2

Evolution and the Diversity of Life

Chapter 2 presents evolutionary relationships as the foundation to understanding life and the history of life on Earth. An introduction to the diversity of life builds a foundation of knowledge for each group of organisms (animals, plants, fungi, protists, bacteria, and archaea) discussed throughout the text. *Archaeopteryx* is used in Chapter 2 as an example to investigate classification and phylogeny, as well as evolutionary trees, through the evolution of birds.

Students should gain insights into common themes in biology by understanding how the domains and kingdoms of life group organisms together by structure, evolutionary history, ecological role, and behavioral patterns.

Learning Objectives

2.1 *Archaeopteryx* and the Evolution of Birds

Describe several characteristics of the Archaeopteryx that support this animal as a transitional form between reptiles (dinosaurs) and birds.

2.2 The Diversity of Life Is Cataloged and Classified by Evolutionary Relationships

Describe why and how the diversity of life is classified.

- Explain the importance of cyanobacteria in both the shaping of the early Earth's atmosphere and in the evolution of plant life.
- State the three broad groups of evidence scientists use to establish evolutionary history and relationships.
- Explain why the classification of organisms is an important tool.
- List the hierarchy of classification from the broadest, most inclusive group to the most specific and exclusive group.
- List and provide examples of the three domains of life and list characteristics of each domain.
- Interpret evolutionary diagrams to state relationships between groups of organisms.
- Explain what shared characteristics are and how they are used to establish relationships.
- Explain what biologists mean when they use the word *species*.

2.3 Animals, Plants, Fungi, and Protists Are Classified in the Domain Eukarya

Discuss the basic characteristics of animals, plants, fungi, and protists.

- List the four kingdoms under the domain Eukarya.
- Place common organisms into one of the kingdoms of life.
- Distinguish between autotrophs and heterotrophs, providing examples of each.
- Compare and contrast the structure of plant and animal cells.
- Compare and contrast how animals, plants, fungi, and protists acquire energy, develop, and reproduce.
- Compare and contrast ecological roles of animals, plants, fungi, and protists.

2.4 Bacteria and Archaea Are Prokaryotic Microorganisms

Discuss the basic characteristics of prokaryotic organisms.

- Describe the structure of prokaryotic cells.
- Compare and contrast the size and structure of eukaryotic and prokaryotic cells.
- Describe how prokaryotic cells acquire energy and reproduce.
- Explain what group of organisms represents the first life forms.
- List one distinguishing feature between archaea and bacteria.
- Discuss various ecological roles of prokaryotes.

Key Concepts

Evolutionary Relationships and the Tree of Life

An understanding of evolutionary relationships is the foundation to understanding life and its history on Earth. Evolutionary trees summarize evolutionary relationships. The more closely related two organisms are, the more similar their characteristics.

Biodiversity and Organizing Life

Life on Earth shows great diversity. Millions of different kinds of organisms, or species, have appeared and disappeared over the history of the Earth. Biologists use taxonomy to organize life based on similar characteristics. Evolutionary biologists use this information to establish evolutionary history. The domains and kingdoms of life group organisms together by structure, evolutionary history, ecological role, and behavioral patterns. Species are also grouped based on shared traits and evidence of descent from a common ancestor.

Key Terms

In order of occurrence:

Archaeopteryx	*taxonomists*	*domains*
niche	**classify** (classification)	**evolutionary tree**
taxonomy	*taxonomic hierarchy*	*lineage*

node
shared characteristics
amniotic egg (or *sac*)
biodiversity
species
reproductive community
multicellular
heterotrophs
consumers
photosynthesis
autotrophs
producers
vacuole
fruiting bodies
mushrooms
yeast
decomposers
digestive enzymes
foxfire
diatoms
silica
Escherichia coli (*E. coli*)
nucleoid
flagella
extremophiles
molecular level
antibiotics

Lecture Outline

2.1 *Archaeopteryx* and the Evolution of Birds

A. Learning Objective—Students should be able to:
   1. *Describe several characteristics of the* Archaeopteryx *that support this animal as a transitional form between reptiles (dinosaurs) and birds.*

B. *Archaeopteryx* shared many characteristics with both dinosaurs and birds.

C. *Archaeopteryx* is considered a transitional form between dinosaurs and birds and indicates one of the earliest adaptations for flight.
   1. Flight was a major adaptation to evade predators, travel far distances, and gain wider distribution.
   2. Adaptations include feathers, hollow bones, aerodynamic shape, and unique bone and muscle structures that allow flapping and lifting.

