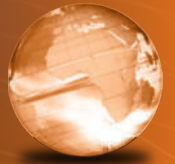


GLOBAL
EDITION



Biology

Life on Earth

WITH PHYSIOLOGY

ELEVENTH EDITION

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ALWAYS LEARNING

PEARSON

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simple and straightforward. It is based on four postulates about populations:

Postulate 1: Individual members of a population differ from one another in many respects.

Postulate 2: At least some of the differences among members of a population are due to characteristics that may be passed from parent to offspring.

Postulate 3: In each generation, some individuals in a population survive and reproduce successfully but others do not.

Postulate 4: The fate of individuals is not determined entirely by chance or luck. Instead, an individual's likelihood of survival and reproduction depends on its characteristics. Individuals with advantageous traits survive longest and leave the most offspring, a process known as **natural selection**.

Darwin and Wallace understood that if all four postulates were true, populations would inevitably change over time. If members of a population have different traits, and if the individuals that are best suited to their environment leave more offspring, and if those individuals pass their favorable traits to their offspring, then the favorable traits will become more common in subsequent generations. The characteristics of the population will change slightly with each generation. This process is evolution by natural selection.

Are the four postulates true? Darwin thought so, and devoted much of *On the Origin of Species* to describing supporting evidence. Let's briefly examine each postulate, in some cases with the advantage of knowledge that had not yet come to light during the lifetimes of Darwin and Wallace.

Postulate 1: Individuals in a Population Vary

The accuracy of postulate 1 is apparent to anyone who has glanced around a crowded room. People differ in size, eye color, skin color, and many other physical features. Similar variability is present in populations of other organisms, although it may be less obvious to the casual observer (**FIG. 15-6**).

Postulate 2: Traits Are Passed from Parent to Offspring

The principles of genetics had not yet been discovered when Darwin published *On the Origin of Species*. Therefore, although observation of people, pets, and farm animals seemed to show that offspring generally resemble their parents, Darwin and Wallace did not have scientific evidence in support of postulate 2. Mendel's later work, however, demonstrated conclusively that particular traits can be passed to offspring. Since Mendel's time, genetics researchers have produced a detailed picture of how inheritance works.

Postulate 3: Some Individuals Fail to Survive and Reproduce

Darwin's formulation of postulate 3 was heavily influenced by Thomas Malthus's *Essay on the Principle of Population*

(1798), which described the perils of unchecked growth of human populations. Darwin was keenly aware that organisms can produce far more offspring than are required merely to replace the parents. He calculated, for example, that a single pair of elephants would multiply to a population of 19 million in 750 years if each descendant had six offspring that lived to reproduce.

But we aren't overrun with elephants. The number of elephants, like the number of individuals in most natural populations, tends to remain relatively constant. Therefore, more organisms must be born than survive long enough to reproduce. In each generation, many individuals must die young. Even among those that survive, many must fail to reproduce, produce few offspring, or produce less-vigorous offspring that, in turn, fail to survive and reproduce. As you might expect, whenever biologists have measured reproduction in a population, they have found that some individuals have more offspring than others.

Postulate 4: Survival and Reproduction Are Not Determined by Chance

If unequal reproduction is the norm in populations, what determines which individuals leave the most offspring? A large amount of scientific evidence has shown that reproductive success depends on an individual's characteristics. For example, scientists found that larger male elephant seals in a California population have more offspring than smaller males



▲ **FIGURE 15-6** Variation in a population of snails Although these snail shells are all from members of the same population, no two are exactly alike.

THINK CRITICALLY Is sexual reproduction required to generate the variability in structures and behaviors that is necessary for natural selection?

(because females are more likely to mate with large males). In a Colorado population of snapdragons, plants with white flowers have more offspring than plants with yellow flowers (because pollinators find white flowers more attractive). These results, and hundreds of other similar ones, show that in the competition to survive and reproduce, winners are for the most part determined not by chance but by the traits they possess.

