

Imagine walking down a dusty trail along a riverbank. It is a hot summer day; insects circle and buzz lazily in the shade of overhanging trees. Here and there, the trail skirts high bluffs of gray and brown rock. The rock is laid down in layers—different colors, different thicknesses, and different textures. In places, the river has undercut the bank, and sheets of rock have peeled away and tumbled downhill. You round a bend and see a large slab up-ended beside the trail. There is a crack running all the way through the slab, so it is easy to pull the layers apart. You have to jump back as the surface layer falls away and shatters at your feet. The newly exposed surface is solid with the impressions of hundreds of fossil seashells. It is like finding a buried treasure. Nobody has ever seen these fossils before; they have been hidden for millions of years. Where did the shells come from? How did they get here? How old are they? What can they tell us about the history of life? These are some of the questions explored in this chapter.

Organizing Your Knowledge

Exercise 1 (Module 15.1)

Web/CD Activity 15A *The Geologic Time Scale*

Review the geological timeline by numbering each of the following events in order and naming the geological era when each occurred.

<i>Order</i>	<i>Era</i>	<i>Event</i>
_____	_____	A. Cone-bearing plants and dinosaurs dominant
_____	_____	B. Humans appear
_____	_____	C. Origin of animals
_____	_____	D. First vertebrates
_____	_____	E. Increase in mammals, birds, insects, and flowers
_____	_____	F. Extinction of dinosaurs
_____	_____	G. Invasion of land by plants and arthropods
_____	_____	H. First insects, amphibians, and reptiles
_____	_____	I. Origin of life (prokaryotes)
_____	_____	J. Permian mass extinction of marine and terrestrial life

Exercise 2 (Module 15.2)

Use the concept of half-life to answer these questions about the ages of fossils.

1. The half-life of carbon-14 is 5730 years. If a mammoth has $\frac{1}{8}$ the ^{14}C -to- ^{12}C ratio that it was thought to have when it was frozen in a Siberian glacier, how old is the mammoth? At an error level of plus or minus 10%, what are the maximum and minimum ages of the fossil?
2. The half-life of potassium-40 is 1.3 billion years. If a rock specimen contained 1 g of potassium-40 when it was formed, how much potassium-40 would be left if the rock is 2.6 billion years old?

Exercise 3 (Modules 15.3 – 15.4)

Review the concepts of plate tectonics and continental drift by matching each of the phrases on the right with a word on the left. The illustrations in the textbook will help.

- | | | |
|----------------------|-------|--|
| A. Pangaea | _____ | 1. The surface of the Earth, broken into plates |
| B. Plate tectonics | _____ | 2. This ocean is surrounded by violent geological events |
| C. Plate | _____ | 3. Southern land mass formed when Pangaea broke up |
| D. Earthquake | _____ | 4. Place where plates slide along one another |
| E. Himalayas | _____ | 5. This ocean grows as North America and Eurasia split apart |
| F. Continental drift | _____ | 6. Island destroyed by volcanic eruption, then recolonized |
| G. Gondwana | _____ | 7. Supercontinent formed 250 million years ago |
| H. Mantle | _____ | 8. Continent formed from the eastern part of Laurasia |
| I. Australia | _____ | 9. Any large, moving segment of the Earth's crust |
| J. Pacific | _____ | 10. Movement resulting from forces exerted at plate edges |
| K. Laurasia | _____ | 11. Mountains formed by collision of Indo-Australian and Eurasian plates |
| L. Crust | _____ | 12. Movement of continents over the Earth's surface |
| M. Fault | _____ | 13. Hot layer that lies beneath the crust |
| N. Atlantic | _____ | 14. Northern land mass formed when Pangaea broke up |
| O. Krakatau | _____ | 15. Many marsupials evolved here, in isolation from other continents |
| P. Eurasia | _____ | 16. Geological forces that cause movements of crustal plates |

Exercise 4 (Modules 15.5 – 15.8)

Web/CD Activity 15B *Overview of Macroevolution*

Web/CD Activity 15C *Paedomorphosis: Morphing Chimps and Humans*

The following story illustrates some of the concepts and terms concerning mass extinctions and their aftermath. Fill in the blanks using words from Modules 15.5–15.8.

