CHAPTER 15

Tracing Evolutionary History

Objectives

Introduction Briefly describe the history of the dinosaurs and bird controversy.

Earth History and Macroevolution

15.1 Briefly describe the history of life on Earth, noting the major eras, when they occurred, and which types of life were most abundant.
15.2 Explain how radiometric dating is used to determine the age of rocks and fossils. Explain when carbon-14 and potassium-40 are most appropriately used.
15.3 Describe the process of continental drift and explain its significance to the history of life on Earth.
15.4 Describe the process and consequences of plate tectonics.
15.5 Describe the causes, frequency, and impact of mass extinctions.
15.6 Define an exaptation and describe examples in animals and plants.
15.7 Explain how genes that program development are important in the evolution of life. Also define and describe examples of the process of paedomorphosis.
15.8 Explain why evolutionary trends do not reflect directions or goals of evolution.
15.9 Explain the meaning of the relationships represented by a phylogenetic tree.

Systematics and Phylogenetic Biology

15.10 Explain the goals of systematics. List in order the progressively broader categories of classification used in systematics.
15.11 Compare and provide examples of homologous and analogous structures.
15.12 Explain how molecular biology is used in systematics. Explain how the results from molecular biology compare to the results from comparative anatomy.
15.12 Compare the results of systematic studies of amino acid sequences, mitochondrial DNA, and ribosomal DNA. Define a molecular clock.
15.13 Describe the goals of phylogenetic systematics. Define and compare the terms clades, monophyletic, derived characters, primitive characters, ingroup, outgroup, cladogram, and parsimony.

The Domains of Life

15.14 Compare the five-kingdom and three-domain systems of classification.

Key Terms

macroevolution	Pangaea	exaptation
geologic time scale	Laurasia	evo-devo
radiometric dating	Gondwana	paedomorphosis
continental drift	plate tectonics	phylogeny

phylogenetic tree
systematics
binomial
genus
species
family
order
class
phylum
kingdom
domain
taxon
convergent evolution
analogy
amino acid sequencing
molecular clock
cladistic analysis
clade
monophyletic
derived character
primitive character
ingroup
outgroup
cladogram
parsimony
five-kingdom system
three-domain system

Word Roots

clado- = branch (*cladogram:* a dichotomous phylogenetic tree that branches repeatedly)

mono- = one (*monophyletic:* pertaining to a taxon derived from a single ancestral species that gave rise to no species in any other taxa)

parsi- = few (*principle of parsimony:* the premise that a theory about nature should be the simplest explanation that is consistent with the facts)

phylo- = tribe; **-geny** = origin (*phylogeny:* the evolutionary history of a taxon)

Lecture Outline

Introduction *Are Birds Really Dinosaurs with Feathers?*

A. Evolutionary biologists can learn much about the history of life on Earth from fossil records. John Ostrum raised the controversial question about the origin of birds and the relationship with dinosaurs as their predecessor.

B. Through careful analysis of fossil records, Ostrum presented a convincing argument supporting the theory that birds are descendents of dinosaurs (*Archaeopteryx,* Figure 15.0A).

C. More evidence was presented in support of Ostrum's theory with the discovery of the fossil *Caudipteryx,* another dinosaur with wings (Figure 15.0B). However, some evolutionary biologists think that birds descended from a different group of reptiles.

D. Both sides of the debate are still gathering evidence in support of their particular theory. And the debate goes on.

I. Earth History and Macroevolution

Module 15.1 The fossil record chronicles macroevolution.

Review: The fossil record (Module 13.2).

A. **Macroevolution,** the main events in the evolutionary history of life on Earth, is determined by comparing the fossil records in strata representing various ages, from various parts of the Earth's surface.

B. The **geologic time scale** is a standardized, hierarchical system of age categories (Figure 15.1).

C. The oldest fossils are of microorganisms from ≈3.5 billion years ago during the early Precambrian era.
NOTE: It has recently been reported that the fossils of prokaryotes are artifacts, possibly crystals.

D. Late Precambrian fossils show that animal life had diversified by ≈610 million years ago (mya).

E. Early Paleozoic (≈570 mya) rocks bear fossils that gave rise to modern organisms, as well as fossils of extinct lineages.

F. By ≈400 mya, during the middle Paleozoic ("ancient animal") era, life had moved out of water and onto dry land.

G. The Mesozoic ("middle animal") era began ≈248 mya and is the age of dinosaurs and cone-bearing plants. During this era the first mammals, birds, and angiosperms appeared.

