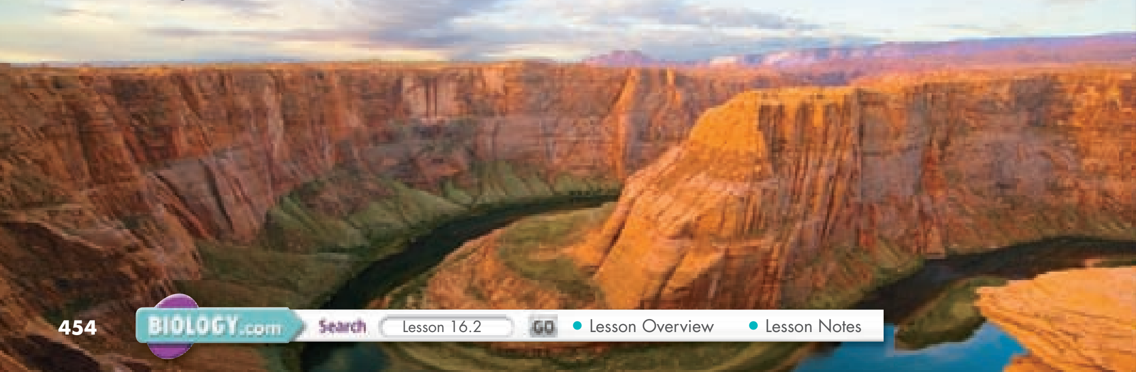


FIGURE 16–4 Ancient Rocks These rock layers in the Grand Canyon were laid down over millions of years and were then slowly washed away by the river, forming a channel.

Hutton and Geological Change Hutton recognized the connections between a number of geological processes and geological features, like mountains, valleys, and layers of rock that seemed to be bent or folded. Hutton realized, for example, that certain kinds of rocks are formed from molten lava. He also realized that some other kinds of rocks, like those shown in **Figure 16–4,** form very slowly, as sediments build up and are squeezed into layers.

Hutton also proposed that forces beneath Earth's surface can push rock layers upward, tilting or twisting them in the process. Over long periods, those forces can build mountain ranges. Mountains, in turn, can be worn down by rain, wind, heat, and cold. Most of these processes operate very slowly. For these processes to have produced Earth as we know it, Hutton concluded that our planet must be much older than a few thousand years. He introduced a concept called *deep time*—the idea that our planet's history stretches back over a period of time so long that it is difficult for the human mind to imagine—to explain his reasoning.

Lyell's *Principles of Geology* Lyell argued that laws of nature are constant over time and that scientists must explain past events in terms of processes they can observe in the present. This way of thinking, called *uniformitarianism,* holds that the geological processes we see in action today must be the same ones that shaped Earth millions of years ago. Ancient volcanoes released lava and gases, just as volcanoes do now. Ancient rivers slowly dug channels, like the one in **Figure 16–5,** and carved canyons in the past, just as they do today. Lyell's theories, like those of Hutton before him, relied on there being enough time in Earth's history for these changes to take place. Like Hutton, Lyell argued that Earth was much, much older than a few thousand years. Otherwise, how would a river have enough time to carve out a valley?

Darwin had begun to read Lyell's books during the voyage of the *Beagle*, which was lucky. Lyell's work helped Darwin appreciate the significance of an earthquake he witnessed in South America. The quake was so strong that it threw Darwin onto the ground. It also lifted a stretch of rocky shoreline more than 3 meters out of the sea—with mussels and other sea animals clinging to it. Sometime later, Darwin observed fossils of marine animals in mountains thousands of feet above sea level.

Those experiences amazed Darwin and his companions. But only Darwin turned them into a startling scientific insight. He realized that he had seen evidence that Lyell was correct! Geological events like the earthquake, repeated many times over many years, could build South America's Andes Mountains—a few feet at a time. Rocks that had once been beneath the sea could be pushed up into mountains. Darwin asked himself, If Earth can change over time, could life change too?

BUILD Vocabulary

ACADEMIC WORDS The noun **process** means "a series of actions or changes that take place in a definite manner." The processes that shape Earth are the series of geological actions that do things such as build mountains and carve valleys.

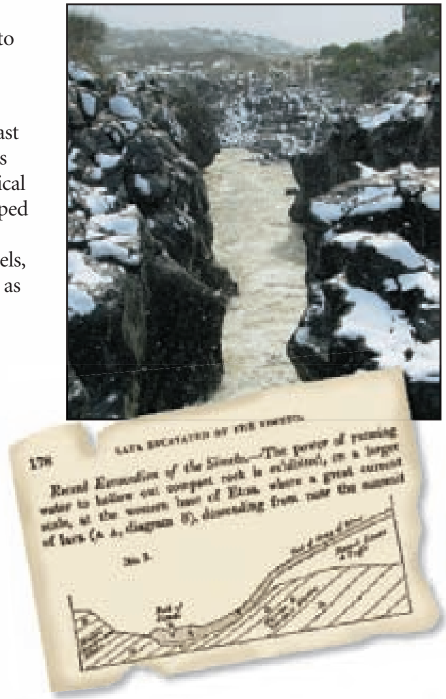


FIGURE 16–5 A woodcut from Lyell's *Principles of Geology* shows geological features near Italy's Mount Etna. Among them is a deep channel, labeled "B," carved into a bed of lava. The channel, shown in the photo, was formed gradually by the movement of water in the Simeto River.

Lamarck's Evolutionary Hypotheses

How did Lamarck propose that species evolve?

Darwin wasn't the first scientist to suggest that characteristics of species could change over time. Throughout the eighteenth century, a growing fossil record supported the idea that life somehow evolved. Ideas differed, however, about just *how* life evolved. The French naturalist Jean-Baptiste Lamarck proposed two of the first hypotheses. **Lamarck suggested that organisms could change during their lifetimes by selectively using or not using various parts of their bodies. He also suggested that individuals could pass these acquired traits on to their offspring, enabling species to change over time.** Lamarck published his ideas in 1809, the year Darwin was born.

FIGURE 16–6 Acquired Characteristics? According to Lamarck, this black-necked stilt's long legs were the result of the bird's innate tendency toward perfection. He claimed that if a water bird needs long legs to wade in deep water, it can acquire them by making an effort to stretch and use its legs in new ways. He also claimed that the bird can then pass the trait on to its offspring.

Lamarck's Ideas Lamarck proposed that all organisms have an inborn urge to become more complex and perfect. As a result, organisms change and acquire features that help them live more successfully in their environments. He thought that organisms could change the size or shape of their organs by using their bodies in new ways. According to Lamarck, for example, a water bird could have acquired long legs because it began to wade in deeper water looking for food. As the bird tried to stay above the water's surface, its legs would grow a little longer. Structures of individual organisms could also change if they were not used. If a bird stopped using its wings to fly, for example, its wings would become smaller. Traits altered by an individual organism during its life are called *acquired characteristics.*

Lamarck also suggested that a bird that acquired a trait, like longer legs, during its lifetime could pass that trait on to its offspring, a principle referred to as *inheritance of acquired characteristics.* Thus, over a few generations, birds like the one in **Figure 16–6** could evolve longer and longer legs.

Evaluating Lamarck's Hypotheses Today, we know that Lamarck's hypotheses were incorrect in several ways. For one thing, organisms don't have an inborn drive to become more perfect. Evolution does not mean that over time a species becomes "better" somehow, and evolution does not progress in a predetermined direction. We now also know that traits acquired by individuals during their lifetime cannot be passed on to offspring. However, Lamarck was one of the first naturalists to suggest that species are not fixed. He was among the first to try to explain evolution scientifically using natural processes. He also recognized that there is a link between an organism's environment and its body structures. So, although Lamarck's explanation of evolutionary change was wrong, his work paved the way for later biologists, including Darwin.

In Your Notebook *Why are Lamarck's ideas called scientific hypotheses and not scientific theories?*

Population Growth

What was Malthus's view of population growth?

In 1798, English economist Thomas Malthus noted that humans were being born faster than people were dying, causing overcrowding, as shown in **Figure 16–7.** **Malthus reasoned that if the human population grew unchecked, there wouldn't be enough living space and food for everyone.** The forces that work against population growth, Malthus suggested, include war, famine, and disease.