The disappearance of the dinosaurs at the end of the ¹ _____ period, ² _____ million years ago, is one of the great mysteries of evolution. The dinosaurs ruled the Earth for ³ _____ million years; then, in just a few million years, they vanished.

There have been several mass extinctions in the history of life; in fact, there have been ⁴ _____ major periods of mass extinction in the last 600 million years.

At the end of the Permian period, about 250 million years ago, continental drift brought all the continents together, forming the supercontinent of ⁵ _____. This may have altered climate and shorelines. More than ⁶ _____% of marine animal species perished, and many land-dwellers disappeared as well. The climate was cooling late in the Cretaceous period, and shallow seas were disappearing. Perhaps the dinosaurs were simply victims of ongoing climate change can be used by ⁷ _____.

Many other hypotheses have been suggested to explain the Cretaceous extinction. All of the sediments laid down at this time contain deposits of ⁸ _____, an element rare on the Earth but common in ⁹ _____. It is possible that a ¹⁰ _____ or ¹¹ _____ struck the Earth, raising a cloud of dust that could have blocked the sun and disrupted the climate. This could have also interfered with plant growth, creating a shortage of food. Alternatively, evidence from India suggests that ¹² _____ might have injected particles into the atmosphere that could have blocked the sun and played havoc with the climate and food supply.

Mammals first appeared on the scene 75 million years before the demise of the dinosaurs. The first mammals were small, scurrying creatures that played a secondary role to the great reptiles. But unlike the dinosaurs (and numerous kinds of marine life), mammals survived the Cretaceous extinction. Why did mammals survive, while the mighty dinosaurs did not? Perhaps it was due to the fact that mammals are covered with insulating ¹³ _____, or perhaps it was due to the way they take care of their young and feed them ¹⁴ _____. Mammals are also able to generate their own body heat, which may not have been the case for the dinosaurs. In addition, the early mammals were probably nocturnal scavengers, so they would have been well suited for finding a meal in the dark, cold aftermath of a catastrophe. Body heat, insulation, and nocturnal habits are all examples of ¹⁵ _____, characteristics that evolve in one context and later are found to be useful for another function.

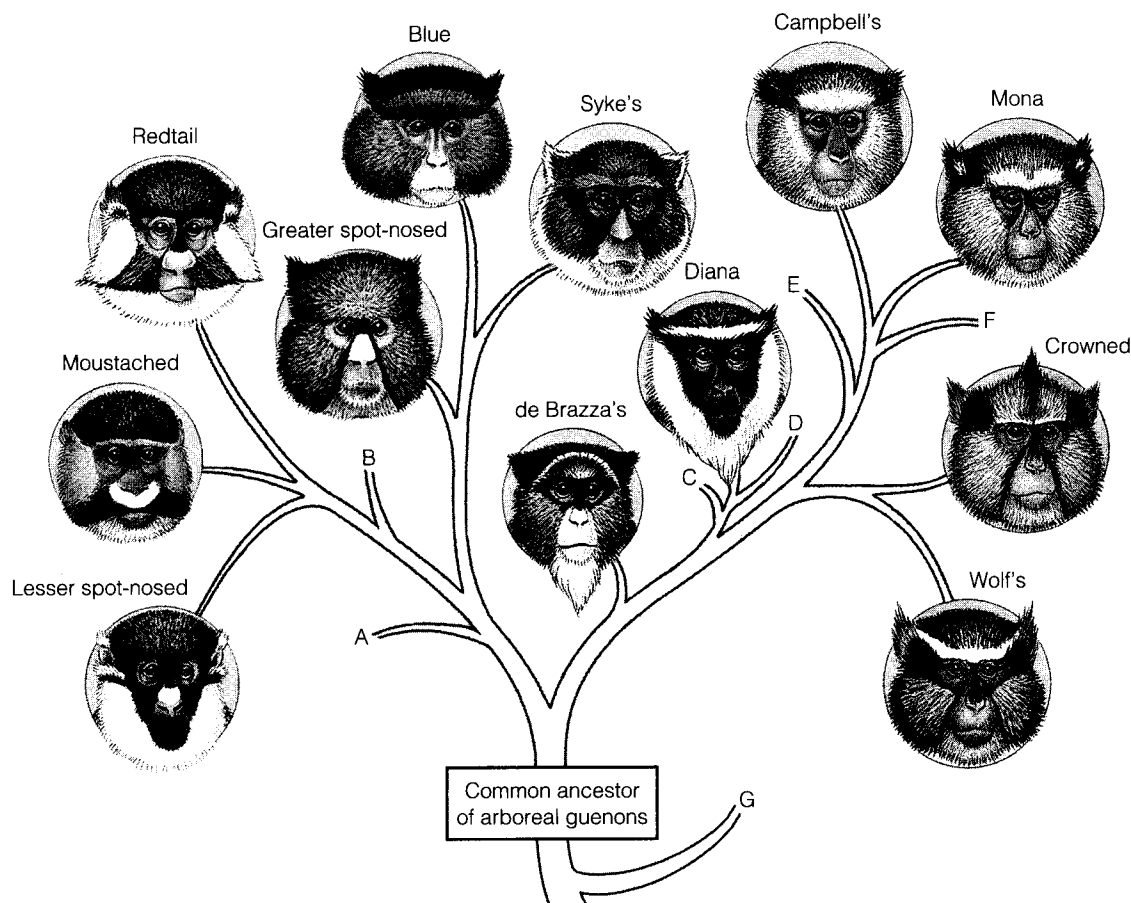
An explosive increase in mammals followed the Cretaceous extinction. Freed from domination by the dinosaurs, the mammals inherited a whole world, and they adapted to every possible environment. Long-legged herbivores ran through woodlands and meadows, pursued by carnivores with powerful jaws and sharp teeth. Early horses were dog-sized forest browsers with four toes on each foot. Their ancestors gave rise to many descendant species. Apparently, the larger species with fewer toes lasted ¹⁶ _____ and gave rise to more descendant species. Over time, this trend produced modern horses—larger grazers with only one toe on each foot. Thus, a trend such as increase in size may result from unequal ¹⁷ _____, or unequal survival of ¹⁸ _____, where the environment favors certain forms. Some large mammals even returned to the sea, giving rise to modern whales and dolphins. Some mammals climbed trees, and some—the bats—even took to the air.