H. The Cenozoic ("recent animal") era began ≈65 mya and is the age of mammals and flowering plants.

I. *Homo sapiens* arose during the Pleistocene epoch (≈100,000–200,000 years ago).
Preview: Human evolution is discussed in Chapter 19.

Module 15.2 The actual ages of rocks and fossils mark geologic time.

A. The record of fossils in rock strata chronicles the relative ages of life.

B. The actual ages of fossils can be obtained by **radiometric dating.** Radioactive isotopes "decay" at a known rate relative to other isotopes. For instance, half of an amount of ^{14}C decays to ^{12}C in 5730 years. Measuring the relative amounts of the two isotopes in a sample (and comparing this ratio to the ratio known to have been in the original organism, that is, the ratio of ^{14}C to ^{12}C in the atmosphere) gives the actual age of the sample, with an error factor of about 10%. Elements with longer half-lives are used to date older fossils.

Module 15.3 Continental drift has played a major role in macroevolution.

A. In 1912, Wegener proposed **continental drift** as a mechanism that accounts for the similarities of coastal outlines of present-day continents. The proposal was not accepted because geologists knew of no method that would cause continents to move.

B. Continents are the above-water parts of crustal plates that "float" on the lower fluid mantle. New crust is formed along ocean ridges, and old crust is destroyed at the leading margins of the plates (Figure 15.3A).

C. About 250 mya, the present continents were united as a single supercontinent called **Pangaea.** This must have made weather patterns and climate much different than they are now (Figure 15.3B).

D. ≈180 mya (early Mesozoic), Pangaea began to break apart, first forming northern **(Laurasia)** and southern **(Gondwana)** landmasses. This process was completed ≈135 mya (Figure 15.3B).

E. ≈65 mya, the beginnings of the modern continents could be seen (Figure 15.3B).

F. Relative distributions of present-day life forms and their fossilized ancestors are explained by the known course of recent continental drift.

G. Continental drift is an ongoing process. For example, the ongoing collision in the Himalayan region is creating forces that are splitting the Indo-Australian plate, resulting in Australia moving independently of India.
NOTE: The example that your students will be most familiar with are the California earthquakes (Module 15.4).

Module 15.4 Connection: Tectonic trauma imperils local life.

A. The forces responsible for the movement of the Earth's crust are called **plate tectonics.**

B. Earthquakes are the result of the movement of crustal plates (Figure 15.4A).

C. Volcanic eruptions occur along plate margins or mid-ocean ridges and can build mountains or islands, such as the Galápagos (Figure 15.4B), and can pose a threat to local populations (Figure 15.4C).

Module 15.5 Mass extinctions were followed by diversification of life forms.

A. At the end of the Cretaceous period (≈65 mya), many lineages of terrestrial plants and animals, and about half the marine animals, became extinct.

B. Particularly noteworthy was the demise of the dinosaurs (within a span of less than '10 million years), which had dominated the land and air for ≈150 million years during the Mesozoic era (Figure 15.5).

C. Several, not necessarily mutually exclusive, explanations have been proposed to account for this change: an asteroid impact in what is now the Caribbean Sea; slow changes in climate due to continental drift; and massive volcanic activity in India during the late Cretaceous that contributed to cooling.

D. During the last 600 million years there have been six mass extinction events. During these events, the extinction rate was nearly six times the average rate.

E. Another major extinction occurred at the end of the Permian period, coinciding with the formation of Pangaea. At this time over 90% of all species of marine animals went extinct.
NOTE: The ends of the major eras (Paleozoic and Mesozoic) discussed in Module 15.3 correspond to the major extinction events. The dividing lines between the periods correspond to other major changes in fossil assemblages.

F. Mass extinction events are followed by huge increases in diversity as surviving organisms (apparently) exploit new environmental opportunities.

Module 15.6 Key adaptations may enable species to proliferate after mass extinctions.

A. Each of the six periods of mass extinction in the past 600 million years has been followed by an "explosion" in evolution of certain groups of organisms.

B. Chance can play a role; an organism just happens to "make it" in the right place. Key adaptations also play a role in allowing a species to survive a mass extinction event.

C. An **exaptation** is a feature that evolved in one context and was later adapted for another function. For example, the spread of bromeliads into aerial environments depended on the ancestral forms having developed catch-basins, formed from leaf bases, and water-absorbing trichomes on leaf margins (Figure 15.6). The opening essay offers another good example of exaptation. It is unlikely that feathers and light bones were developed initially for flight, but instead were adapted for flight once present.

Module 15.7 "Evo-Devo": Genes that control development play a major role in evolution.

