8.1

Lines of Evidence for Evolution

Geological evidence indicates that Earth is billions of years old.

CAN YOU EXPLAIN IT?

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

a Modern chicken

b *Archaeopteryx* fossil

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

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

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

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

Molecular and Genetic Evidence

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

Hands-On Activity

Piecing Together Evidence

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

MATERIALS
- picture cut into strips

PROCEDURE

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

ANALYZE

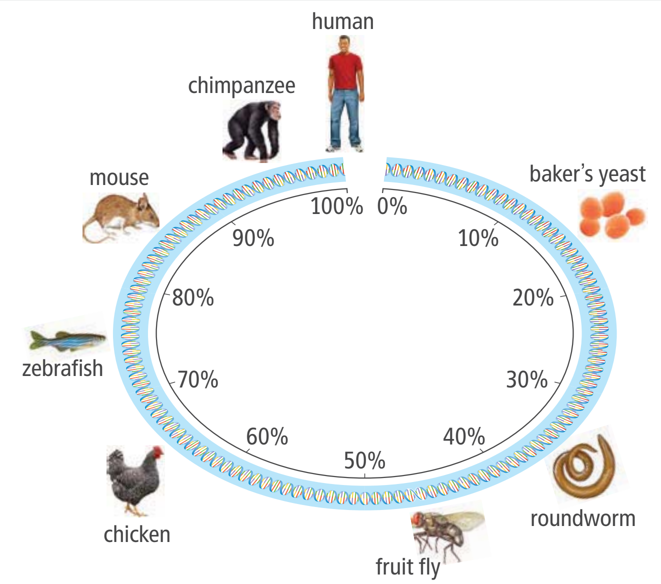
1. What type of evidence might evolutionary biologists find that would let them see the big picture of a species' evolutionary past?

Molecular Similarities

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

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

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



Explore Online

Hands-On Activity

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

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

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

Engineering

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

Using Model Organisms to Study Human Diseases

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

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

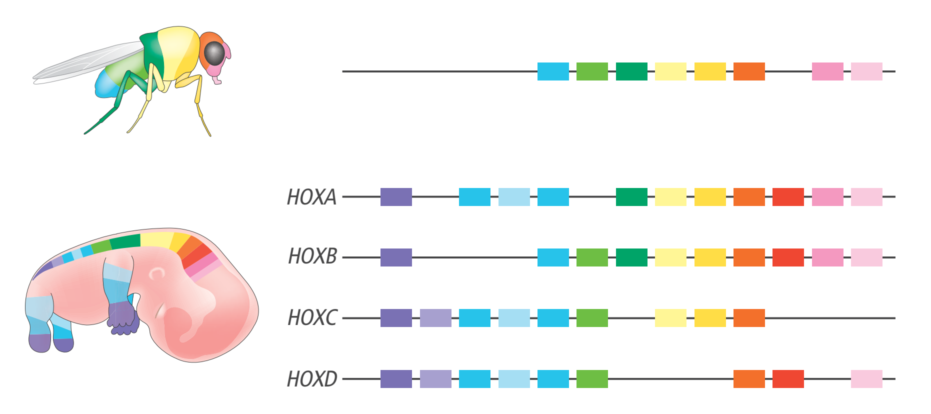
In addition to sharing much of our genetic material, zebrafish also have eyes that are similar to the human eye in many ways. Several zebrafish mutants have been identified that display eye defects and visual impairment. These mutants have helped scientists better understand how different genes are involved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