All of these mammalian adaptations started with changes in genes. Even a slight change can have drastic effects on development and body form if the genes that are altered are ones that program ¹⁹ _____, shaping an animal's form as it grows from a zygote into an ²⁰ _____. This may have happened in our primate ancestors. A subtle genetic change could have resulted in retention of the rounded skull and small face of a fetus throughout life. This retention of juvenile body features in an adult is termed ²¹ _____. Within the skull was room for a larger, more complex human brain. The main function of our long ²² _____ may be to program our large brains, so that we can ²³ _____ from adults how to live in our complex world.

Exercise 5 (Module 15.9)

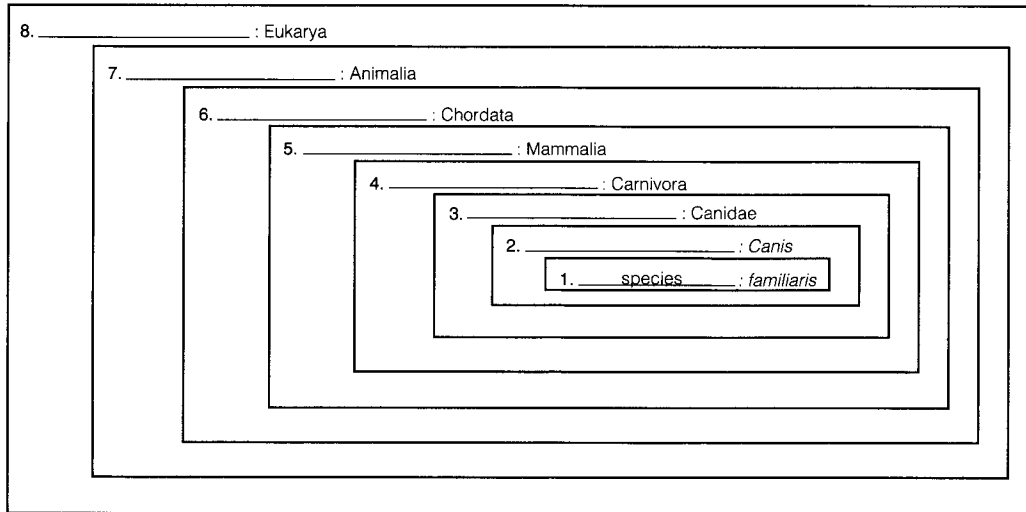
You are the first zoologist to penetrate the Timbasi Swamp and explore the Okongo Forest. Amazingly, you have identified seven species of guenon monkeys previously unknown to science. You have risked your neck to obtain blood samples from the elusive monkeys. Using similarities in blood proteins and facial markings, you have figured out the relationship of the new guenons with the known species of guenons shown on the chart. Test your understanding of phylogenetic trees by matching each of the new monkeys listed below with one of the letters inserted into the revised phylogenetic tree.