Natural Selection Modifies Populations over Time

Observation and experiment suggest that the four postulates of Darwin and Wallace are sound. Logic suggests that the resulting consequence ought to be change over time in the characteristics of populations. In *On the Origin of Species*, Darwin proposed the following example: “Let us take the case of a wolf, which preys on various animals, securing [them] by . . . fleetness The swiftest and slimmest wolves would have the best chance of surviving, and so be preserved or selected Now if any slight innate change of habit or structure benefited an individual wolf, it would have the best chance of surviving and of leaving offspring. Some of its young would probably inherit the same habits or structure, and by the repetition of this process, a new variety might be formed.” The same logic applies to the wolf’s prey: The fastest or most alert or best camouflaged would be most likely to avoid predation and would pass these traits to its offspring.

Notice that natural selection acts on individuals. Eventually, however, the influence of natural selection on the fates of individuals has consequences for the population as a whole. Over generations, the population changes as the percentage of individuals inheriting favorable traits increases. An individual cannot evolve, but a population can.

CHECK YOUR LEARNING

Can you ...

- explain how natural selection works and how it affects populations?
- describe the logic, based on four postulates, by which Darwin and Wallace deduced that populations must evolve by natural selection?

15.3 HOW DO WE KNOW THAT EVOLUTION HAS OCCURRED?

Today, evolution is an accepted scientific theory. (A scientific theory is a general explanation of important natural phenomena, developed through extensive, reproducible observations; see Chapter 1). An overwhelming body of evidence supports the conclusion that evolution has occurred. The key lines of evidence come from fossils, comparative anatomy (the study of how body structures differ among species), embryology (the study of developing organisms in the period

from fertilization to birth or hatching), biochemistry, and genetics.

Fossils Provide Evidence of Evolutionary Change over Time

If many fossils are the remains of species ancestral to modern species, we might expect to find fossils in a progressive series that starts with an ancient organism, progresses through several intermediate stages, and culminates in a modern species. Such series have indeed been found. For example, fossils of the ancestors of modern whales illustrate stages in the evolution of an aquatic species from land-dwelling ancestors (**FIG. 15-7**). Series of fossil giraffes, elephants, horses, and mollusks also show the evolution of body structures over time. These fossil series suggest that new species evolved from, and replaced, previous species.

Comparative Anatomy Gives Evidence of Descent with Modification

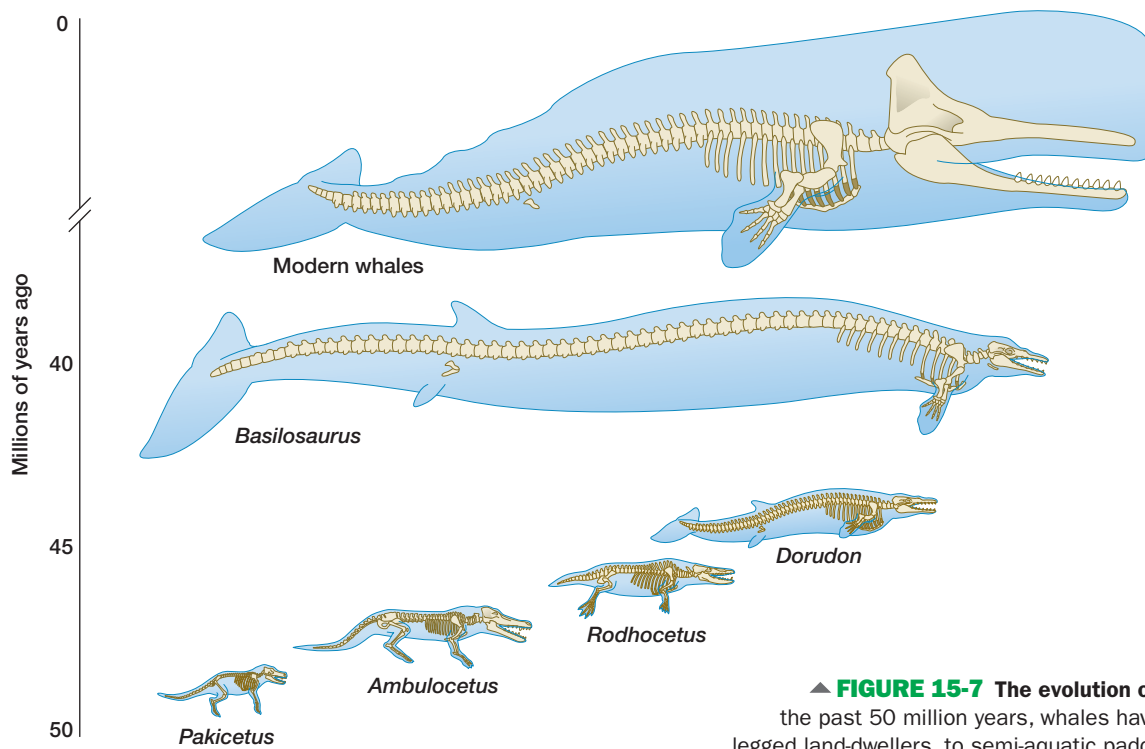
Fossils provide snapshots of the past that allow biologists to trace evolutionary changes, but careful examination of today’s organisms can also uncover evidence of evolution. Comparing the bodies of organisms of different species can reveal similarities that can be explained only by shared ancestry and differences that could result only from evolutionary change during descent from a common ancestor. In this way, the study of comparative anatomy has supplied strong evidence that different species are linked by a common evolutionary heritage.