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

Homeobox Genes and Body Plan Expression

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

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



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

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

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

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

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

Developmental and Anatomical Evidence

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

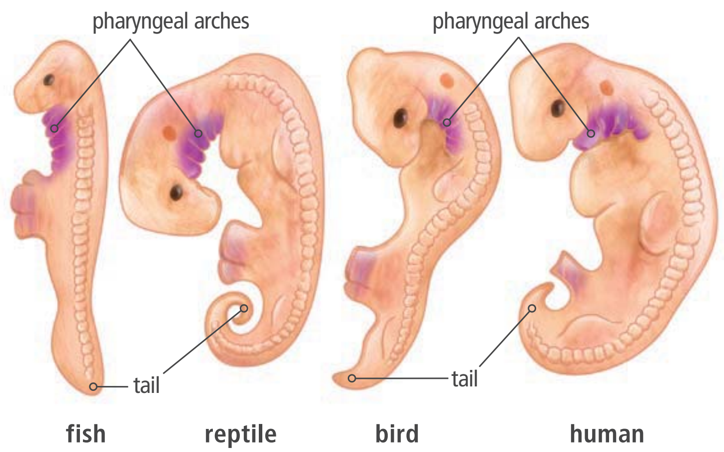
Developmental Similarities

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

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

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

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



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

Anatomical Evidence

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

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

a Human hands b Bat wings c Dog feet

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

Analogous Structures

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

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

a Parrot wings b Dragonfly wings

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

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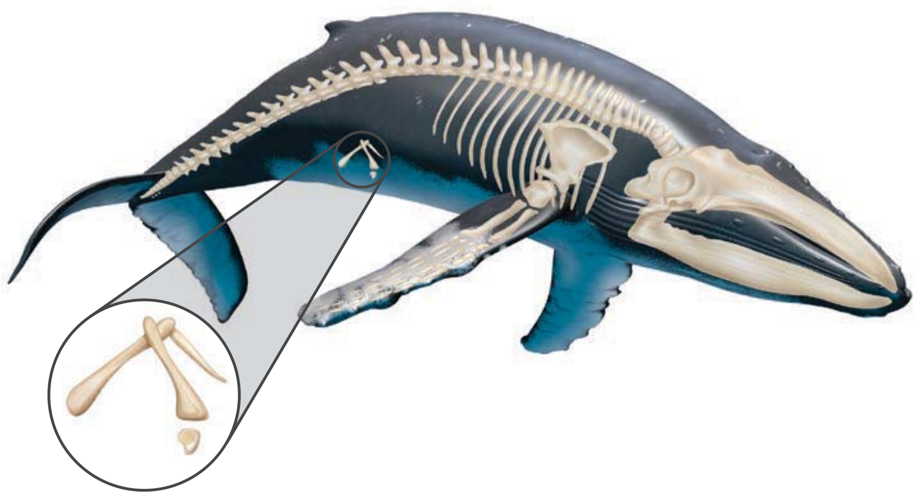
Vestigial Structures

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

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



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

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

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

Geological and Fossil Evidence

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

Geological Evidence

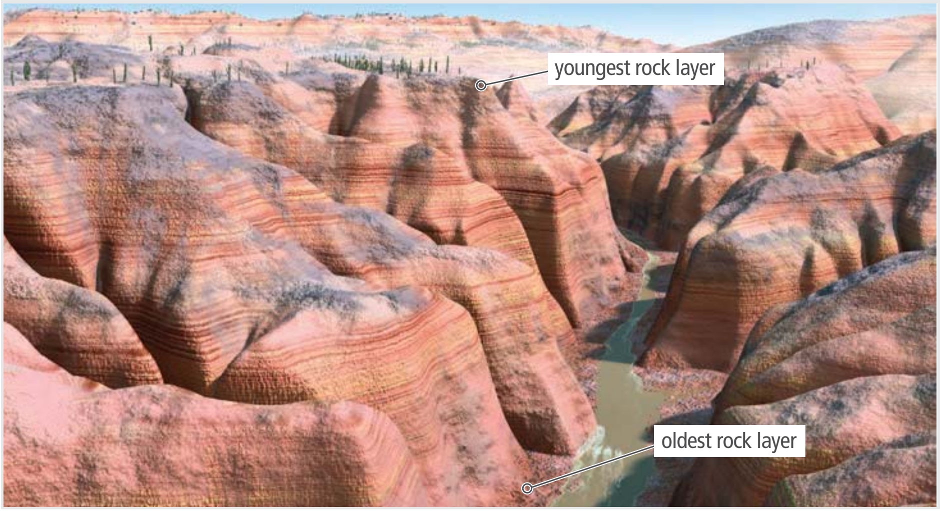
The age of Earth was a key issue in the early debates over evolution in the early 19th century. The common view was that Earth was created about 6,000 years earlier, and that since that time, neither Earth nor the species that lived on it had changed.