- ___ 1. Ann's: More closely related to Diana than any other species
- ___ 2. Flat-topped: As close to Mona as Mona is to Campbell's
- ___ 3. Gladstone's: Closer to redtail and moustached than any other new species
- ___ 4. Bearded: Related to Diana but not as closely as Ann's
- ___ 5. Liebaert's: A ground-dweller not closely related to any of the others
- ___ 6. Perkins's: Related to Mona and Campbell's, but it branched off earlier
- ___ 7. Striped: Equally related to blue and redtail, but closer to ancestor



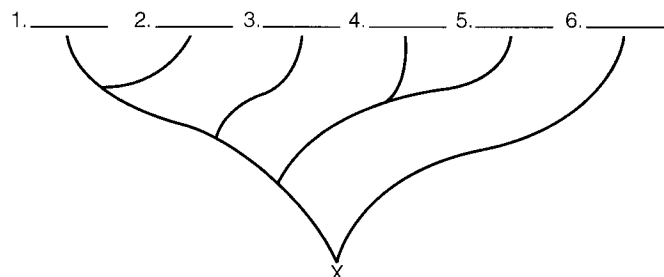
Exercise 6 (Module 15.10)

The system of taxonomic categories used by biologists is like a set of boxes into which organisms are sorted. A cocker spaniel—*Canis familiaris*—for example, is first placed in a small box, the specific name *familiaris* that separates it from all other species. This is placed in a slightly larger box, the genus *Canis*, which also holds *Canis lupus* (the wolf) and *Canis latrans* (the coyote). This genus box is placed in a larger box, along with other genera of doglike animals, and so on, all the way up to the last box that separates eukaryotes from prokaryotes. Imagine that the nested boxes below represent the taxonomic categories, starting with species (omitting subphylum). Label the boxes to show the relationships among the categories.

**Exercise 7 (Modules 15.11 – 15.12)**

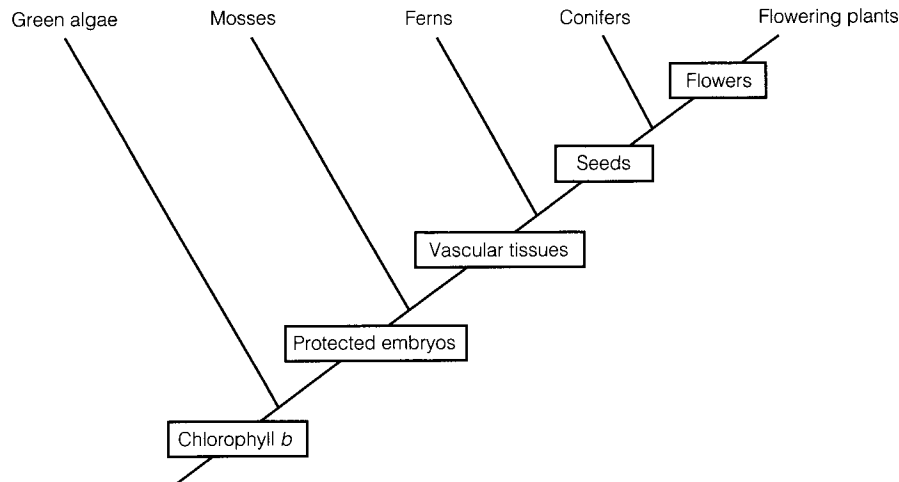
Homologous structures—similar structures derived from the same structure in a common ancestor—tell us about phylogenetic relationships among organisms. But convergent evolution can make unrelated organisms look alike; their similarities may be analogous, not homologous. Fortunately, we can dig beneath surface similarities and compare biological molecules to measure relatedness between species. DNA-DNA hybridization measures similarity indirectly, by determining how well DNA strands from different organisms bond to each other. Amino acid sequencing and DNA and rRNA sequence analysis take molecules apart and count the similarities. Imagine that albumin, a blood protein, has been sequenced for six species of rodents, A through F. All the rodents are thought to have evolved from a common ancestor, X. The number of differences in albumin amino acid sequence is compiled in the table below, which reads like a road map mileage chart. For example, there are 4 differences between A and C, and 9 differences between A and D. Use the differences in sequence to place Species A through F on the phylogenetic tree.

