

15-3 Darwin Presents His Case

Standards: Bio 7a, 7d, 8a, 8b

Vocabulary

artificial selection, struggle for existence, fitness, adaptation, survival of the fittest, natural selection, descent with modification, common descent, homologous structure, vestigial organ

When Darwin returned to England in 1836, he brought back specimens from around the world. Subsequent findings about these specimens soon had the scientific community abuzz, Darwin learned that his Galapagos mockingbirds actually belonged to three separate species found nowhere else in the world! Even more surprising, the brown birds that Darwin had thought to be wrens, warblers, and blackbirds were all finches. They, too, were found nowhere else. The same was true of the Galapagos tortoises, the marine iguanas, and many plants that Darwin had collected on the islands. Each island species looked a great deal like a similar species on the South American mainland. Yet, the island species were clearly different from the mainland species and from one another.

Publication of *On the Origin of Species*

Darwin began filling notebooks with his ideas about species diversity and the process that would later be called evolution. However, he did not rush out to publish his thoughts. Recall that Darwin's ideas challenged fundamental scientific beliefs of his day. Darwin was not only stunned by his discoveries, he was disturbed by them. Years later, he wrote, "It was evident that such facts as these . . . could be explained on the supposition that species gradually became modified, and the subject haunted me." Although he discussed his work with friends, he shelved his manuscript for years and told his wife to publish it in case he died.

In 1858, Darwin received a short essay from Alfred Russel Wallace, a fellow naturalist who had been doing field work in Malaysia. That essay summarized the thoughts on evolutionary change that Darwin had been mulling over for almost 25 years! Suddenly, Darwin had an incentive to publish his own work. At a scientific meeting later that year, Wallace's essay was presented together with some of Darwin's work.

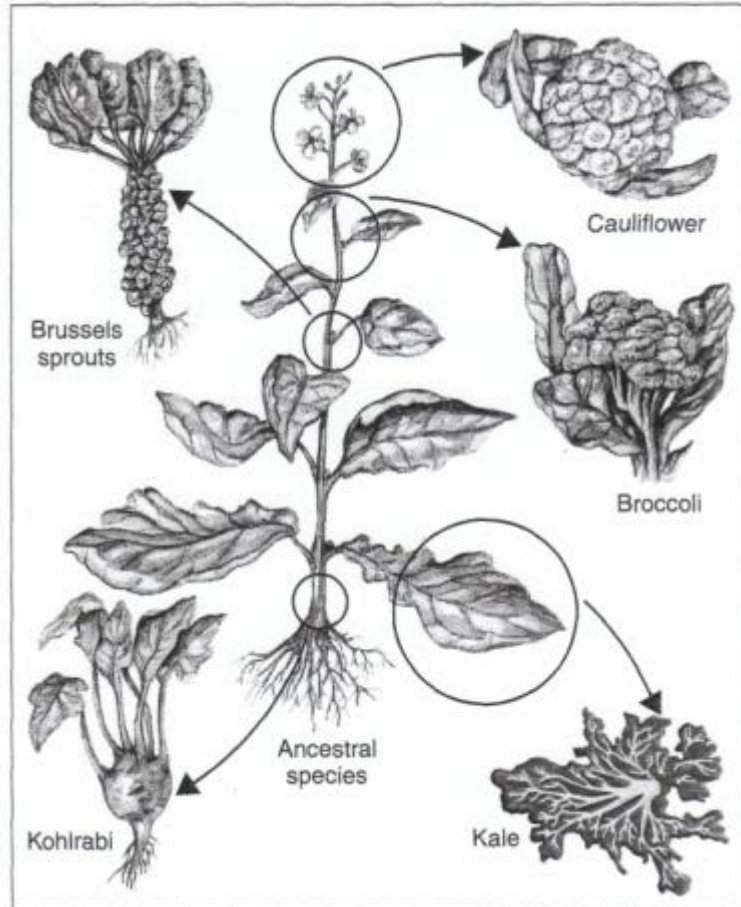
Eighteen months later, in 1859, Darwin published the results of his work, *On the Origin of Species*. In his book, he proposed a mechanism for evolution that he called natural selection. He then presented evidence that evolution has been taking place for millions of years—and continues in all living things. Darwin's work caused a sensation. Many people considered his arguments to be brilliant, while others strongly opposed his message. But what did Darwin actually say?