Darwin realized that Malthus's reasoning applied even more to other organisms than it did to humans. A maple tree can produce thousands of seeds each summer. One oyster can produce millions of eggs each year. If all the descendants of almost any species survived for several generations, they would overrun the world. Obviously, this doesn't happen. Most offspring die before reaching maturity, and only a few of those that survive manage to reproduce.

Why was this realization so important? Darwin had become convinced that species evolved. But he needed a mechanism—a scientific explanation based on a natural process—to explain how and why evolution occurred. When Darwin realized that most organisms don't survive and reproduce, he wondered which individuals survive … and why.

FIGURE 16–7 Overcrowding in London A nineteenth-century engraving shows the crowded conditions in London during Darwin's time. **Relate Cause and Effect** *According to Malthus, what would happen if the population of London continued to grow?*

Artificial Selection

How is inherited variation used in artificial selection?

To find an explanation for change in nature, Darwin studied change produced by plant and animal breeders. Those breeders knew that individual organisms vary—that some plants bear larger or smaller fruit than average for their species, that some cows give more or less milk than others in their herd. They told Darwin that some of this variation could be passed from parents to offspring and used to improve crops and livestock.

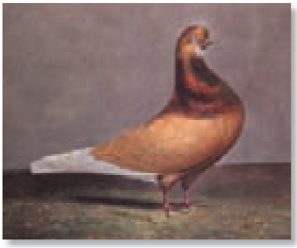
Quick Lab
GUIDED INQUIRY

Variation in Peppers

1. Obtain a green, yellow, red, or purple bell pepper.
2. Slice open the pepper and count the number of seeds it contains.
3. Compare your data with the data of other students who have peppers of a different color.

Analyze and Conclude

1. **Calculate** Find the average (mean) number of seeds in your class's peppers. Then determine by how much the number of seeds in each pepper differs from the mean number. MATH
2. **Pose Questions** Think of the kinds of variations among organisms that Darwin observed. If Darwin had seen your data, what questions might he have asked?



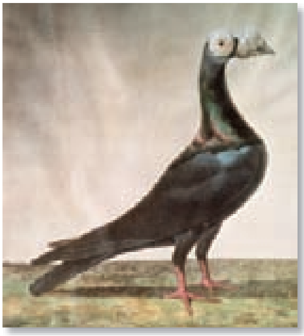


FIGURE 16–8 Artificial Selection Darwin used artificial selection in breeding fancy pigeons at his home outside London.

Farmers would select for breeding only trees that produced the largest fruit or cows that produced the most milk. Over time, this selective breeding would produce more trees with even bigger fruit and cows that gave even more milk. Darwin called this process **artificial selection.** **In artificial selection, nature provides the variations, and humans select those they find useful.** Darwin put artificial selection to the test by raising and breeding plants and fancy pigeon varieties, like those in **Figure 16–8.**

Darwin had no idea how heredity worked or what caused heritable variation. But he did know that variation occurs in wild species as well as in domesticated plants and animals. Before Darwin, scientists thought variations among individuals in nature were simply minor defects. Darwin's breakthrough was in recognizing that natural variation was very important because it provided the raw material for evolution. Darwin had all the information he needed. His scientific explanation for evolution was now formed—and when it was published, it would change the way people understood the living world.

16.2 Assessment

Review Key Concepts

1. a. **Review** What were Hutton's and Lyell's ideas about the age of Earth and the processes that shape the planet?
   b. **Apply Concepts** How would Hutton and Lyell explain the formation of the Grand Canyon?
2. a. **Review** What is an acquired characteristic? What role did Lamarck think acquired characteristics played in evolution?
   b. **Evaluate** What parts of Lamarck's hypotheses have been proved wrong? What did Lamarck get right?
3. a. **Review** According to Malthus, what factors limit human population growth?
   b. **Draw Conclusions** How did Malthus influence Darwin?
4. a. **Review** What is artificial selection?
   b. **Infer** Could artificial selection occur without inherited variation? Explain your answer.

WRITE ABOUT SCIENCE

Creative Writing

5. Imagine you are Thomas Malthus and the year is 1798. Write a newspaper article that explains your ideas about the impact of a growing population on society and the environment.

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Biology & HISTORY

Origins of Evolutionary Thought The groundwork for the modern theory of evolution was laid during the 1700s and 1800s. Charles Darwin developed the central idea of evolution by natural selection, but others before and during his lifetime influenced his thinking.

1780 1790 1800 1810 1820 1830 1840 1850 1860

1785

▼ James Hutton

Hutton proposes that slow-acting geological forces shape the planet. He estimates Earth to be millions—not thousands—of years old.

1798

Thomas Malthus

In his *Essay on the Principle of Population*, Malthus predicts that left unchecked, the human population will grow beyond the space and food needed to sustain it.

1809

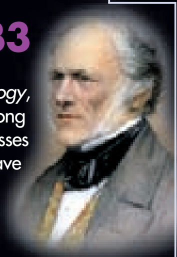
Jean-Baptiste Lamarck

Lamarck publishes his hypotheses of the inheritance of acquired traits. The ideas are flawed, but he is one of the first to propose a mechanism explaining how organisms change over time. ▼

1830–1833

Charles Lyell ▶

In his *Principles of Geology*, Lyell explains that over long periods, the same processes affecting Earth today have shaped Earth's ancient geological features.



1831

Charles Darwin

Darwin sets sail on the HMS *Beagle*, a voyage that will provide him with vast amounts of evidence to support his explanation of how evolution works. ▶

1858

Alfred Russel Wallace

Wallace writes to Darwin, speculating on evolution by natural selection, based on his studies of the distribution of plants and animals.

1859

Darwin publishes *On the Origin of Species.*

WRITING Use the library or the Internet to find out more about Darwin and Wallace. Then write a dialogue between these two men, in which the conversation shows the similarities in their careers and theories.

16.3 Darwin Presents His Case

Key Questions

Under what conditions does natural selection occur?

What does Darwin's mechanism for evolution suggest about living and extinct species?

Vocabulary

adaptation
fitness
natural selection

Taking Notes

Preview Visuals Before you read this lesson, look at **Figure 16–10.** Read the information in the figure, and then write three questions you have about it. As you read, answer your questions.

THINK ABOUT IT Soon after reading Malthus and thinking about artificial selection, Darwin worked out the main points of his theory about natural selection. Most of his scientific friends considered Darwin's arguments to be brilliant, and they urged him to publish them. But although he wrote up a complete draft of his ideas, he put the work aside and didn't publish it for another 20 years. Why? Darwin knew that many scientists, including some of Darwin's own teachers, had ridiculed Lamarck's ideas. Darwin also knew that his own theory was just as radical, so he wanted to gather as much evidence as he could to support his ideas before he made them public.

Then, in 1858, Darwin reviewed an essay by Alfred Russel Wallace, an English naturalist working in Malaysia. Wallace's thoughts about evolution were almost identical to Darwin's! Not wanting to get "scooped," Darwin decided to move forward with his own work. Wallace's essay was presented together with some of Darwin's observations at a scientific meeting in 1858. The next year, Darwin published his first complete work on evolution: *On the Origin of Species.*

Evolution by Natural Selection

Under what conditions does natural selection occur?

Darwin's great contribution was to describe a process in nature—a scientific mechanism—that could operate like artificial selection. In *On the Origin of Species,* he combined his own thoughts with ideas from Malthus and Lamarck.

The Struggle for Existence After reading Malthus, Darwin realized that if more individuals are produced than can survive, members of a population must compete to obtain food, living space, and other limited necessities of life. Darwin described this as *the struggle for existence.* But which individuals come out on top in this struggle?

Variation and Adaptation Here's where individual variation plays a vital role. Darwin knew that individuals have natural variations among their heritable traits. He hypothesized that some of those variants are better suited to life in their environment than others. Members of a predatory species that are faster or have longer claws or sharper teeth can catch more prey. And members of a prey species that are faster or better camouflaged can avoid being caught.

Any heritable characteristic that increases an organism's ability to survive and reproduce in its environment is called an **adaptation.** Adaptations can involve body parts or structures, like a tiger's claws; colors, like those that make camouflage or mimicry possible; or physiological functions, like the way a plant carries out photosynthesis. Many adaptations also involve behaviors, such as the complex avoidance strategies prey species use. Examples of adaptations are shown in **Figure 16–9.**

Survival of the Fittest Darwin, like Lamarck, recognized that there must be a connection between the way an organism "makes a living" and the environment in which it lives. According to Darwin, differences in adaptations affect an individual's fitness. **Fitness** describes how well an organism can survive and reproduce in its environment.