A						
B	10					
C	4	11				
D	9	5	10			
E	14	16	15	15		
F	10	2	10	6	16	
A	B	C	D	E	F	



Exercise 8 (Module 15.13)

Cladistic analysis seeks to clarify evolutionary and taxonomic relationships by finding clades, groups of organisms made up of an ancestor and all its descendants. This simplified phylogenetic tree uses cladistic analysis (based on anatomy, but backed up by molecular data) to reconstruct the relationships among four groups of plants and their closest relatives, the green algae. Read Module 15.13, examine the trees in the module and below, and then answer the following questions. This exercise is rather difficult, so take your time.



1. Which four groups of organisms above make up the ingroup?
2. Which organisms constitute the outgroup?
3. Are analogous or homologous features used in cladistic analysis?
4. Which characters are unique to a lineage of organisms, shared derived characters or shared primitive characters? Which are more useful in differentiating among (separating out) distinct lineages?
5. What is a shared primitive character common to all plants?
6. What is a shared derived character common to all plants?
7. What is a shared primitive character common to all plants with seeds?
8. What is a shared derived character common to all plants with seeds?
9. Which characters are most useful in deciding whether an organism is in the outgroup or the ingroup, shared primitive characters or shared derived characters?
10. If we are interested in focusing on all plants that have vascular tissues, which groups on the phylogenetic tree constitute the outgroup? The ingroup?
11. What is the name of a taxonomic group consisting of an ancestor and all its descendants?
12. What other organisms are in the clade that includes the first plants with seeds?
13. Name or describe nine different clades shown on the phylogenetic tree above.

Exercise 9 (Module 15.14)Web/CD Activity 15D *Classification Schemes*

Since the 1960s, biologists have classified living things into five kingdoms. Recently, a three-domain classification system has gained favor among biologists. Compare these classification schemes by checking the statements that apply to a five-kingdom system, a three-domain system, or both.

	5-kingdom system	3-domain system
1. Four major groups of eukaryotes and one major group of prokaryotes	_____	_____
2. Two major groups of prokaryotes and one major group of eukaryotes	_____	_____
3. Two fundamentally different groups of organisms	_____	_____
4. Three fundamentally different groups of organisms	_____	_____
5. Classification based primarily on structure and nutrition	_____	_____
6. Classification based more on molecular studies	_____	_____
7. Implies that prokaryotes are more closely related to each other than to eukaryotes	_____	_____
8. Implies that one group of prokaryotes is closer to eukaryotes than to other prokaryotes	_____	_____
9. An attempt to classify life in a useful way that reflects evolution	_____	_____
10. Not a fact of nature, but a human construction	_____	_____