Inherited Variation and Artificial Selection

One of Darwin's most important insights was that members of each species vary from one another in important ways. Observations during his travels and conversations with plant and animal breeders convinced him that variation existed both in nature and on farms. For example, some plants in a species bear larger fruit than others. Some cows give more milk than others. From breeders, Darwin learned that some of this was heritable variation—differences that are passed from parents to offspring. Darwin had no idea of how heredity worked.

Today, we know that heritable variation in organisms is caused by variations in their genes. We also know that genetic variation is found in wild species as well as in domesticated plants and animals.

Darwin argued that this variation mattered. This was a revolutionary idea, because in Darwin's day, variations were thought to be unimportant, minor defects. But Darwin noted that plant and animal breeders used heritable variation—what we now call genetic variation—to improve crops and livestock. They would select for breeding only the largest hogs, the fastest horses, or the cows that produced the most milk. Darwin termed this process artificial selection. **In artificial selection, nature provided the variation, and humans selected those variations that they found useful.** Artificial selection has produced many diverse domestic animals and crop plants, including the plants shown below, by selectively breeding for different traits.



Evolution by Natural Selection

Darwin's next insight was to compare processes in nature to artificial selection. By doing so, he developed a scientific hypothesis to explain how evolution occurs. This is where Darwin made his greatest contribution—and his strongest break with the past.

The Struggle for Existence Darwin was convinced that a process like artificial selection worked in nature. But how? He recalled Malthus's work on population growth. Darwin realized that high birth rates and a shortage of life's basic needs would eventually force organisms into a competition for resources. The **struggle for existence** means that members of each species compete regularly to obtain food, living space, and other necessities of life. In this struggle, the predator that are faster or have a particular way of ensnaring other organisms can catch more prey. Those prey that are faster, better camouflaged, or better protected, such as the

porcupine shown in below, can avoid being caught. This struggle for existence was central to Darwin's theory of evolution.

Survival of the Fittest A key factor in the struggle for existence, Darwin observed, was how well suited an organism is to its environment. Darwin called the ability of an individual to survive and reproduce in its specific environment **fitness**. Darwin proposed that fitness is the result of adaptations. An **adaptation** is any inherited characteristic that increases an organism's chance of survival. Successful adaptations, Darwin concluded, enable organisms to become better suited to their environment and thus better able to survive and reproduce. Adaptations can be anatomical, or structural, characteristics, such as a porcupine's sharp quills. Adaptations also include an organism's physiological processes, or functions, such as the way in which a plant performs photosynthesis. More complex features, such as behavior in which some animals live and hunt in groups, can also be adaptations.



The concept of fitness, Darwin argued, was central to the process of evolution by natural selection. Generation after generation, individuals compete to survive and produce offspring. The baby birds, for example, compete for food and space while in the nest. Because each individual differs from other members of its species, each has unique advantages and disadvantages. Individuals with characteristics that are not well suited to their environment—that is, with low levels of fitness—either die or leave few offspring. Individuals that are better suited to their environment—that is, with adaptations that enable fitness—survive and reproduce most successfully. Darwin called this process **survival of the fittest**.



Because of its similarities to artificial selection, Darwin referred to the survival of the fittest as **natural selection**. In both artificial selection and natural selection, only certain individuals of a population produce new individuals. However, in natural selection, the traits being selected—and therefore increasing over time—contribute to an organism's fitness in its environment. Natural selection also takes place without human control

or direction. **Over time, natural selection results in changes in the inherited characteristics of a population. These changes increase a species' fitness in its environment.** Natural selection cannot be seen directly; it can only be observed as changes in a population over many successive generations.

✓*Checkpoint* **What did Darwin mean when he described certain organisms as "more fit" than others?**

Descent With Modification Darwin proposed that over long periods, natural selection produces organisms that have different structures, establish different niches, or occupy different habitats. As a result, species today look different from their ancestors. Each living species has descended, with changes, from other species over time. He referred to this principle as **descent with modification**.

Descent with modification also implies that all living organisms are related to one another. 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 horses, dogs, and bats. Farther back still are the common ancestors of mammals, birds, alligators, and fishes. If we look far enough back, the logic concludes, we could find the common ancestors of all living things. This is the principle known as **common descent**. According to this principle, all species—living and extinct—were derived from common ancestors. Therefore, a single "tree of life" links all living things.