Homologous Structures Provide Evidence of Common Ancestry

A body structure may be modified by evolution to serve different functions in different species. The forelimbs of birds and mammals, for example, are variously used for flying, swimming, running, and grasping objects. Despite this enormous diversity of function, the internal anatomy of all bird and mammal forelimbs is remarkably similar (**FIG. 15-8**). It seems inconceivable that the same bone arrangements would be used to serve such diverse functions if each animal had been created separately. Such similarity is exactly what we would expect, however, if bird and mammal forelimbs were derived from the forelimb of a common ancestor. Through natural selection, the ancestral forelimb has undergone different modifications in different kinds of animals. The resulting internally similar structures are called **homologous structures**, meaning that they have the same evolutionary origin despite any differences in current function or appearance.

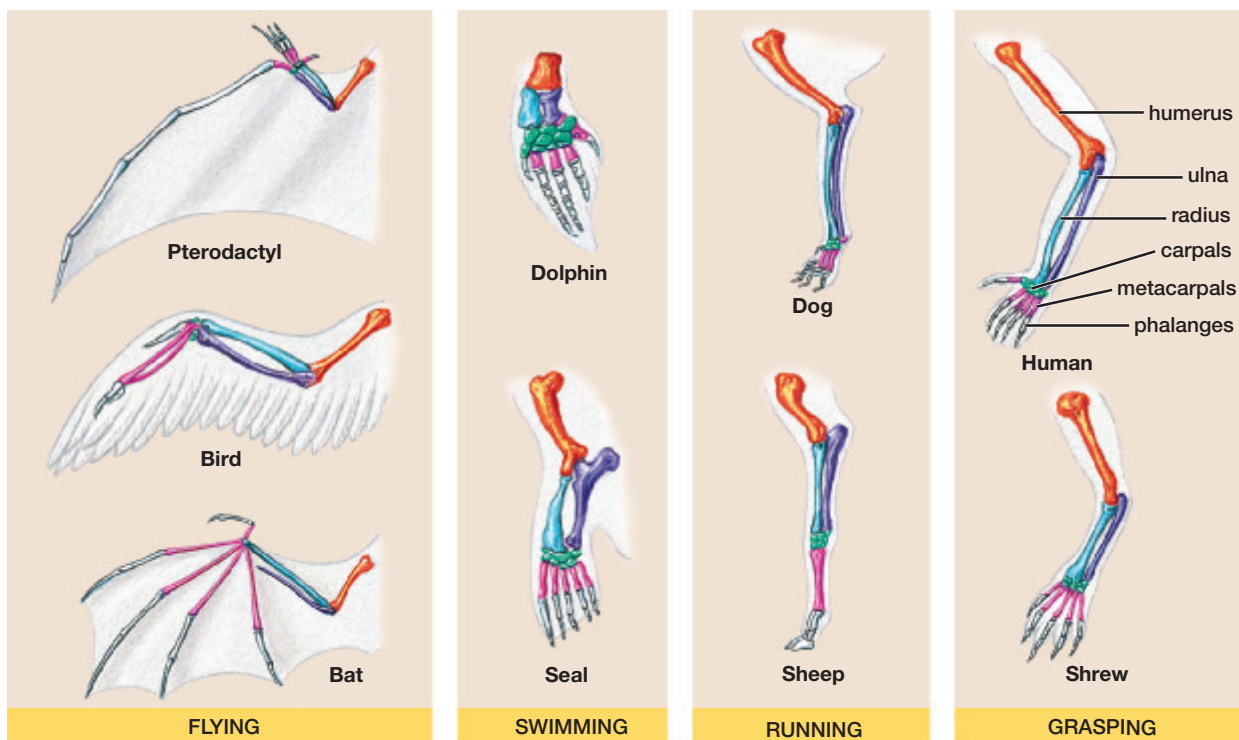
Vestigial Structures Are Inherited from Ancestors