Testing Your Knowledge

Multiple Choice

- Which of the following matches an event in the history of life with the correct geological era?
 - first mammals—Precambrian
 - appearance of humans—Mesozoic
 - dominance of dinosaurs—Cenozoic
 - movement of plants and animals onto land—Paleozoic
 - first flowering plants—Precambrian
- Changes in genes that act in development might be very important in evolution because
 - they are not affected by natural selection.
 - they might cause major changes in subsequent body form.
 - they speed up the rate of convergent evolution.
 - they provide insurance against future mass extinctions.
 - they are more readily passed on to offspring.
- If you want to see a dinosaur, it would be best to set the controls of your time machine for the
 - Mesozoic era.
 - Paleozoic era.
 - Pleistocene period.
 - Paleozoic era.
 - Precambrian era.
- Which of the following taxonomic categories contains all the others?
 - genus
 - class
 - family
 - subclass
 - order
- Until recently, most biologists classified living things into five kingdoms. A newer scheme recognizes three basic groups, called "domains":
 - bacteria, plants, and animals
 - prokaryotes, eukaryotes, and plants
 - plants, animals, and fungi
 - eukaryotes and two kinds of prokaryotes
 - bacteria, protists, and eukaryotes
- Organisms that survive mass extinctions
 - often diversify, taking advantage of new opportunities.
 - usually are so reduced in numbers that they soon go extinct.
 - are often "living fossils" that have existed unchanged for long periods.
 - usually cannot cope with the new conditions that follow.
 - usually lack exaptations for their new environment.
- Pangaea
 - was a land mass that broke up to form the present-day continents.
 - is the idea that all life on Earth is related.
 - was an animal common in ancient seas but now extinct.
 - is the evolutionary history of a species, family, or phylum.
 - is the theory that crustal plates can move relative to one another.
- The theory of plate tectonics helps us to explain all of the following except
 - locations of volcanoes.
 - formation of river systems.
 - distribution of animals and plants.
 - formation of mountain ranges like the Himalayas.
 - earthquakes.
- What evidence most strongly suggests that an impact by an asteroid or meteorite may have caused the extinction of the dinosaurs?
 - Fossils show that dinosaurs suffered from cold and starvation.
 - Sedimentary rocks contain a layer of mineral uncommon on Earth.
 - There have been several near misses in recent years.
 - The dinosaurs disappeared rather abruptly—virtually overnight.
 - Fossils indicate that most dinosaurs were looking up when they died.
- The oldest fossils usually
 - contain more radioactive isotopes than younger fossils.
 - are found in the deepest strata.
 - have the longest half-lives.
 - are found above younger fossils.
 - are found in sediments from the Cenozoic era.

Essay

1. Explain how the formation of Pangaea may have led to mass extinctions at the end of the Permian period, about 250 million years ago.
2. Place the following events in the history of life in the proper order: appearance of humans, origin of eukaryotes, dominance of dinosaurs and cone-bearing plants, origin of animals, appearance of first vertebrates, diversification of mammals, origin of flowering plants, first prokaryotes, movement of plants and animals onto land.
3. Unlike hours, days, or weeks, geological eras and periods are not of uniform lengths. The Precambrian era, for example, lasted for billions of years, the Mesozoic era only for about 180 million. Explain why the units of the geologic time scale are uneven.
4. Describe two different ways in which plate tectonics and continental drift cause mountains to form.
5. The following list shows the classification of a human being, *Homo sapiens*. Name the category that corresponds to each of the taxa listed.

Eukarya	Primates
Animalia	Hominidae
Chordata	<i>Homo sapiens</i>
Vertebrata	
Mammalia	
2. The wings of birds and insects have the same function, but they do not have the same evolutionary origin. Bird and insect wings are
 - a. homologous.
 - b. phylogenetic.
 - c. analogous.
 - d. binomial.
 - e. taxonomic.
3. Two animals in the same family would not have to be in the same
 - a. genus.
 - b. domain.
 - c. order.
 - d. phylum.
 - e. class.
4. A phylogenetic tree of bird families would most clearly show which of the following?
 - a. characteristics shared by all bird families
 - b. evolutionary relationships among families
 - c. families that look most alike
 - d. analogous structures shared by various species
 - e. relative ages of living species of birds
5. Fossils of an ancient reptile called *Lystrosaurus* have been found in Africa, India, and Antarctica. Which of the following best explains this distribution?
 - a. They were able to move between continents before the oceans filled.
 - b. Movement of India due to continental drift carried them from place to place.
 - c. These areas were once next to each other and have since drifted apart.
 - d. They were able to migrate over frozen seas during the Ice Ages.
 - e. Changes in climate forced them to migrate from place to place.