Evidence of Evolution

With this unified, dynamic theory of life, Darwin could finally explain many of the observations he had made during his travels aboard the *Beagle*. **Darwin argued that living things have been evolving on Earth for millions of years. Evidence for this process could be found in the fossil record, the geographical distribution of living species, homologous structures of living organisms, and similarities in early development, or embryology.**

The Fossil Record By Darwin's time, scientists knew that fossils were the remains of ancient life and that different layers of rock had been formed at different times during Earth's history. Darwin saw fossils as a record of the history of life on Earth. Darwin, like Lyell, proposed that Earth was many millions—rather than thousands—of years old. During this long time, Darwin proposed, countless species had come into being, lived for a time, and then vanished. By comparing fossils from older rock layers with fossils from younger layers, scientists could document the fact that life on Earth has changed over time as shown.



Since Darwin's time, the number of known fossil forms has grown enormously. Researchers have discovered many hundreds of transitional fossils that document various intermediate stages in the evolution of modern species from organisms that are now extinct. Gaps remain, of course, in the fossil records of many species, although a lot of them shrink each year as new fossils are discovered. These gaps do not indicate weakness in the theory of evolution itself. Rather, they point out uncertainties in our understanding of exactly how some species evolved.

Geographic Distribution of Living Species

Remember that many parts of the biological puzzle that Darwin saw on his Beagle voyage involved living organisms. After Darwin discovered that those little brown birds he collected in the Galapagos were all finches, he began to wonder how they came to be similar, yet distinctly different from one another. Each species was slightly different from every other species. They were also slightly different from the most similar species on the mainland of South America. Could the island birds have changed over time, as populations in different places adapted to different local environments? Darwin struggled with this question for a long time. He finally decided that all these birds couldn't have descended with modification from a common mainland ancestor.

There were other parts to the living puzzle as well. Recall that Darwin found entirely different species of animals on the continents of South America and Australia. Yet, when he looked at similar environments on those continents, he sometimes saw different animals that had similar anatomies and behaviors. Darwin's theory of descent with modification made scientific sense of this part of the puzzle as well. Species now living on different continents, as shown in **Figure 15-14**, had each descended from different ancestors. However, because some animals on each continent were living under similar ecological conditions, they were exposed to similar pressures of natural selection. Because of these similar selection pressures, different animals ended up evolving certain striking features in common.

✓**Checkpoint:** *How can two species that look very different from each other be more closely related than two other species that look similar to each other?*

Homologous Body Structures Further evidence of evolution can be found in living animals. By Darwin's time, researchers had noticed striking anatomical similarities among the body parts of animals with backbones. For example, the limbs of reptiles, birds, and mammals—arms, wings, legs, and nippers—vary greatly in form and function. Yet, they are all constructed from the same basic bones, as shown.

Each of these limbs has adapted in ways that enable organisms to survive in different environments. Despite these different functions, however, these limb bones all develop from the same clumps of cells in embryos. Structures that have different mature forms but develop from the same embryonic tissues are called **homologous** (hoh-MAHL-uh-guhs) **structures**. Homologous structures provide strong evidence that all four-limbed vertebrates have descended, with modifications, from common ancestors.

There is still more information to be gathered from homologous structures. If we compare the front limbs, we can see that all bird wings are more similar to one another than any of them are to bat wings. Other bones in bird skeletons most closely resemble the homologous bones of certain reptiles—including crocodiles and extinct reptiles such as dinosaurs. The bones that support the wings of bats, by contrast, are more similar to the front limbs of humans, whales, and other mammals than they are to those of birds. These similarities and differences help biologists group animals according to how recently they last shared a common ancestor.

Not all homologous structures serve important functions. The organs of many animals are so reduced in size that they are just vestiges, or traces, of homologous organs in other species. These **vestigial organs** may resemble miniature legs, tails, or other structures. The legs of the skinks shown, are an example of vestigial organs. Why would an organism possess organs with little or no function? One possibility is that the presence of a vestigial organ may not affect an organism's ability to survive and reproduce. In that case, natural selection would not cause the elimination of that organ.