Individuals with adaptations that are well suited to their environment can survive and reproduce and are said to have high fitness. Individuals with characteristics that are not well suited to their environment either die without reproducing or leave few offspring and are said to have low fitness. This difference in rates of survival and reproduction is called *survival of the fittest.* Note that *survival* here means more than just staying alive. In evolutionary terms, *survival* means reproducing and passing adaptations on to the next generation.

In Your Notebook *If an organism produces many offspring, but none of them reach maturity, do you think the organism has high or low fitness? Explain your answer.*

BUILD Vocabulary

RELATED WORD FORMS The verb *inherited* and the adjective *heritable* are related word forms. Inherited traits are passed on to offspring from their parents. They are described as *heritable* (or sometimes *inheritable*) characteristics.

VISUAL SUMMARY

ADAPTATIONS

FIGURE 16–9 Adaptations take many forms.

A. The scarlet king snake (bottom) is exhibiting mimicry—an adaptation in which an organism copies, or mimics, a more dangerous organism. Although the scarlet king snake is harmless, it looks like the poisonous eastern coral snake (top), so predators avoid it, too.

B. A scorpionfish's coloring is an example of camouflage—an adaptation that allows an organism to blend into its background and avoid predation.

C. Adaptations often involve many systems and even behavior. Here, a crane is displaying defensive behavior in an effort to scare off the nearby fox.

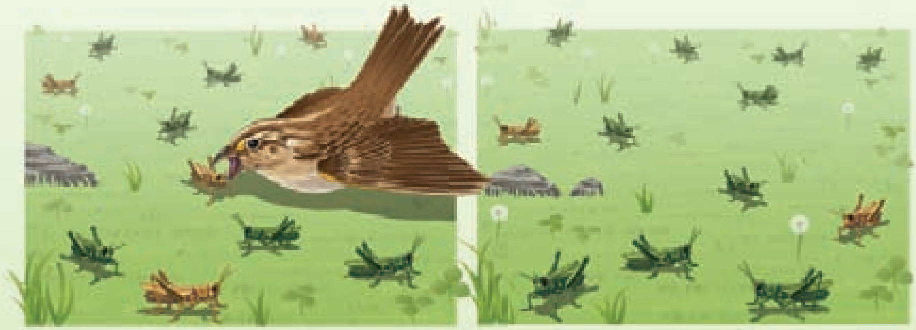
VISUAL SUMMARY

NATURAL SELECTION

FIGURE 16–10 This hypothetical population of grasshoppers changes over time as a result of natural selection. **Interpret Visuals** ***In the situation shown here, what characteristic is affecting the grasshoppers' fitness?***

1 The Struggle for Existence Organisms produce more offspring than can survive. Grasshoppers can lay over 200 eggs at a time. Only a small fraction of these offspring survive to reproduce.

2 Variation and Adaptation There is variation in nature, and certain heritable variations—called adaptations—increase an individual's chance of surviving and reproducing. In this population of grasshoppers, heritable variation includes yellow and green body color. Green coloration is an adaptation: Green grasshoppers blend into their environment and so are less visible to predators.



3 Survival of the Fittest Because their green color serves to camouflage them from predators, green grasshoppers have a higher fitness than yellow grasshoppers. This means that green grasshoppers survive and reproduce more often than do yellow grasshoppers in this environment.

4 Natural Selection Green grasshoppers become more common than yellow grasshoppers in this population over time because: (1) more grasshoppers are born than can survive, (2) individuals vary in color and color is a heritable trait, and (3) green individuals have a higher fitness in their current environment.

Natural Selection Darwin named his mechanism for evolution *natural selection* because of its similarities to artificial selection. **Natural selection** is the process by which organisms with variations most suited to their local environment survive and leave more offspring. In both artificial and natural selection, only certain individuals in a population produce new individuals. But in natural selection, the environment—not a farmer or animal breeder—influences fitness.

When does natural selection occur? **Natural selection occurs in any situation in which more individuals are born than can survive (the struggle for existence), there is natural heritable variation (variation and adaptation), and there is variable fitness among individuals (survival of the fittest).** Well-adapted individuals survive and reproduce. From generation to generation, populations continue to change as they become better adapted, or as their environment changes. **Figure 16–10** uses a hypothetical example to show the process of natural selection. Notice that natural selection acts only on inherited traits because those are the only characteristics that parents can pass on to their offspring.

Natural selection does not make organisms "better." Adaptations don't have to be perfect—just good enough to enable an organism to pass its genes to the next generation. Natural selection also doesn't move in a fixed direction. There is no one, perfect way of doing something, as demonstrated by **Figure 16–11.** Natural selection is simply a process that enables species to survive and reproduce in a local environment. If local environmental conditions change, some traits that were once adaptive may no longer be useful, and different traits may become adaptive. And if environmental conditions change faster than a species can adapt to those changes, the species may become extinct. Of course, natural selection is not the only mechanism driving evolution. You will learn about other evolutionary mechanisms in the next chapter.

In Your Notebook *Give at least two reasons why the following statement is NOT true: "The goal of natural selection is to produce perfect organisms."*

MYSTERY CLUE

How might natural selection explain the history of the Hawaiian honeycreepers?

FIGURE 16–11 No Such Thing as Perfect Many different styles of pollination have evolved among flowering plants. Oak tree flowers (right) are pollinated by wind. Apple tree flowers (left) are pollinated by insects. Neither method is "better" than the other. Both kinds of pollination work well enough for these plants to survive and reproduce in their environments.

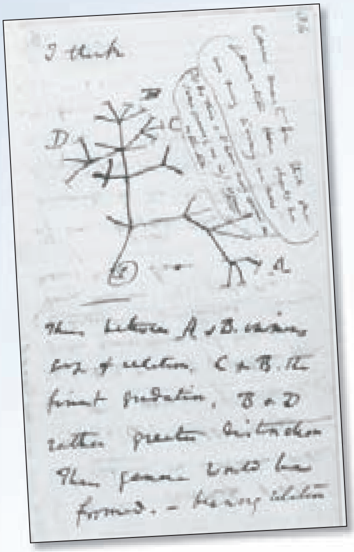


FIGURE 16–12 Descent With Modification This page from one of Darwin's notebooks shows the first evolutionary tree ever drawn. This sketch shows Darwin's explanation for how descent with modification could produce the diversity of life. Note that, just above the tree, Darwin wrote, "I think."

Common Descent

What does Darwin's mechanism for evolution suggest about living and extinct species?

Natural selection depends on the ability of organisms to reproduce, which means to leave descendants. Every organism alive today is descended from parents who survived and reproduced. Those parents descended from their parents, and so forth back through time.

Just as well-adapted individuals in a species survive and reproduce, well-adapted species survive over time. Darwin proposed that, over many generations, adaptation could cause successful species to evolve into new species. He also proposed that living species are descended, with modification, from common ancestors—an idea called *descent with modification.* Notice that this aspect of Darwin's theory implies that life has been on Earth for a very long time—enough time for all this descent with modification to occur! This is Hutton and Lyell's contribution to Darwin's theory: Deep time gave enough time for natural selection to act. For evidence of descent with modification over long periods of time, Darwin pointed to the fossil record.

Darwin based his explanation for the diversity of life on the idea that species change over time. To illustrate this idea, he drew the very first evolutionary tree, shown in **Figure 16–12.** This "tree-thinking" implies that all organisms are related. Look back in time, and you will find common ancestors shared by tigers, panthers, and cheetahs. Look farther back, and you will find ancestors that these felines share with dogs, then horses, and then bats. Farther back still is the common ancestor that all mammals share with birds, alligators, and fish. Far enough back are the common ancestors of all living things. **According to the principle of common descent, all species—living and extinct—are descended from ancient common ancestors.** A single "tree of life" links all living things.

16.3 Assessment

Review Key Concepts

1. a. **Review** What happens in the process of natural selection?
   b. **Explain** Why do organisms with greater fitness generally leave more offspring than organisms that are less fit?
   c. **Compare and Contrast** How are natural selection and artificial selection similar? How are they different?
2. a. **Review** Why were Hutton's and Lyell's ideas important to Darwin?
   b. **Apply Concepts** What do evolutionary trees show? What does a tree of life imply about all species living and extinct?