Applying Your Knowledge

Multiple Choice

1. Which of the following would cast doubt on the asteroid-impact hypothesis for the extinction of the dinosaurs?
 - a. finding a crater 200 million years old
 - b. finding fossil dinosaur bones beneath a layer of iridium
 - c. determining that birds are closely related to dinosaurs
 - d. finding fossil dinosaur bones above a layer of iridium
 - e. finding that many forms of marine life disappeared at the same time as the dinosaurs
6. Look at the monkey phylogenetic tree in Exercise 5. The species in which of the following pairs are most closely related to each other?
 - a. Crowned and Mona
 - b. Blue and greater spot-nosed
 - c. Diana and Syke's
 - d. Diana and de Brazza's
 - e. Campbell's and Mona

7. Anthropologists suggest that the grasping hands and eye-hand coordination that early humans inherited from their tree-dwelling primate ancestors enabled humans to start making and using tools. This illustrates the concept of
 - a. phylogeny.
 - b. homology.
 - c. exaptation.
 - d. paedomorphosis.
 - e. convergent evolution.
8. Which of the following illustrates paedomorphosis?
 - a. Separate groups of mice in Africa and Asia come to look much alike.
 - b. Two families of trees are descended from a common ancestor.
 - c. Eyes of octopuses and fish evolved separately but look alike.
 - d. Many kinds of clams appeared after the Permian mass extinction.
 - e. A species of insect is able to reproduce while still in the immature stage.
9. A microbiologist recently discovered a new single-celled eukaryotic organism. It is green and swims, propelled by two flagella. This organism would probably be placed in Kingdom
 - a. Monera.
 - b. Plantae.
 - c. Archaea.
 - d. Protista.
 - e. Animalia.
10. In a detailed phylogenetic tree showing the evolutionary relationships within a class, the "trunk" of the tree might represent the _____, while the ends of individual "twigs" might represent _____.
 - a. phylum . . . classes
 - b. class . . . species
 - c. genus . . . species
 - d. species . . . families
 - e. class . . . phyla
2. Australia is famous for its many marsupials—mammals that are born at an early stage in development and then mature in the mother's pouch. Koalas, kangaroos, wombats, and opossums are all marsupials. Marsupials are considered offshoots of an earlier type of mammal than the more familiar placental mammals, whose young remain longer in the uterus, connected to the mother by the placenta. Marsupials are found elsewhere, but in most places most marsupials have been displaced by the more "efficient" placentals. Speculate about why the marsupials managed to hang on in Australia.
3. The dinosaurs perished in a mass extinction at the end of the Cretaceous period, 65 million years ago. Briefly describe alternative hypotheses that have been suggested to explain the extinction of the dinosaurs. Did other forms of life disappear during the same period? Does this cast doubt on any of the hypotheses? Why?
4. Biologists like to look at fossils to trace evolutionary relationships. But birds are very delicate and unlikely to be fossilized; only a handful of old bird fossils are known. How might the molecules in the cells of living birds be compared to determine how ducks, sparrows, and hawks are related? Briefly name the molecules, what characteristic of the molecules would be compared, and how this would indicate how closely related the birds are.
5. Molecular comparisons indicate that the vultures of Africa and America are more closely related to separate hawklike ancestors than they are to each other. If the two groups of vultures are not closely related, why do you think they look so much alike?

Essay

1. When a tree was buried in a swamp, it contained 400 mg of carbon-14. The half-life of carbon-14 is 5730 years. How long ago was the tree buried if it now contains 100 mg of carbon-14?

Extending Your Knowledge

1. Have you ever collected fossils? It is a very interesting and rewarding hobby. In fact, several well-known paleontologists got started as amateurs. Are there fossil deposits in your area? If you are interested in looking for fossils, you

can get information from state departments of geology or mining, geological surveys, departments of natural resources, bureaus of mines, university geology departments, or local rockhound clubs.

2. If you are interested in learning more about fossils and the history of life, many university museums have fossil collections. Some of the best dinosaur exhibits are located at the American Museum of Natural History in New York, the Smithsonian Institution in Washington, DC, the Royal Ontario Museum

in Toronto, the National Museum of Canada in Ottawa, the Royal Tyrell museum in Drumheller, Alberta, the Peabody Museum at Yale University, the Carnegie Museum in Pittsburgh, the Field Museum of Natural History in Chicago, the Denver Museum of Natural History, and the Los Angeles County Museum. Assembled dinosaur skeletons can be seen at Dinosaur National Monument in Utah, and Dinosaur Provincial Park in Alberta. You can see dinosaur tracks at Rocky Hill, Connecticut, and near Glen Rose, Texas.