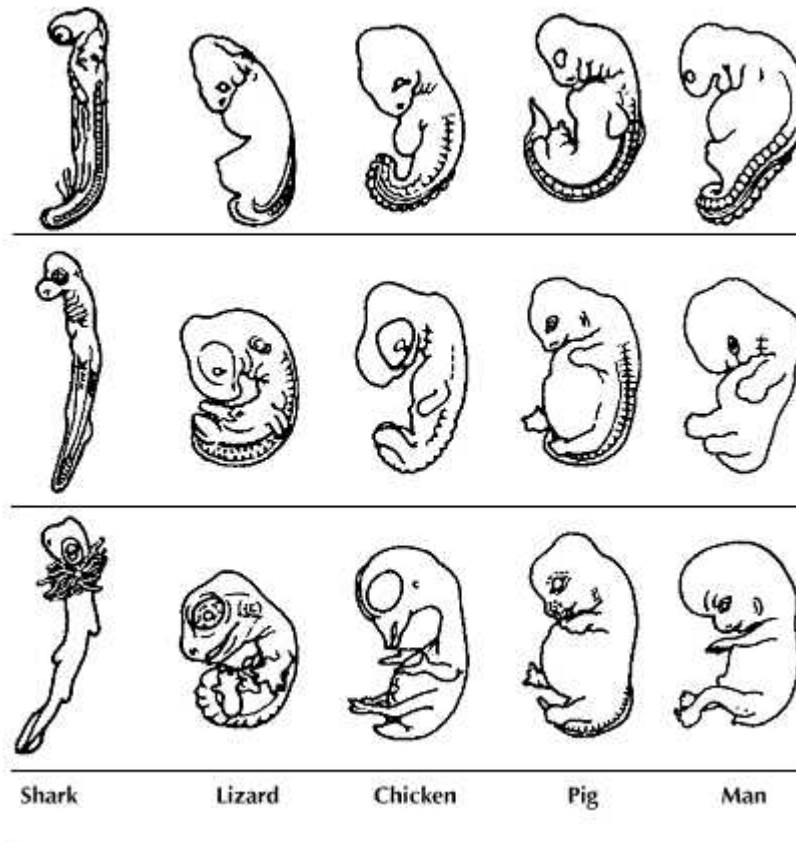
Homologies also appear in other aspects of plant and animal anatomy and physiology. Certain groups of plants and algae, for example, share homologous variations in stem, leaf, root, and flower structures, and in the way they carry out photosynthesis. Mammals share many homologies that distinguish them from other vertebrates. Dolphins may look something like fishes, but homologies show that they are mammals. For example, like other mammals, they have lungs rather than gills and obtain oxygen from air rather than water.

Similarities in Embryology The early stages, or embryos, of many animals with backbones are very similar. This does not mean that a human embryo is ever identical to a fish or a bird embryo. However, as you can see in Figure 15-17, many embryos look especially similar during early stages of development. What do these similarities mean?

There have, in the past, been incorrect explanations for these similarities. Also, the biologist Ernst Haeckel fudged some of his drawings to make the earliest stages of some embryos seem more similar than they actually are! Errors aside, however, it is clear that the same groups of embryonic cells develop in the same order and in similar patterns to produce the tissues and organs of all vertebrates. These common cells and tissues, growing in similar ways, produce the homologous structures discussed earlier.

✓*Checkpoint: What are homologous structures?*

Vertebrate Embryos at Certain Stages of Development



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Summary of Darwin's Theory

Darwin's theory of evolution can be summarized as follows:

- Individual organisms differ, and some of this variation is heritable.
- Organisms produce more offspring than can survive, and many that do survive do not reproduce.
- Because more organisms are produced than can survive, they compete for limited resources.
- Each unique organism has different advantages and disadvantages in the struggle for existence. Individuals best suited to their environment survive and reproduce most successfully. These organisms pass their heritable traits to their offspring. Other individuals die or leave fewer offspring. This process of natural selection causes species to change over time.

- Species alive today are descended with modification from ancestral species that lived in the distant past. This process, by which diverse species evolved from common ancestors, unites all organisms on Earth into a single tree of life.

Strengths and Weaknesses of Evolutionary Theory

Scientific advances in many fields of biology, along with geology and physics, have confirmed and expanded most of Darwin's hypotheses. Today, evolutionary theory offers vital insights to all biological and biomedical sciences—from infectious-disease research to ecology. In fact, evolution is often called the "grand unifying theory of the life sciences."

Like any scientific theory, evolutionary theory continues to change as new data are gathered and new ways of thinking arise. As you will see shortly, researchers still debate such important questions as precisely how new species arise and why species become extinct. There is also uncertainty about how life began.

15-3 Section Assessment

1. How is artificial selection dependent on variation in nature?
2. The theory of evolution by natural selection explains, in scientific terms, how living things evolve over time. What is being selected in this process?
3. What types of evidence did Darwin use to support his theory of change over time?
4. Critical Thinking Evaluating Use scientific evidence to evaluate Darwin's theory of evolution by natural selection.