VISUAL THINKING

3. Look at the teeth in the lion's mouth. How is the structure of the lion's teeth an adaptation?

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16.4 Evidence of Evolution

THINK ABOUT IT Darwin's theory depended on assumptions that involved many scientific fields. Scientists in some fields, including geology, physics, paleontology, chemistry, and embryology, did not have the technology or understanding to test Darwin's assumptions during his lifetime. And other fields, like genetics and molecular biology, didn't exist yet! In the 150 years since Darwin published *On the Origin of Species*, discoveries in all these fields have served as independent tests that could have supported or refuted Darwin's work. Astonishingly, every scientific test has supported Darwin's basic ideas about evolution.

Biogeography

How does the geographic distribution of species today relate to their evolutionary history?

Darwin recognized the importance of patterns in the distribution of life—the subject of the field called biogeography. **Biogeography** is the study of where organisms live now and where they and their ancestors lived in the past. **Patterns in the distribution of living and fossil species tell us how modern organisms evolved from their ancestors.** Two biogeographical patterns are significant to Darwin's theory. The first is a pattern in which closely related species differentiate in slightly different climates. The second is a pattern in which very distantly related species develop similarities in similar environments.

Closely Related but Different To Darwin, the biogeography of Galápagos species suggested that populations on the island had evolved from mainland species. Over time, natural selection on the islands produced variations among populations that resulted in different, but closely related, island species.

Distantly Related but Similar On the other hand, similar habitats around the world are often home to animals and plants that are only distantly related. Darwin noted that similar ground-dwelling birds inhabit similar grasslands in Europe, Australia, and Africa. Differences in body structures among those animals provide evidence that they evolved from different ancestors. Similarities among those animals, however, provide evidence that similar selection pressures had caused distantly related species to develop similar adaptations.

Key Questions

How does the geographic distribution of species today relate to their evolutionary history?

How do fossils help to document the descent of modern species from ancient ancestors?

What do homologous structures and similarities in embryonic development suggest about the process of evolutionary change?

How can molecular biology be used to trace the process of evolution?

What does recent research on the Galápagos finches show about natural selection?

Vocabulary

biogeography
homologous structure
analogous structure
vestigial structure

Taking Notes

Concept Map Construct a concept map that shows the kinds of evidence that support the theory of evolution.

MYSTERY CLUE

How can biogeography help explain why some species of honeycreepers are found only on the Hawaiian Islands?

The Age of Earth and Fossils

How do fossils help to document the descent of modern species from ancient ancestors?

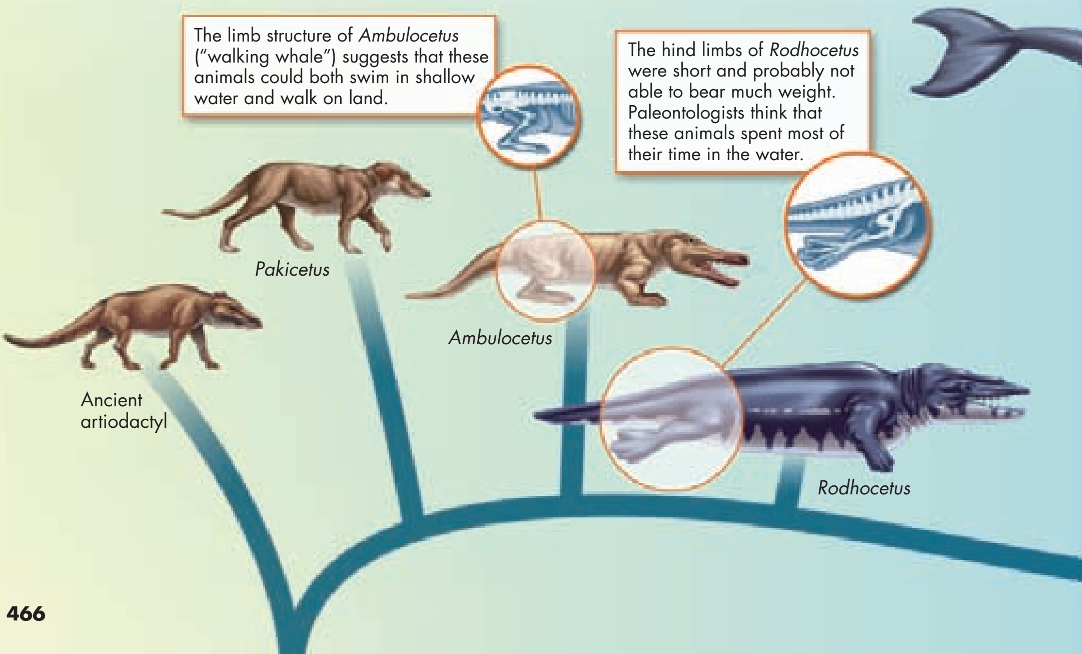
Two potential difficulties for Darwin's theory involved the age of Earth and gaps in the fossil record. Data collected since Darwin's time have answered those concerns and have provided dramatic support for an evolutionary view of life.

The Age of Earth Evolution takes a long time. If life has evolved, then Earth must be very old. Hutton and Lyell argued that Earth was indeed very old, but technology in their day couldn't determine just how old. Half a century after Darwin published his theory, however, physicists discovered radioactivity. Geologists now use radioactivity to establish the age of certain rocks and fossils. This kind of data could have shown that Earth is young. If that had happened, Darwin's ideas would have been refuted and abandoned. Instead, radioactive dating indicates that Earth is about 4.5 billion years old—plenty of time for evolution by natural selection to take place.

VISUAL SUMMARY

EVIDENCE FROM FOSSILS

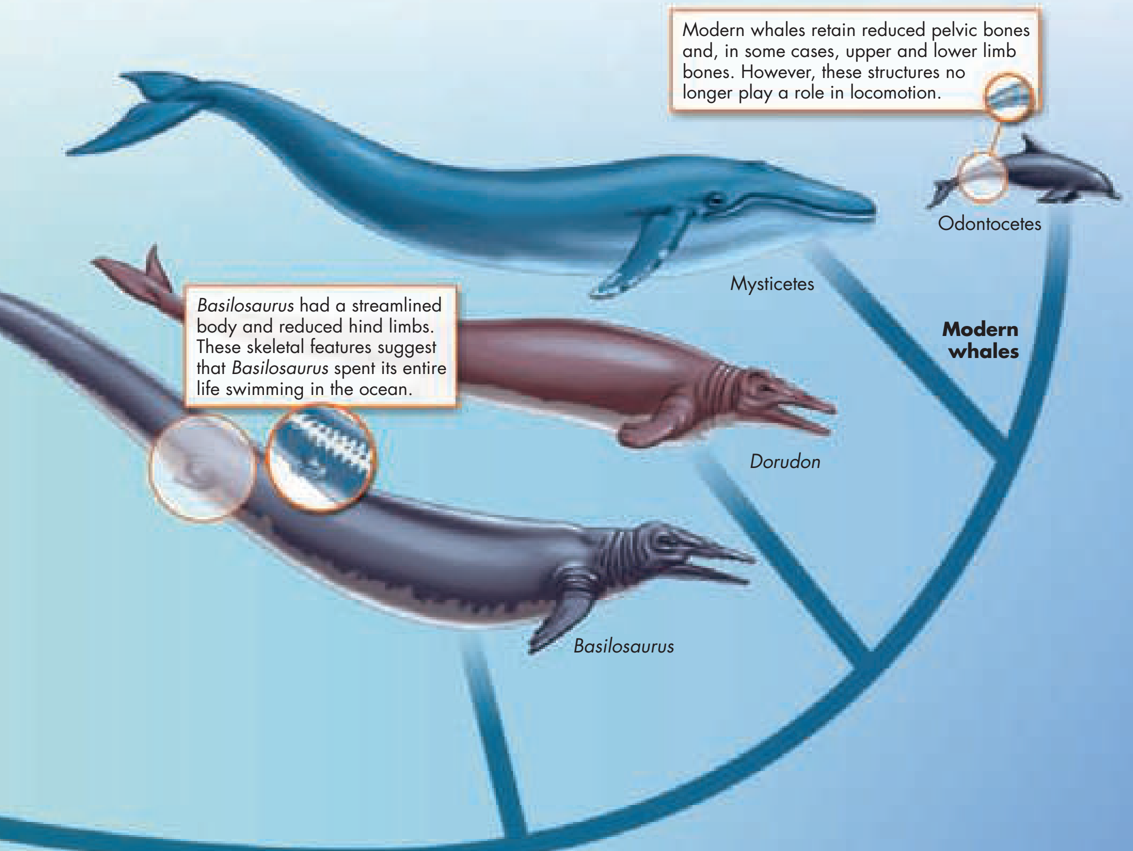
FIGURE 16–13 Recently, researchers have found more than 20 related fossils that document the evolution of modern whales from ancestors that walked on land. Several reconstructions based on fossil evidence are shown below in addition to the modern mysticete and odontocete. **Infer** ***Which of the animals shown was probably the most recent to live primarily on land?***