A. The convergence of two scientific disciplines into one has led to some interesting concepts. Evolutionary biology and developmental biology have merged into **evo-devo,** which looks at how slight genetic changes can be magnified into significant phenotypic changes. Changes in the genes that control development can have profound effects on the end product (the adult).

B. **Paedomorphosis** is the retention of juvenile body features in the adult (Figure 15.7A).

C. Paedomorphosis has been important in the evolution of humans and chimpanzees from a common ancestor. The large, paedomorphic human skull and the long period of time as a nonreproductive child provide the human with more space for a larger brain and more time to learn from adults (Figure 15.7B).
Preview: Human evolution is discussed in detail in Chapter 19.

D. Evolutionary biologist Stephen Jay Gould contends that youthful characteristics in children elicit parental affection and care. He uses Mickey Mouse's early evolution as a cartoon character to illustrate this concept (Figure 15.7C).

Module 15.8 Evolutionary trends do not mean that evolution is directed toward a goal.

A. Evolutionary trends show gradual, one-directional changes in morphology over long periods of evolutionary time, such as the increase in brain complexity among human ancestors and the increase in size and modification of the limbs seen in the lineage that gave rise to modern horses (Figure 15.8).

B. Unequal survival of new species can explain this apparent trend.

C. Unequal speciation with equal survival of all new species can also explain the data. Current debate exists over the relative importance of each of these mechanisms.

D. Evolutionary trends are not preordained or unchangeable. Such trends can stop or reverse.

Module 15.9 Phylogenetic trees strive to represent evolutionary history.

A. **Phylogeny** is the evolutionary history of a group of organisms.

B. **Phylogenetic trees** represent the most likely phylogeny of a group. The phylogeny of Galápagos finches in Figure 15.9 is based on body structures, especially beak structure, and field studies of reproductive isolation and feeding behavior.

C. Each branch axis represents the evolution of subsequent groups based on some important feature.

D. Organisms on branches close to the base of the tree are more primitive (in the sense of having appeared earlier in time), showing more ancestral features than organisms on later branches.

II. Systematics and Phylogenetic Biology

Module 15.10 Systematists classify organisms by phylogeny.

A. Reconstructing phylogenies, assigning scientific names, and classifying the names are all aspects of the biological science of **systematics.**

B. Common names can be ambiguous because there are so many species and because different people use different names for the same species.

C. In addition to protein sequence analysis, molecular methods used in phylogenetic analysis include DNA-DNA hybridization, DNA sequence analysis, mtDNA, and ribosomal RNA (rRNA) sequence analysis.
Review: Many molecular techniques are discussed in Chapter 12.

D. Some segments of DNA mutate at a constant rate and can therefore be used as a **molecular clock,** tracking the changes in DNA sequence over time. Based on the molecular evidence gathered we are more closely related to the chimpanzee than to the gorilla (Figure 15.12B).

Module 15.13 Systematists attempt to make classification consistent with phylogeny.

A. **Cladistic analysis** is concerned only with the order of branching in phylogenetic lineages. Each branch on a cladogram represents the most recent ancestor common to all the taxa beyond that point. All the taxa above a branch share one or more homologous features. The end result of this analysis should be **clades** (groupings) consisting of monophyletic taxa (Figure 15.13A).

B. Homologous characters shared by a group of species and their common ancestor are called **primitive characters.** For example, the common ancestor of all vertebrates had five toes; therefore, the presence of five toes is a primitive character.

C. Homologous characters unique to each lineage are called **derived characters.**
NOTE: These shared derived characteristics are termed *synapomorphies.*

D. The comparison of an **ingroup** with an **outgroup** aids in the determination of whether a character is primitive or derived. The ingroup consists of the taxa being analyzed. The outgroup, while having a known relationship to the ingroup, is not a member of the ingroup. Characters shared by the ingroup and the outgroup are considered primitive characters; characters unique to the ingroup are considered derived characters.

E. Derived characters are used to identify the branch points of a **cladogram.** For example, hair and mammary glands are derived characters that distinguish the mammalian lineage.

F. Cladistics is particularly suited for analysis of the similarities and differences of molecular data, which may be done entirely objectively and parsimoniously. **Parsimony** seeks the simplest explanation of observed data.

G. Cladistic analysis has demonstrated that birds are a lineage of dinosaurs more closely related to crocodiles than are lizards and snakes (Figure 15.13B).

H. In contrast, classical evolutionary taxonomy also takes into account the apparent degree of divergence of taxa. Unlike cladistic analysis, classical analysis places the crocodiles with lizards and snakes and places birds in a separate taxon (Figure 15.13C). This is the more familiar classification of these groups that texts (including this one) continue to use.