D. Birds evolved during the Cretaceous period.
   1. There are currently 10,000 different species of birds that have been identified.
   2. Birds have filled many different niches around the world.

E. Evidence for the evolutionary past of birds comes from fossils, molecular data, modern characteristics, and developmental patterns.

2.2 The Diversity of Life Is Cataloged and Classified by Evolutionary Relationships

A. Learning Objective—Students should be able to:
   1. *Describe why and how the diversity of life is classified.*

B. Life began in a very hot atmosphere without much oxygen.
   1. Prokaryotes evolved around 3.5 billion years ago.
   2. Eukaryotes diverged 1.7 million years after prokaryotic life began.

C. Cyanobacteria are aquatic bacteria that initially produced most of the oxygen on the planet today.
   1. Chloroplasts, the organelle that modern plants use to conduct photosynthesis, evolved from cyanobacteria.
   2. Characteristics of chloroplasts are similar to other bacteria: cell walls, no nucleus, small size, and formation of colonies.

D. There are at least 3 million and perhaps up to 30 million species on the planet today.

E. Classification organizes life's diversity
   1. Taxonomists classify organisms based on various characteristics.
      a. These may include form, structures, development, molecular data (DNA and proteins), and physiology.
      b. Evolutionary relationships are the basis for classification.
   2. The hierarchy of classification works from most broad to most specific: domain, kingdom, phylum, class, order, family, genus, species.
   3. Classification can allow inference of a given organism's characteristics.

4. There are three domains of life.
    a. Domain Bacteria and Domain Archaea are the most primitive life forms.
        i. Each is composed of single-celled organisms with no nucleus.
        ii. Many play important roles in disease, medicine, and ecological relationships.
        iii. Archaeans live in extreme environments.
    b. Domain Eukarya includes all other forms of life.

F. Evolutionary trees summarize evolutionary relationships
1. Evolutionary trees connect taxonomy with evolutionary relationships.
    a. Each branch represents a lineage.
    b. A node is where two groups diverge and represents a common ancestor.

G. Shared characteristics distinguish organisms and establish relationships
1. Traits that are common to a group of organisms are known as shared characteristics.
2. These are used to distinguish groups and establish relationships.
3. Evolutionary study is more complex than a simple tree can indicate.

H. Species are the fundamental units of evolution and diversity
1. The number of Earth's life forms is measured as biodiversity.
2. Biologists have named approximately 1.8 million eukaryotic species to date.
3. It is estimated that 99 percent of all species that have ever existed are now extinct.
4. A number of different factors, including molecular, ecological, structural, and behavioral information, define a species.
    a. Members of a species belong to a reproductive community.
    b. A group of individuals that can interbreed and produce viable offspring are considered a species.

2.3 Animals, Plants, Fungi, and Protists Are Classified in the Domain Eukarya

A. Learning objective—Students should be able to:
1. *Discuss the basic characteristics of animals, plants, fungi, and protists.*

B. Members of a kingdom have unique characteristics, as well as niches, genomes, and morphological differences, as well as energy acquisition and life history adaptations.

C. Animals have multicellular bodies that move
1. Movement includes flying, jumping, digging, swimming, and many other forms.
    a. Animals must have muscle and nervous tissues to move and to sense the world, respectively.
2. Animals are the most abundant eukaryotes.
    a. There are over 35 phyla with 1.25 million identified species to date.
    b. Animals can be subdivided into vertebrates and invertebrates.
        i. Invertebrates lack a hard, bony backbone.
        ii. Vertebrates include mammals, reptiles, birds, fish, and amphibians.
3. Animals are multicellular with similar characteristics.
    a. Cells are eukaryotic and have an outer membrane.
    b. Animal cells do not have a cell wall.
    c. Animals feed by ingesting and then digesting internally.
    d. Animals are identified by body form, structure, and complexity.
    e. Animals often have more than one developmental stage and maintain homeostasis through complex physiology.
    f. Animals are heterotrophs (consumers) and do not make their own food.
        i. Animals can be herbivores, carnivores, omnivores, scavengers, or detritivores.
    g. Animals require oxygen to utilize the energy in their food.

D. Plants produce food and oxygen for many living things
1. Plants include mosses, ferns, pines, and flowering plants.

a. Plants are important economically and aesthetically.