Recent Fossil Finds Darwin also struggled with what he called the "imperfection of the geological record." Darwin's study of fossils had convinced him and other scientists that life evolved. But paleontologists in 1859 hadn't found enough fossils of intermediate forms of life to document the evolution of modern species from their ancestors. **Many recently discovered fossils form series that trace the evolution of modern species from extinct ancestors.**

Since Darwin, paleontologists have discovered hundreds of fossils that document intermediate stages in the evolution of many different groups of modern species. One recently discovered fossil series documents the evolution of whales from ancient land mammals, as shown in **Figure 16–13.** Other recent fossil finds connect the dots between dinosaurs and birds, and between fish and four-legged land animals. In fact, so many intermediate forms have been found that it is often hard to tell where one group begins and another ends. All historical records are incomplete, and the history of life is no exception. The evidence we do have, however, tells an unmistakable story of evolutionary change.

Fossil of the Eocene whale *Ambulocetus natans* (about 49 million years old)



Comparing Anatomy and Embryology

What do homologous structures and similarities in embryonic development suggest about the process of evolutionary change?

By Darwin's time, scientists had noted that all vertebrate limbs had the same basic bone structure, as shown in **Figure 16–14.** Yet, some were used for crawling, some for climbing, some for running, and others for flying. Why should the same basic structures be used over and over again for such different purposes?

BUILD Vocabulary

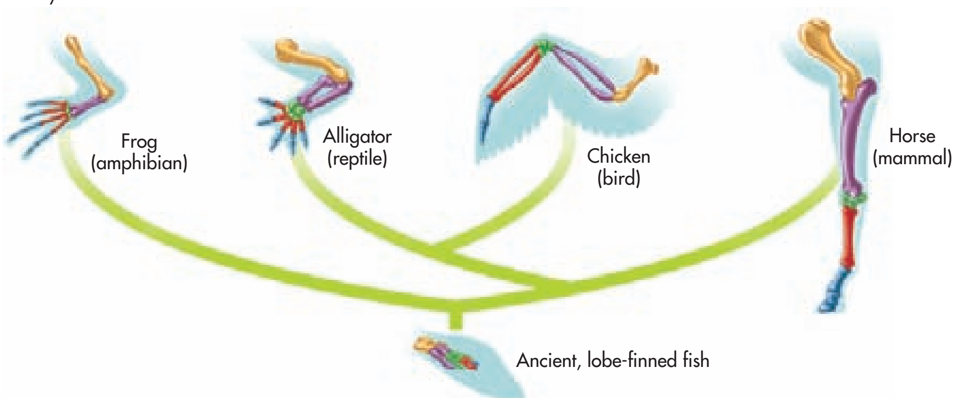
WORD ORIGINS The word **homologous** comes from the Greek word *homos*, meaning "same." Homologous structures may not look exactly the same, but they share certain characteristics and a common ancestor.

Homologous Structures Darwin proposed that animals with similar structures evolved from a common ancestor with a basic version of that structure. Structures that are shared by related species and that have been inherited from a common ancestor are called **homologous structures. Evolutionary theory explains the existence of homologous structures adapted to different purposes as the result of descent with modification from a common ancestor.** Biologists test whether structures are homologous by studying anatomical details, the way structures develop in embryos, and the pattern in which they appeared over evolutionary history.

Similarities and differences among homologous structures help determine how recently species shared a common ancestor. For example, the front limbs of reptiles and birds are more similar to each other than either is to the front limb of an amphibian or mammal. This similarity—among many others—indicates that the common ancestor of reptiles and birds lived more recently than the common ancestor of reptiles, birds, and mammals. So birds are more closely related to crocodiles than they are to bats! The common ancestor of all these four-limbed animals was an ancient lobe-finned fish that lived over 380 million years ago.

Homologous structures aren't just restricted to animals. Biologists have identified homologies in many other organisms. Certain groups of plants, for example, share homologous stems, roots, and flowers.

FIGURE 16–14 Homologous Limb Bones Homologous bones, as indicated by color-coding, support the differently shaped front limbs of these modern vertebrates. These limbs evolved, with modifications, from the front limbs of a common ancestor whose bones resembled those of an ancient fish. If these animals had no recent common ancestor, they would be unlikely to share so many common structures.



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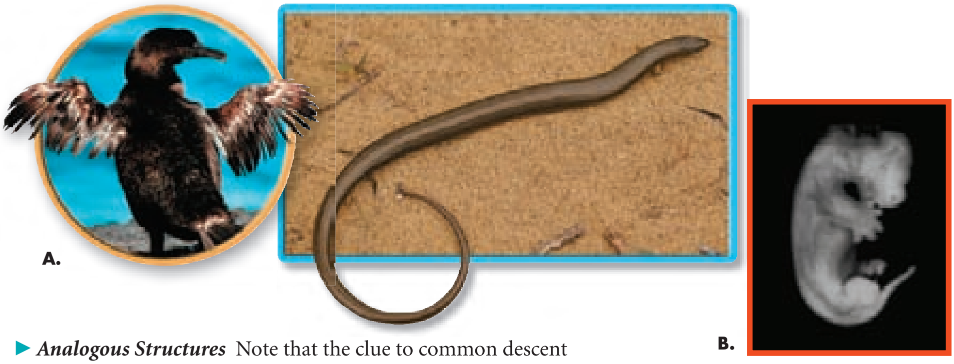


FIGURE 16–15 Vestigial Organs and Embryology
A. The wings of the flightless cormorant and the legs of the Italian three-toed skink are vestigial structures. **B.** Because the early stages of development among vertebrates are so similar, it would take an expert to identify this as an opposum embryo. **Infer** ***Looking at the legs of the skink, do you think its ancestors had functioning legs? Explain your answer.***

▶ ***Analogous Structures*** Note that the clue to common descent is common *structure*, not common *function*. A bird's wing and a horse's front limb have different functions but similar structures. Body parts that share common function, but not structure, are called **analogous structures.** The wing of a bee and the wing of a bird are analogous structures.

In Your Notebook *Do you think the shell of a clam and the shell of a lobster are homologous or analogous structures? Explain.*

▶ ***Vestigial Structures*** Not all homologous structures have important functions. **Vestigial structures** are inherited from ancestors but have lost much or all of their original function due to different selection pressures acting on the descendant. For example, the hipbones of the bottlenose dolphin, shown on page 467, are vestigial structures. In their ancestors, hipbones played a role in terrestrial locomotion. However, as the dolphin lineage adapted to life at sea, this function was lost. Why do dolphins and the organisms in **Figure 16–15** retain structures with little or no function? One possibility is that the presence of the structure does not affect an organism's fitness, and, therefore, natural selection does not act to eliminate it.

Embryology

Researchers noticed a long time ago that the early developmental stages of many animals with backbones (called vertebrates) look very similar. Recent observations make clear that the same groups of embryonic cells develop in the same order and in similar patterns to produce many homologous tissues and organs in vertebrates. For example, despite the very different adult shapes and functions of the limb bones in **Figure 16–14,** all those bones develop from the same clumps of embryonic cells. Evolutionary theory offers the most logical explanation for these similarities in patterns of development. **Similar patterns of embryological development provide further evidence that organisms have descended from a common ancestor.**

Darwin realized that similar patterns of development offer important clues to the ancestory of living organisms. He could not have anticipated, however, the incredible amount of evidence for his theory that would come from studying the genes that control development—evidence from the fields of genetics and molecular biology.

Genetics and Molecular Biology

How can molecular biology be used to trace the process of evolution?

The most troublesome "missing information" for Darwin had to do with heredity. Darwin had no idea how heredity worked, and he was deeply worried that this lack of knowledge might prove fatal to his theory. As it happens, some of the strongest evidence supporting evolutionary theory comes from genetics. A long series of discoveries, from Mendel to Watson and Crick to genomics, helps explain how evolution works. **At the molecular level, the universal genetic code and homologous molecules provide evidence of common descent.** Also, we now understand how mutation and the reshuffling of genes during sexual reproduction produce the heritable variation on which natural selection operates.