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

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

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

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



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

Cause and Effect

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

Fossil Evidence

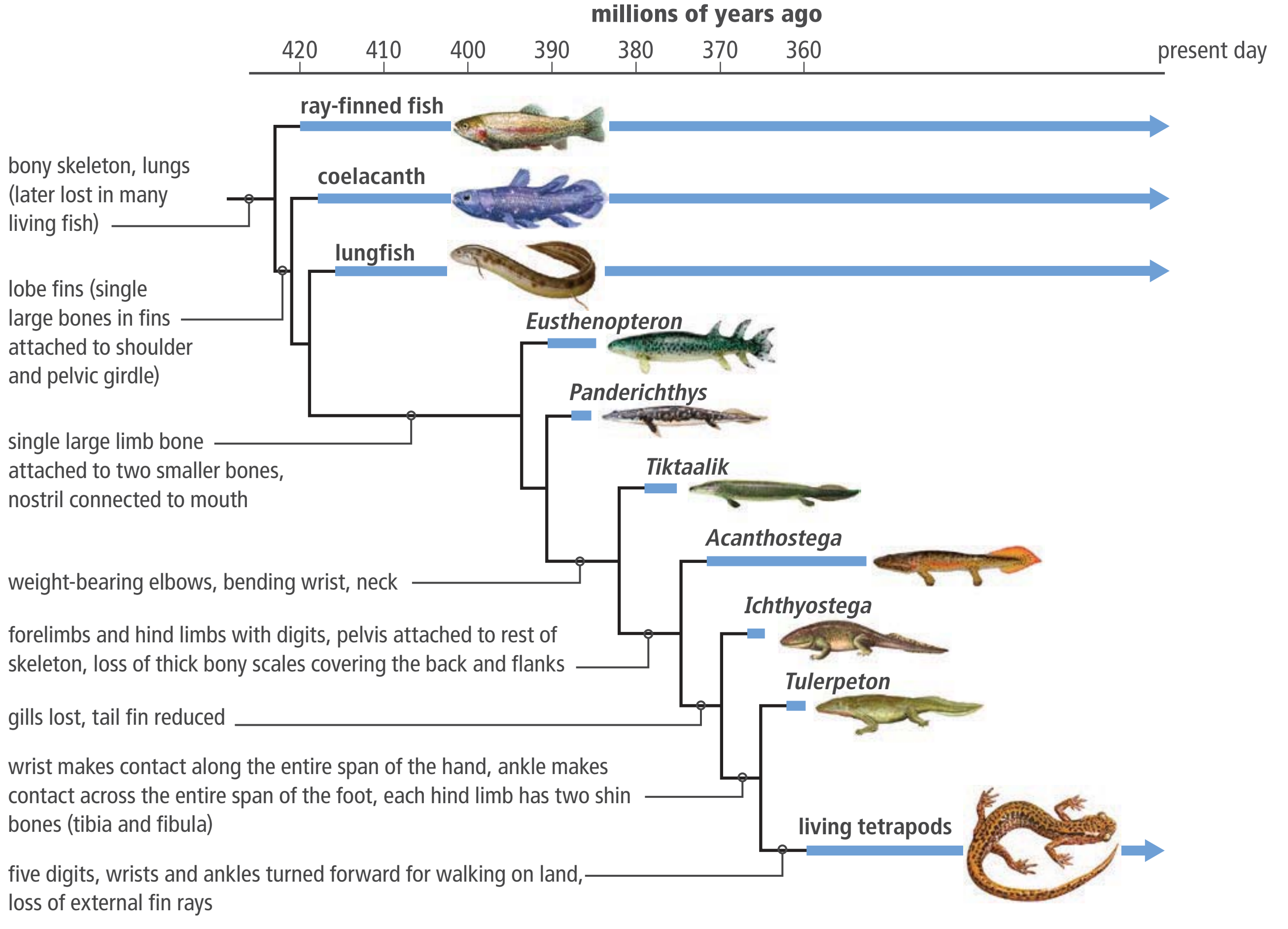
A fossil is the preserved remains of an organism, or the trace evidence of an organism's existence in the past. Most fossils form in sedimentary rock, which is made by many layers of sediment, or small rock particles. The best environments for any type of fossilization include wetlands, bogs, and areas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