A **vestigial structure** no longer performs the function for which it evolved in a species’ ancestors. Although vestigial structures are sometimes co-opted for new uses, they often seem to serve no function at all. Examples of functionless



▲ **FIGURE 15-7** The evolution of the whale During the past 50 million years, whales have evolved from four-legged land-dwellers, to semi-aquatic paddlers, to fully aquatic swimmers with shrunken hind legs, to today's sleek ocean-dwellers.

THINK CRITICALLY The fossil history of some kinds of modern organisms, such as sharks and crocodiles, shows that their structure and appearance have changed very little over hundreds of millions of years. Is this lack of change evidence that such organisms have not evolved during that time?



▲ **FIGURE 15-8** Homologous structures Despite wide differences in function, the forelimbs of all of these animals contain the same set of bones, inherited from a common ancestor. The different colors of the bones highlight the correspondences among the various species.

vestigial structures include molar teeth in vampire bats (which live on a diet of blood and, therefore, don't chew their food) and pelvic bones in whales and certain snakes (**FIG. 15-9**). Both of these vestigial structures are clearly homologous to structures that are found in—and used by—other vertebrates (animals with a backbone). The continued existence in organisms of structures for which they have no use is best explained as a sort of “evolutionary baggage.” For example, the ancestral mammals from which whales evolved had four legs and a well-developed set of pelvic bones (see Figure 15-7). Whales do not have hind legs, yet they have small pelvic and leg bones embedded in their sides. During whale evolution, losing the hind legs provided an advantage, better streamlining the body for movement through water. The result is the modern whale with small, useless pelvic bones that persist because they have shrunk to the point that they no longer constitute a survival-reducing burden.