Life's Common Genetic Code One dramatic example of molecular evidence for evolution is so basic that by this point in your study of biology you might take it for granted. All living cells use information coded in DNA and RNA to carry information from one generation to the next and to direct protein synthesis. This genetic code is nearly identical in almost all organisms, including bacteria, yeasts, plants, fungi, and animals. This is powerful evidence that all organisms evolved from common ancestors that shared this code.

Analyzing Data

Molecular Homology in *Hoxc8*

Molecular homologies can be used to infer relationships among organisms. The diagram below shows a small portion of the DNA for the same gene, *Hoxc8,* in three animals—a mouse, a baleen whale, and a chicken.

1. Calculate What percentage of the nucleotides in the baleen whale's DNA are different from those of the mouse? (*Hint*: First count the number of DNA nucleotides in one entire sequence. Then count the nucleotides in the whale DNA that differ from those in the mouse DNA. Finally, divide the number of nucleotides that are different by the total number of nucleotides, and multiply the result by 100.) MATH

2. Calculate What percentage of the nucleotides in the chicken are different from those of the mouse? MATH

3. Draw Conclusions Do you think a mouse is more closely related to a baleen whale or to a chicken? Explain your answer.

4. Evaluate Do you think that scientists can use small sections of DNA, like the ones shown here, to infer evolutionary relationships? Why or why not?

Animal	Sequence of Bases in Section of *Hoxc8*
Mouse	C A G A A A T G C C A C T T T T A T G G C C C T G T T T G T C T C C C T G C T C
Baleen whale	C **C** G A A A T G C C **T** C T T T T A T G G C **G** C T G T T T G T C T C C C T G C **G** C
Chicken	**A** A **A** A A A T G C C **G** C T T T T A **C** **A** G C **T** C T G T T T G T C T C **T** C T G C T **A**

Homologous Molecules In Darwin's day, biologists could only study similarities and differences in structures they could see. But physical body structures can't be used to compare mice with yeasts or bacteria. Today, we know that homology is not limited to physical structures. As shown in **Figure 16–16,** homologous proteins have been found in some surprising places. Homologous proteins share extensive structural and chemical similarities. One homologous protein is cytochrome c, which functions in cellular respiration. Remarkably similar versions of cytochrome c are found in almost all living cells, from cells in baker's yeast to cells in humans.

There are many other kinds of homologies at the molecular level. Genes can be homologous, too, which makes sense given the genetic code that all plants and animals share. One spectacular example is a set of ancient genes that determine the identities of body parts. Known as the Hox genes, they help to determine the head-to-tail axis in embryonic development. In vertebrates, sets of homologous Hox genes direct the growth of front and hind limbs. Small changes in these genes can produce dramatic changes in the structures they control. So, relatively minor changes in an organism's genome can produce major changes in an organism's structure and the structure of its descendants. At least some homologous Hox genes are found in almost all multicellular animals, from fruit flies to humans. Such profound biochemical similarities are best explained by Darwin's conclusion: Living organisms evolved through descent with modification from a common ancestor.

FIGURE 16–16 Similar Genes Bacteria in this hot spring live in near-boiling water—an inhospitable environment to animals. Their cells even look different from animal cells. Yet many of their genes, and therefore the proteins coded by those genes, are similar to those of animals. This is more evidence that all organisms share an ancient common ancestor.

Testing Natural Selection

What does recent research on the Galápagos finches show about natural selection?

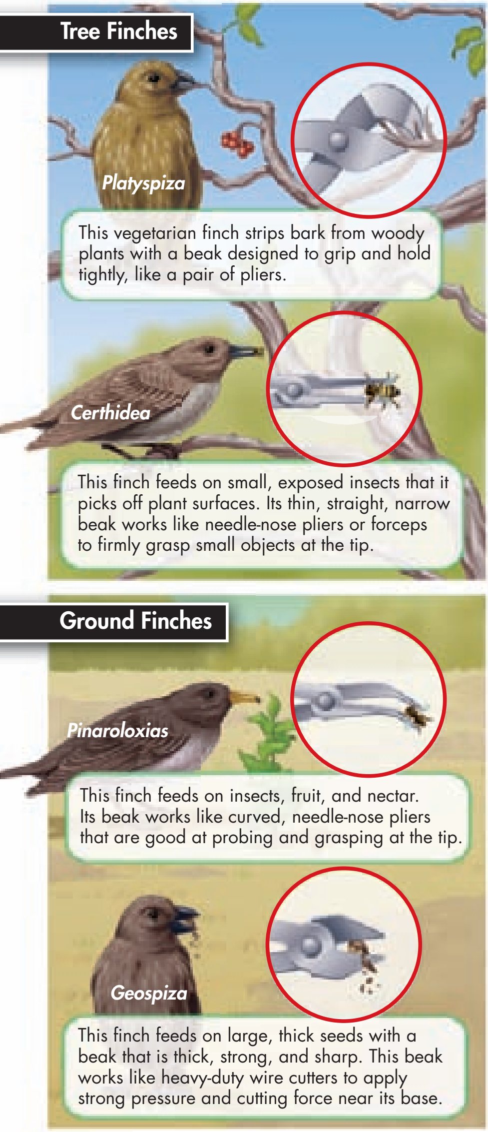
One way to gather evidence for evolutionary change is to observe natural selection in action. But most kinds of evolutionary change we've discussed so far took place over millions of years—which makes it tough to see change actually happening. Some kinds of evolutionary change, however, have been observed and studied repeatedly in labs and in controlled outdoor environments. Scientists have designed experiments involving organisms from bacteria to guppies to test Darwin's theories. Each time, the results have supported Darwin's basic ideas. But one of the best examples of natural selection in action comes from observations on animals living in their natural environment. Fittingly, those observations focused on Galápagos finches.

A Testable Hypothesis Remember that when Darwin first saw the Galápagos finches, he thought they were wrens, warblers, and blackbirds because they looked so different from one another. Once Darwin learned that the birds were all finches, he hypothesized that they had descended from a common ancestor.

VISUAL ANALOGY

FINCH BEAK TOOLS

FIGURE 16–17 Finches use their beaks as tools to pick up and handle food. Different types of foods are most easily handled with beaks of different sizes and shapes.



Darwin noted that several finch species have beaks of very different sizes and shapes. Each species uses its beak like a specialized tool to pick up and handle its food, as shown in **Figure 16–17.** Darwin proposed that natural selection had shaped the beaks of different bird populations as they became adapted to eat different foods. That was a reasonable hypothesis. But was there any way to test it? No one thought there was a way until Peter and Rosemary Grant of Princeton University came along.

The Grants have spent more than 35 years studying Galápagos finches. They realized that Darwin's hypothesis rested on two testable assumptions. First, for beak size and shape to evolve, there must be enough heritable variation in those traits to provide raw material for natural selection. Second, differences in beak size and shape must produce differences in fitness.

The Grants have tested these hypotheses on the medium ground finch (*Geospiza*) on the island of Daphne Major. This island is large enough to support good-sized finch populations, yet small enough to allow the Grants to catch, tag, and identify nearly every bird of the species.

During their study, the Grants periodically recapture the birds. They record which individuals are alive and which have died, which have reproduced and which have not. For each individual, the Grants record anatomical characteristics like wing length, leg length, beak length, beak depth, beak color, feather colors, and total mass. The data the Grants have recorded show that there is indeed great variation of heritable traits among Galápagos finches.

Natural Selection The Grants' data have shown that individual finches with different-size beaks have better or worse chances of surviving both seasonal droughts and longer dry spells. When food becomes scarce during dry periods, birds with the largest beaks are more likely to survive, as shown in **Figure 16–18.** As a result, average beak size in this finch population has increased dramatically. **The Grants have documented that natural selection takes place in wild finch populations frequently, and sometimes rapidly.** Changes in food supply created selection pressure that caused finch populations to evolve within decades. This evolutionary change occurred much faster than many researchers thought possible.

Not only have the Grants documented natural selection in nature, their data also confirm that competition and environmental change drive natural selection. Traits that don't matter much under one set of environmental conditions became adaptive as the environment changes during a drought. **The Grants' work shows that variation within a species increases the likelihood of the species' adapting to and surviving environmental change.** Without heritable variation in beak sizes, the medium ground finch would not be able to adapt to feeding on larger, tougher seeds during a drought.