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

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

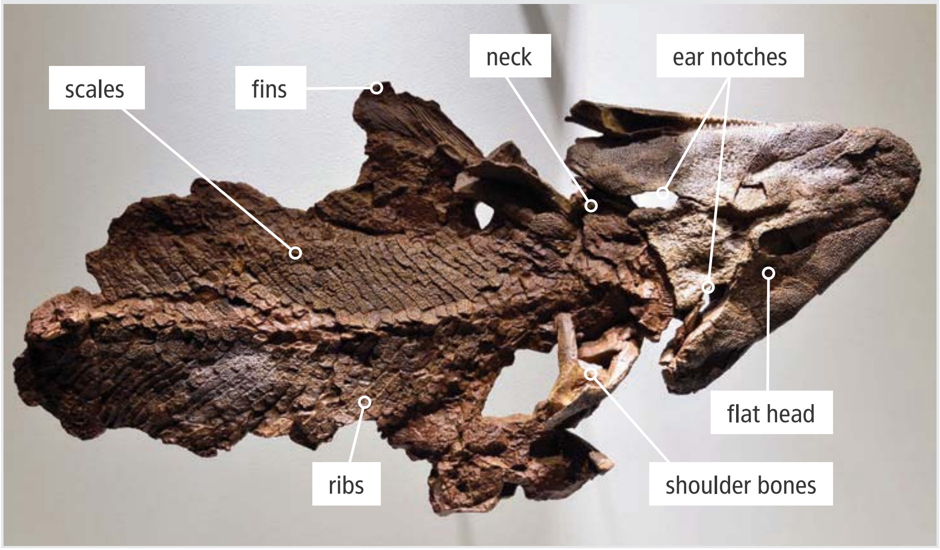
Scientists have been able to fill in some of these gaps by finding fossils of transitional species. These "missing links" demonstrate the evolution of traits within groups as well as the common ancestors between groups. For example, *Tiktaalik roseae* is a transitional species between fish and tetrapods.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

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



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

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



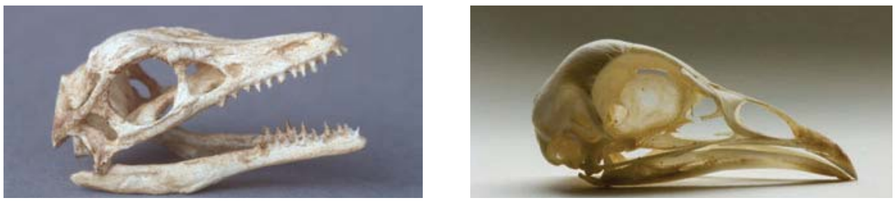
Analyze How do the presence of gills and lungs, as well as a bone structure that is homologous to that of tetrapods, support the idea that *Tiktaalik* fills in the gap between aquatic and land-dwelling species?

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

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

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

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



a *Archaeopteryx* skull replica

b Chicken skull

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

Image Credits: (t) ©Corbin17/Alamy; (bl) ©Natural Visions/Heather Angel/Alamy; (br) ©danilo ducak/Shutterstock

Data Analysis

Radiometric Dating

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

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

FIGURE 13: Isotopes Used in Radiometric Dating

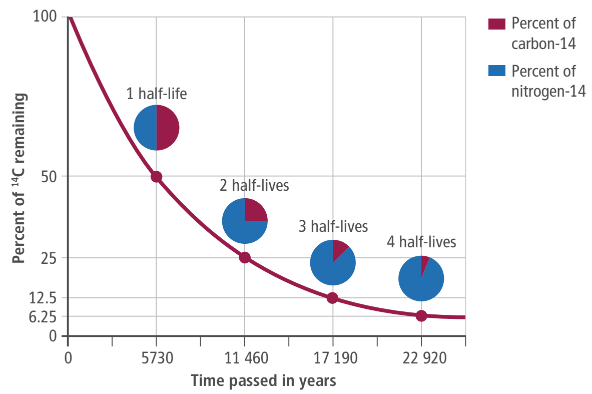
Isotope (parent)	Product (daughter)	Half-life (years)
rubidium-87	strontium-87	48.8 billion
uranium-238	lead-206	4.5 billion
potassium-40	argon-40	1.3 billion
carbon-14	nitrogen-14	5730

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

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

Radiometric Dating

FIGURE 14: Carbon-14 Decay



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

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

Use the figures to answer the following questions.