Some Anatomical Similarities Result from Evolution in Similar Environments

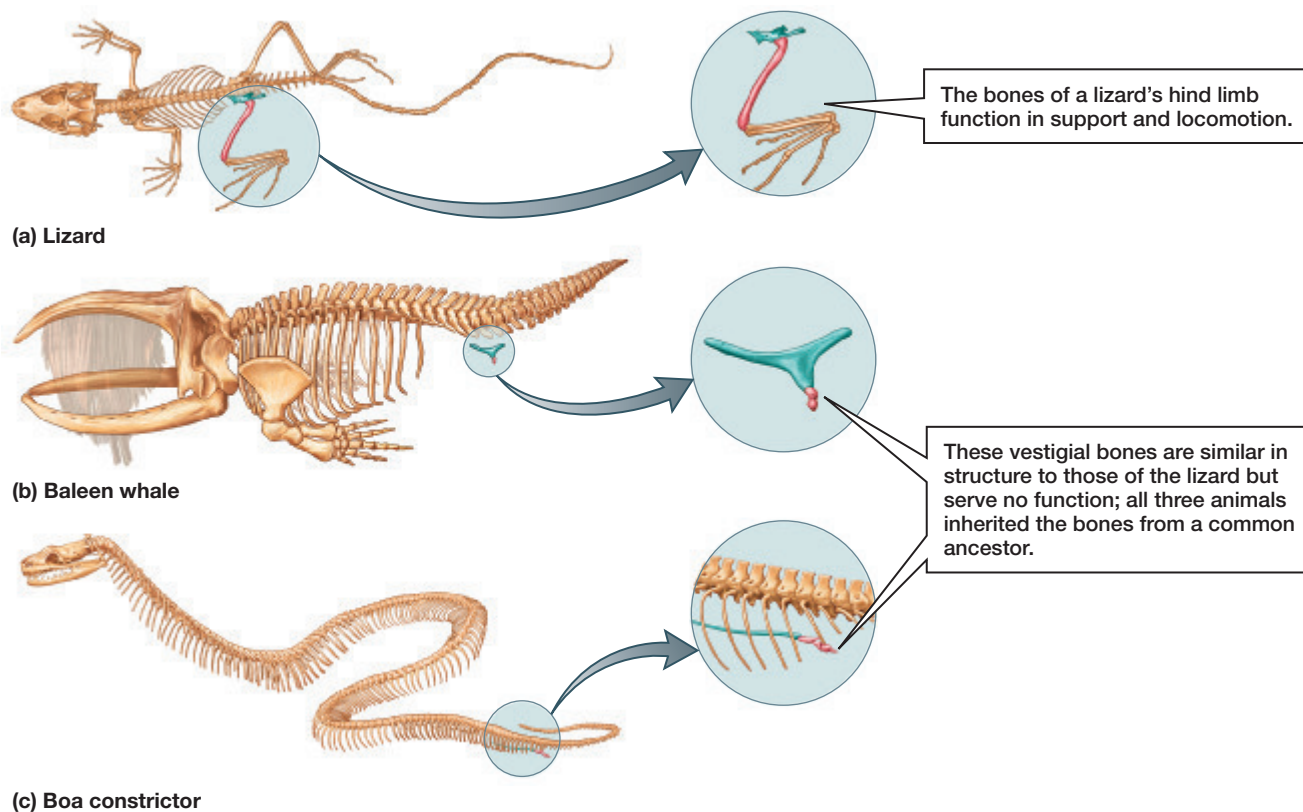
The study of comparative anatomy has demonstrated the shared ancestry of life by identifying a host of homologous structures that different species have inherited from common ancestors, but comparative anatomists have also identified many anatomical similarities that do not stem from common ancestry. Instead, these similarities arose through **convergent evolution**, in which natural selection

CASE STUDY CONTINUED

What Good Are Wisdom Teeth and Ostrich Wings?

Ostrich wings are vestigial because they are too rudimentary to perform the function for which they evolved in the species' flying ancestor. Nonetheless, the ostrich uses its wings for other purposes. For example, an ostrich may extend its wings to the side while running, to help maintain balance, and it may spread its wings as part of a threat display. These uses show that evolution by natural selection can sometimes repurpose vestigial structures that have lost the function for which they originally evolved. But whether a vestigial structure remains useless or acquires a new function, it is homologous to the version that retains its original function in other organisms and provides evidence of common ancestry. But are all similarities between different organisms the result of shared ancestry?

causes non-homologous structures that serve similar functions to resemble one another. For example, both birds and insects have wings, but this similarity did not arise from evolutionary modification of a structure that both birds and insects inherited from a common ancestor. Instead, the similarity arose from parallel modification of two different, non-homologous structures. Because natural selection



▲ **FIGURE 15-9 Vestigial structures** Many organisms have vestigial structures that serve no apparent function. The (a) lizard, (b) baleen whale, and (c) boa constrictor all inherited hind limb bones from a common ancestor. These bones remain functional in the lizard but are vestigial in the whale and snake.



(a) Damselfly



(b) Swallow

▲ **FIGURE 15-10 Analogous structures** Convergent evolution can produce outwardly similar structures that differ anatomically, such as the wings of (a) insects and (b) birds.