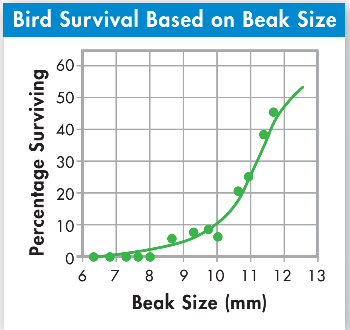


FIGURE 16–18 Survival and Beak Size This graph shows the survival rate of one species of ground finch, the medium ground finch, *Geospiza fortis*, during a drought period. **Interpret Graphs** *What trend does the graph show?*

Evaluating Evolutionary Theory Advances in many fields of biology, along with other sciences, have confirmed and expanded most of Darwin's hypotheses. Today, evolutionary theory—which includes natural selection—offers insights that are vital to all branches of biology, from research on infectious disease to ecology. That's why evolution is often called the grand unifying theory of the life sciences.

Like any scientific theory, evolutionary theory is constantly reviewed as new data are gathered. Researchers still debate important questions such as precisely how new species arise and why species become extinct. And there is also significant uncertainty about exactly how life began. However, any questions that remain are about *how* evolution works—not *whether* evolution occurs. To scientists, evolution is the key to understanding the natural world.

16.4 Assessment

Review Key Concepts

1. a. **Review** What is biogeography?
   b. **Relate Cause and Effect** Why do distantly related species in very different places sometimes share similar traits?
2. a. **Review** Why are fossils important evidence for evolution?
   b. **Interpret Visuals** Use **Figure 16–13** to describe how a modern mysticete whale is different from *Ambulocetus*.
3. a. **Review** How do vestigial structures provide evidence for evolution?
   b. **Compare and Contrast** Explain the difference between homologous and analogous structures. Which are more important to evolutionary biologists? Why?
4. a. **Explain** What is the relationship between Hox genes and embryological development?
   b. **Draw Conclusions** Organisms A and B have very similar Hox genes, and their embryos, in the earliest stages of development, are also very similar. What do these similarities indicate about the ancestry of organisms A and B?
5. a. **Explain** What hypothesis have the Grants been testing?
   b. **Draw Conclusions** How do the Grants' data show that genetic variation is important in the survival of a species?

WRITE ABOUT SCIENCE

Explanation

6. In your own words, write a paragraph that explains how evidence since Darwin's time has strengthened his theories.

Pre Lab: Amino Acid Sequences: Indicators of Evolution

Problem How can you use proteins to determine how closely organisms are related?

Materials light colored highlighting pen

Lab Manual Chapter 16 Lab

Skills Analyze Data, Graph, Draw Conclusions

Connect to the Big idea For years, scientists who studied evolution had to rely on only visible differences among organisms. Then a new source of evidence emerged. Biochemists were able to unravel the sequences of bases in DMA and amino acids in proteins. Scientists are able to use this data to confirm relationships based on anatomy. They also use the data to show that some species that appear very different are in fact more closely related than had been thought.

Biologists can compare the sequences of amino acids in a protein for two species. In general, when the total number of differences is small, the species are closely related. When the total number of differences is large, the species are more distantly related.

In this lab, you will compare amino acid sequences for one protein and analyze the results of a similar comparison for another protein. You will use both sets of data to predict relatedness among organisms.

Background Questions

a. **Review** What are homologous molecules?

b. **Explain** Why might scientists use molecules instead of anatomy to figure out how closely rabbits and fruit flies are related?

c. **Relate Cause and Effect** Amino acid sequences in the proteins of two species are similar. What can you conclude about the DNA in those species, and why?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Predict** Based only on their anatomy, rank gorillas, bears, chimpanzees, and mice from most recent common ancestor with humans to least recent.

2. **Use Analogies** You tell a story to a second person who tells it to a third person, and so on. As the story is retold, changes are introduced. Overtime, the number of changes increases. How is this process an analogy for what happens to DNA over time?

3. **Infer** Hemoglobin from two species is compared. On the long protein chains, there are three locations where the amino acids are different. Where would you place the common ancestor of the two species on the "tree of life," and why?

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Untamed Science Video Islands are rich environments for evolution, as you will find out with the Untamed Science crew.

Art in Motion This animation shows how fossil layers accumulate and are later exposed.

Art Review Review homologus and analogous structures in vertebrates.

Visual Analogy See how different types of finch beaks function like tools.

Data Analysis Collect population data for several generations of grasshoppers and then analyze how the population changed due to natural selection.

16 Study Guide

Big idea Evolution

Natural selection is a natural process through which life evolves. It acts on populations whose individuals must struggle for existence and that have both heritable variation in traits and variable fitness among individuals.

16.1 Darwin's Voyage of Discovery

Darwin developed a scientific theory of biological evolution that explains how modern organisms evolved over long periods of time through descent from common ancestors.

Darwin noticed that (1) different, yet ecologically similar, animal species inhabited separated, but ecologically similar, habitats around the globe; (2) different, yet related, animal species often occupied different habitats within a local area; and (3) some fossils of extinct animals were similar to living species.

evolution (450) fossil (452)

16.2 Ideas That Shaped Darwin's Thinking

Hutton and Lyell concluded that Earth is extremely old and that the processes that changed Earth in the past are the same processes that operate in the present.

Lamarck suggested that organisms could change during their lifetimes by selectively using or not using various parts of their bodies. He also suggested that individuals could pass these acquired traits on to their offspring, enabling species to change over time.

Malthus reasoned that if the human population grew unchecked, there wouldn't be enough living space and food for everyone.

In artificial selection, nature provides the variations, and humans select those they find useful.

artificial selection (458)

16.3 Darwin Presents His Case

Natural selection occurs in any situation in which more individuals are born than can survive, there is natural heritable variation, and there is variable fitness among individuals.

According to the principle of common descent, all species—living and extinct—are descended from ancient common ancestors.

adaptation (461) natural selection (463)
fitness (461)

16.4 Evidence of Evolution

Patterns in the distribution of living and fossil species tell us how modern organisms evolved from their ancestors.

Many recently discovered fossils form series that trace the evolution of modern species from extinct ancestors.

Evolutionary theory explains the existence of homologous structures adapted to different purposes as the result of descent with modification from a common ancestor.

The universal genetic code and homologous molecules provide evidence of common descent.

The Grants have documented that natural selection takes place in wild Galápagos finch populations frequently, and sometimes rapidly, and that variation within a species increases the likelihood of the species adapting to and surviving environmental change.

biogeography (465) analogous structure (469)
homologous structure (468) vestigial structure (469)

Think Visually

Using the information in this chapter, create a concept map that links the following terms: *adaptation, artificial selection, biogeography, camouflage, Charles Darwin, Charles Lyell, evolution, fitness, fossil, homology, James Hutton, Jean-Baptiste Lamarck, mimicry, natural selection,* and *Thomas Malthus.*

16 Assessment

16.1 Darwin's Voyage of Discovery

Understand Key Concepts

1. Who observed variations in the characteristics of plants and animals on different islands of the Galápagos?
   a. James Hutton **c.** Charles Darwin
   b. Charles Lyell **d.** Thomas Malthus

2. In addition to observing living organisms, Darwin studied the preserved remains of ancient organisms called
   a. fossils. **c.** homologies.
   b. adaptations. **d.** vestigial structures.

3. What pattern of variation did Darwin observe among rheas, ostriches, and emus?

4. What connection did Darwin make between the Galápagos tortoises and their environments?

Think Critically

5. **Apply Concepts** Explain what the term *evolution* means, and give an example.

6. **Relate Cause and Effect** Why was Darwin's trip aboard the *Beagle* so important to his development of the theory of natural selection?

7. **Infer** Why was Darwin puzzled by the fact that there were no rabbits in Australia?

16.2 Ideas That Shaped Darwin's Thinking

Understand Key Concepts

8. Which of the following ideas proposed by Lamarck was later found to be incorrect?
   a. Acquired characteristics can be inherited.
   b. All species are descended from other species.
   c. Living things change over time.
   d. There is a relationship between an organism and its environment.