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

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

Lesson Self-Check

CAN YOU EXPLAIN IT?

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

a Modern chicken

b *Archaeopteryx* fossil

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

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

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

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

CHECKPOINTS

Check Your Understanding

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

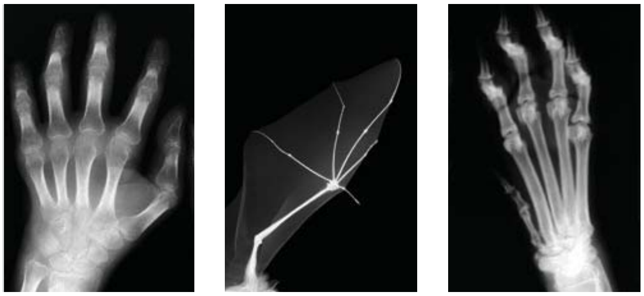
2. *Astyanax mexicanus* is a species of tetra fish that dwells in bodies of water deep inside caves. Even though they cannot see, these fish still have small, nonworking eyes. Their eyes are examples of which type of structures?
   a. embryonic
   b. vestigial
   c. homologous
   d. analogous

3. The idea that present geologic processes are the key to the past is a tenet of which geologic theory?
   a. gradualism
   b. catastrophism
   c. uniformitarianism
   d. metamorphism

4. As embryos, all vertebrates have which of the following structures? Select all correct answers.
   a. pharyngeal arches
   b. limb buds
   c. tail
   d. lungs

5. The similarity in homologous structures between different species is evidence that they
   a. share a common ancestor.
   b. are members of the same genus.
   c. use the similar structures in the same way.
   d. evolved from each other.

FIGURE 16: Anatomical Structures



6. Which of the following statements correctly describes the evidence shown by the structures in Figure 16?
   a. The bat and the dog share analogous bone structures in their forelimbs.
   b. Only the human and the bat share homologous bone structures in their forelimbs.
   c. The human and the bat share analogous bone structures in their forelimbs.
   d. All three species share homologous structures in their forelimbs.

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

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

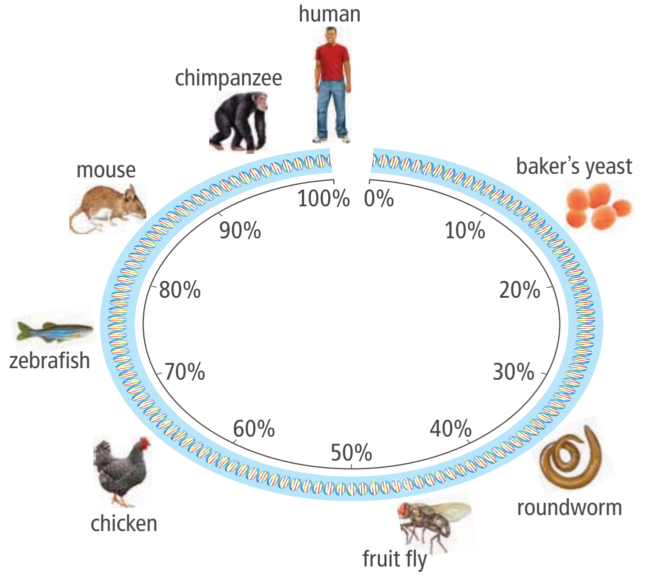
9. How can the location of a fossil reveal its age? Explain your answer.

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

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

MAKE YOUR OWN STUDY GUIDE

FIGURE 17: Shared DNA



Use Figure 17 to answer Questions 12 and 13.

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

a. zebrafish

b. fruit fly

c. roundworm

d. chimpanzee

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

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

Multiple lines of evidence support common ancestry and evolution.

Remember to include the following information in your study guide:

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

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