III. The Domains of Life

Module 15.14 Arranging life into kingdoms is a work in progress.

A. Linnaeus used a two-kingdom system to categorize life at the most inclusive level of classification.
Review: The diversity of life can be arranged into three domains (Module 1.4).

B. In 1969, Whittaker proposed a **five-kingdom system** (Figure 15.14A): Monera (prokaryotes), Protista (unicellular eukaryotes), Plantae (multicellular eukaryotes, photosynthetic autotrophs with cell walls), Fungi (eukaryotic decomposers with cell walls), and Animalia (multicellular eukaryotes without cell walls, heterotrophs).

NOTE: The multicellular protists are highly variable in the degree to which their cells are cooperative/specialized. A sequence can be set up that reflects hypothesized intermediates from unicellularity to true multicellularity.

C. The Protista comprise a polyphyletic group that will be split into several kingdoms.

D. With the advent of molecular systematics and cladistic analysis, the classification systems in current use will certainly undergo modifications.

E. This text uses the **three-domain system** (Figure 15.14B): Bacteria (also called Eubacteria; prokaryotes), Archaea (also called Archaebacteria; prokaryotes), and Eukarya (eukaryotes).

F. *Preview:* As will be discussed in Module 16.8, Archaea are more closely related to Eukarya than they are to Eubacteria.

Class Activities

1. Have the students imagine what the dominant life form might now be if the Cretaceous mass extinction had not taken place (Module 15.5). Would a dinosauran lineage have evolved humanlike intelligence? What might have happened to that insectivore lineage whose descendants evolved into modern humans?
2. Working in groups, have your students choose a species and consider how a particular structure might be an exaptation in the evolutionary future of that species.
3. Have your students consider the basis of distinguishing homology from analogy. For example, are the torpedo-shaped bodies of dolphins, sharks, and penguins homologous or analogous? the wings of birds, bats, and insects? the forelimbs of humans, bats, whales? Consider what evolutionary processes are responsible for the similarity of these structures.

Transparency Acetates

Figure 15.1	Geologic time scale
Figure 15.3A	Earth's crustal plates
Figure 15.3B	Continental drift *(combined with Figure 15.3A)*
Figure 15.3D	Lungfish distribution, a result of continental drift
Figure 15.4A	The San Andreas fault (shown north of Los Angeles), a boundary between two crustal plates
Figure 15.5	Animals and plants before and after the Cretaceous mass extinction
Figure 15.7B	Chimpanzee and human skulls compared
Figure 15.8	Trends in the evolution of horses
Figure 15.9	A phylogenetic tree for Galápagos finches
Table 15.10	Classification of the domestic cat
Figure 15.10	The relationship of classification and phylogeny for some carnivores
Figure 15.12A	A phylogenetic tree based on molecular data
Figure 15.12B	Phylogenetic tree illustrating relationships between humans and apes, based on molecular studies

Figure 15.13A	Constructing a phylogenetic tree using cladistic analysis
Figure 15.13B	Phylogenetic tree of four groups of vertebrates according to cladistic analysis
Figure 15.13C	Phylogenetic tree of four groups of vertebrates according to classical systematics
Figure 15.14A	The five-kingdom classification scheme
Figure 15.14B	The three-domain classification scheme

Thinking as a Scientist Question 2: Cladogram

Media

See the beginning of this book for a complete description of all media available for instructors and students. Animations and videos are available in the Campbell Image Presentation Library. Media Activities and Thinking as a Scientist investigations are available on the student CD-ROM and web site.

Animations and Videos	File Name
Geologic Time Scale Animation	15-01-GeologicTimeScaleAnim.mov
Macroevolution Animation	15-01-MacroevolutionAnim.mov
Lava Flow Video	15-04C-LavaFlowVideo-B.mov
Lava Flow Video	15-04C-LavaFlowVideo-S.mov
Volcanic Eruption Video	15-04C-VolcanoEruptVideo-B.mov
Volcanic Eruption Video	15-04C-VolcanoEruptVideo-S.mov
Paedomorphosis Animation	15-07A-PaedomorphosisAnim.mov
Classification Schemes Animation	15-14-ClassificationAnim.mov

Activities and Thinking as a Scientist	Module Number
Web/CD Activity 15A: *The Geologic Time Scale*	15.1
Web/CD Activity 15B: *Overview of Macroevolution*	15.6
Web/CD Activity 15C: *Paedomorphosis: Morphing Chimps and Humans*	15.7
Web/CD Thinking as a Scientist: *How Is Phylogeny Determined Using Protein Comparisons?*	15.12
Web/CD Activity 15D: *Classification Schemes*	15.14