THINK CRITICALLY Are a peacock's tail and a dog's tail homologous structures or analogous structures?

avored flight in both birds and insects, the two groups evolved wings of roughly similar appearance, but the similarity is superficial. Such outwardly similar but non-homologous structures are called **analogous structures** (FIG. 15-10). Analogous structures are typically very different in internal anatomy, because the parts are not derived from common ancestral structures.

Embryological Similarity Suggests Common Ancestry

Evidence of common ancestry is apparent in the striking similarity of embryos of different species (FIG. 15-11). For

example, in their early embryonic stages, fish, turtles, chickens, mice, and humans all develop tails and gill slits (also called gill grooves).

Why are vertebrates that are so different as adults so similar at an early stage of development? The only plausible explanation is that all of these species descended from an ancestral vertebrate that possessed genes that directed the development of gills and tails. All of the descendants still have those genes. In fish, these genes are active throughout development, resulting in adults with fully developed tails and gills. In humans and chickens, these genes are active only during early developmental stages; the structures are lost or become inconspicuous before adulthood.



(a) Lemur



(b) Pig



(c) Human

▲ **FIGURE 15-11 Embryological stages reveal evolutionary relationships** Early embryonic stages of a (a) lemur, (b) pig, and (c) human, showing strikingly similar anatomical features.

HAVE YOU EVER WONDERED...

many people, the condition is chronic. This state of affairs is an unfortunately painful consequence of the evolutionary process. We walk upright on two legs, but our distant ancestors walked on all fours. Thus, natural selection formed our vertically oriented spine by remodeling one whose normal orientation was parallel to the ground. Our spinal anatomy evolved some modifications in response to its new posture, but as is often the case with evolution, the changes involved some trade-offs. The arrangements of bone and muscle that permit our smooth, bipedal gait also generate vertical compression of the spine, and the resulting pressure can, and frequently does, cause painful damage to muscle and nerve tissues.

Between 70% and 85% of people will experience lower back pain at some point in life, and for

Why Backaches Are So Common?

Modern Biochemical and Genetic Analyses Reveal Relatedness Among Diverse Organisms

Biologists have been aware of anatomical and embryological similarities among organisms for centuries, but it took the emergence of modern technology to reveal similarities at the molecular level. Biochemical similarities among organisms provide perhaps the most striking evidence of their evolutionary relatedness. Just as relatedness is revealed by homologous anatomical structures, it is also revealed by homologous molecules.

Today's scientists have access to a powerful tool for revealing molecular homologies: DNA sequencing. It is now possible to quickly determine the sequence of nucleotides in a DNA molecule and to compare the DNA of different organisms. For example, consider the gene that encodes the protein cytochrome *c* (see Chapters 12 and 13 for information on DNA and how it encodes proteins). Cytochrome *c* is present in all plants and animals (and many single-celled organisms) and performs the same function in all of them. The sequence of nucleotides in the gene for cytochrome *c* is similar in these diverse species (**FIG. 15-12**). The widespread presence of the same complex protein, encoded by the same gene and performing the same function, is evidence that the common ancestor of plants and animals had cytochrome *c* in its cells. At the same time, though, the sequence of the cytochrome *c* gene differs slightly in different species, showing that variations arose during the independent evolution of Earth's multitude of plant and animal species.

Some biochemical similarities are so fundamental that they extend to all living cells. For example:

- All cells have DNA as the carrier of genetic information.
- All cells use RNA, ribosomes, and approximately the same genetic code to translate that genetic information into proteins.
- All cells use roughly the same set of 20 amino acids to build proteins.
- All cells use ATP as a cellular energy carrier.

The most plausible explanation for such widespread sharing of complex and specific biochemical traits is that the



FIGURE 15-12 Molecular similarity shows evolutionary relationships The DNA sequences of the genes that code for cytochrome *c* in a human and a mouse. Of the 315 nucleotides in the gene, only 30 (shaded blue) differ between the two species.