9. Which of the following would an animal breeder use to increase the number of cows that give the most milk?
   a. overproduction **c.** acquired characteristics
   b. genetic isolation **d.** artificial selection

10. What accounts for the presence of marine fossils on mountaintops?

11. How did Lyell's *Principles of Geology* influence Darwin?

12. According to Malthus, what factors limit population growth? Why did Malthus's ideas apply to other organisms better than they did to humans?

13. What is artificial selection? How did this concept influence Darwin's thinking?

Think Critically

14. **Relate Cause and Effect** A sunflower produces many seeds. Will all the seeds grow into mature plants? Explain your answer.

15. **Evaluate** Explain why Lamarck made a significant contribution to science even though his explanation of evolution was wrong.

16.3 Darwin Presents His Case

Understand Key Concepts

16. An inherited characteristic that increases an organism's ability to survive and reproduce in its specific environment is called a(n)
    a. vestigial structure. **c.** speciation.
    b. adaptation. **d.** analogous structure.

17. How well an organism survives and reproduces in its environment can be described as its
    a. fitness. **c.** common descent.
    b. homologies. **d.** analogies.

18. How does natural variation affect evolution?

19. Explain the following statement: "Descent with modification explains the diversity of life we see today."

20. Describe the conditions necessary for natural selection to occur.

Think Critically

21. **Apply Concepts** How would Darwin explain the long legs of the water bird in **Figure 16–6**? How would Darwin's explanation differ from Lamarck's explanation?

22. **Compare and Contrast** Distinguish between fitness and adaptation. How are the two concepts related?

23. **Infer** How does the process of natural selection account for the diversity of organisms that Darwin observed on the Galápagos Islands?

24. **Infer** Many species of birds build nests in which they lay eggs and raise the newly hatched birds. How might nest-building behavior be an adaptation that ensures reproductive fitness?

16.4 Evidence of Evolution

Understand Key Concepts

25. Structures that have different mature forms but develop from the same embryonic tissue are called
   a. analogous. **c.** homologous.
   b. adaptations. **d.** fossils.

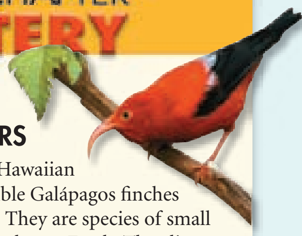
26. Intermediate fossil forms are important evidence of evolution because they show
   a. how organisms changed over time.
   b. how animals behaved in their environments.
   c. how the embryos of organisms develop.
   d. molecular homologies.

27. How does the geographic distribution of organisms support the theory of evolution?

28. How do vestigial structures indicate that present-day organisms are different from their ancient ancestors?

29. How do DNA and RNA provide evidence for common descent?

solve the CHAPTER MYSTERY



SUCH VARIED HONEYCREEPERS

The 'i'iwi and other Hawaiian honeycreepers resemble Galápagos finches in a number of ways. They are species of small birds found nowhere else on Earth. They live on islands that are separated from one another by stretches of open sea and that are hundreds of miles from the nearest continent. They are also related to finches!

There are more than 20 known species of Hawaiian honeycreeper. Like the species of Galápagos finches, the honeycreeper species are closely related to one another. This is an indication that they are all descended, with modification, from a relatively recent common ancestor. Experts think the ancestor colonized the islands between 3 million and 4 million years ago. Many honeycreepers have specialized diets, evolutionary adaptations to life on the particular islands they call home. Today, habitat loss is endangering most of the honeycreepers. In fact, many species of honeycreeper are thought to have become extinct since humans settled on the islands.

1. **Infer** Suppose a small group of birds, not unlike the modern honeycreepers, landed on one of Hawaii's islands millions of years ago and then reproduced. Do you think all the descendants would have stayed on that one island? Explain your answer.

2. **Infer** Do you think that the climate and other environmental conditions are exactly the same everywhere on the Hawaiian Islands? How might environmental conditions have affected the evolution of honeycreeper species?

3. **Form a Hypothesis** Explain how the different species of honeycreepers in Hawaii today might have evolved from one ancestral species.

4. **Connect to the Big idea** Why are islands often home to species that exist nowhere else on Earth?

Think Critically

30. **Infer** Which animal—a cricket or a cat—would you expect to have cytochrome c more similar to that of a dog? Explain your answer.

31. **Infer** In all animals with backbones, oxygen is carried in blood by a molecule called hemoglobin. What could this physiological similarity indicate about the evolutionary history of vertebrates (animals with backbones)?

32. **Apply Concepts** Do you think some species of snake might have vestigial hip and leg bones? Explain your answer.

Connecting Concepts

Use Science Graphics

Use the illustration below to answer questions 33 and 34.

33. **Infer** Based on what you can see, which mice—white or brown—are better adapted to their environment? Explain your answer.

34. **Apply Concepts** In what way is the coloring of the brown mice an adaptation? What other adaptations besides coloring might affect the mice's ability to survive and reproduce?

Write About Science

35. **Explanation** Write a paragraph that explains how the age of Earth supports the theory of evolution.

36. **Summary** Summarize the conditions under which natural selection occurs. Then, describe three lines of evidence that support the theory of evolution by natural selection.

37. **Assess the Big idea** Write a newspaper article about the meeting at which Darwin's and Wallace's hypotheses of evolution were first presented. Explain the theory of evolution by natural selection for an audience that knows nothing about the subject.

38. **Assess the Big idea** Look back at **Figure 16–10** on page 462. Explain how conditions could change so that yellow coloring becomes adaptive. What would happen to the relative numbers of green and yellow grasshoppers in the population?

Analyzing Data

Cytochrome c is a small protein involved in cellular respiration. The table compares the cytochrome c of various organisms to that of chimpanzees. The left column indicates the organism, and the right column indicates the number of amino acids that are different from those in chimpanzee cytochrome c.

Organism	Number of Amino Acids That Are Different From Chimpanzee Cytochrome c
Dog	10
Moth	24
Penguin	11
Yeast	38

39. **Interpret Data** Which of these organisms probably shares the most recent common ancestor with chimpanzees?

a. dog
b. moth
c. penguin
d. yeast

40. **Calculate** The primary structure of cytochrome c contains 104 amino acids. Approximately how many of these amino acids are the same in the chimpanzee and moth? MATH

a. 10
b. 24
c. 80
d. 128

Standardized Test Prep

Multiple Choice

1. Which scientist formulated the theory of evolution through natural selection?
A Charles Darwin **C** James Hutton
B Thomas Malthus **D** Jean-Baptiste Lamarck

2. Lamarck's ideas about evolution were wrong because he proposed that
A species change over time.
B species descended from other species.
C acquired characteristics can be inherited.
D species are adapted to their environments.

3. Lyell's *Principles of Geology* influenced Darwin because it explained how
A organisms change over time.
B adaptations occur.
C the surface of Earth changes over time.
D the Galápagos Islands formed.

4. A farmer's use of the best livestock for breeding is an example of
A natural selection. **C** extinction.
B artificial selection. **D** adaptation.

5. The ability of an individual organism to survive and reproduce in its natural environment is called
A natural selection.
B evolution.
C descent with modification.
D fitness.

6. Which of the following is an important concept in Darwin's theory of evolution by natural selection?
A descent with modification
B homologous molecules
C processes that change the surface of Earth
D the tendency toward perfection

7. Which of the following does NOT provide evidence for evolution?
A fossil record
B natural variation within a species
C geographical distribution of living things
D homologous structures of living organisms

8. DNA and RNA provide evidence of evolution because
A all organisms have nearly identical DNA and RNA.
B no two organisms have exactly the same DNA.
C each RNA codon specifies just one amino acid.
D in most organisms, the same codons specify the same amino acids.

9. A bird's wings are homologous to a(n)
A fish's tailfin. **C** dog's front legs.
B alligator's claws. **D** mosquito's wings.

Questions 10 and 11

The birds shown below are 2 of the species of finches Darwin found on the Galápagos Islands.

Woodpecker Finch **Large Ground Finch**

10. What process produced the two different types of beaks shown?
A artificial selection
B natural selection
C geographical distribution
D disuse of the beak

11. The large ground finch obtains food by cracking seeds. Its short, strong beak is an example of
A the struggle for existence.
B the tendency toward perfection.
C an adaptation.
D a vestigial organ.

Open-Ended Response

12. Compare and contrast the processes of artificial selection and natural selection.

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9	10	11	12
See Lesson	16.1	16.2	16.2	16.2	16.3	16.3	16.4	16.4	16.4	16.3	16.3	16.3