2. Plants have eukaryotic cells that are evolutionarily closely related to green algae.
   a. There are 12 phyla with over 300,000 identified species to date.
   b. Most plants identified are flowering.
3. Plants are autotrophs and make their own food through photosynthesis.
   a. They convert the sun's energy and carbon dioxide into sugar molecules.
   b. Oxygen is released as a byproduct that is then used by many other organisms.
4. Plants fill a wide variety of niches.
   a. Most are adapted to land or freshwater.
   b. Some can live in saltwater.
   c. Plants are producers and provide energy to all other trophic levels.
   d. Plant roots help to stabilize soils.
   e. Plants provide habitat for other living things.
5. Plants have some similar structures as animal cells but some unique features as well.
   a. Plants have a cell wall in addition to a cell membrane.
   b. Vacuoles are used to store water and minerals.
   c. Chloroplasts are used to conduct photosynthesis in plants.
6. Woody plants have unique adaptations for transporting water.
7. Plants have limited mobility.
   a. This makes them vulnerable to environmental change.
   b. Many have adaptations to deal with attacks, disease, and/or fire, as they cannot move.
8. Most plants can reproduce asexually or sexually.
   a. Sprouting of new growth from an established root system is a common method of asexual reproduction.

E. Fungi break down living and nonliving materials

1. Fungi are important to daily life.
   a. They are sources of food, medicines, chemicals, and disease.
   b. Composed of five phyla, there have been 100,000 species identified, with perhaps over 1.4 million possible species yet to be described.
2. Fungi typically grow where they cannot be seen.
   a. The largest colony of fungus discovered to date is in the soils of Washington and Oregon.
   b. It is over 3.5 miles across and estimated to be 2,400 years old.
3. Fungi are more closely related to animals than plants.
   a. Most fungi are multicellular; yeasts are single-celled.
   b. Fungi are decomposers and so are heterotrophic.
   c. Fungi make available the nutrients tied up in tissues of other organisms.
   d. Fungi are limited in movement and have branching growth patterns.
   e. Fungi have cell walls and vacuoles.
   f. Fungi require water, oxygen, and food for cellular respiration.
   g. Fungi obtain nutrients from outside of their body through excreted digestive enzymes.
   h. Fungi can reproduce asexually or sexually.
   i. Some fungi can glow in the dark.

F. The protists are an assemblage of simple eukaryotic organisms

1. The Protist Kingdom is so diverse that some taxonomists consider it to be many kingdoms.

2. Because the group is so diverse, it is difficult to find common characteristics among organisms in the kingdom.
    a. Approximately 60,000 species have been identified in a wide variety of environments.
    b. Most of the organisms are placed into the protist category because they do not fit easily into other groups.
    c. DNA analysis is now used frequently with this group to understand relationships.
3. Protists fill many niches in the ecosystem and have many commercial and industrial uses.
    a. Some are producers, some are consumers, and others are decomposers or parasites.
    b. Some are crucial forms of food for ecosystems, such as diatoms in plankton.
        i. Diatoms can also be utilized for their silica
    c. Protists can cause diseases in humans or other species.
        i. Water molds and downy mildew affect plants.
        ii. *Plasmodium* causes malaria in humans.
4. Some protists live in colonies and have unique specializations.
    a. *Volvox* colonies work together to obtain food, to grow, and to reproduce.

2.4 Bacteria and Archaea Are Prokaryotic Microorganisms

A. Learning Objectives—Students should be able to:
    1. *Discuss the basic characteristics of prokaryotic organisms.*

B. Over 500 different species of bacteria may live on human skin.

C. Bacteria likely make up 90 percent of the cells of a human body.

D. Most bacteria are harmless or helpful.
    1. Some can cause diseases such as cavities, food poisoning, or strep throat.
    2. *E. coli* helps animal digestion by making available nutrients that would otherwise be unobtainable.

E. Bacteria grow and divide rapidly.
    1. The average length of a cell cycle in bacteria is 20 minutes.
    2. Most bacterial reproduction is asexual.

F. Bacteria are found throughout the planet, even in areas that are inhospitable to other life forms.

G. Bacteria and archaea share similar characteristics
    1. All bacteria are prokaryotic.
        a. They are microscopic, single-celled, and lack membrane-bound organelles.
        b. Genetic material is found in a central region called the nucleoid, but there is no true nucleus.
        c. Bacteria have ribosomes to produce proteins, a cell wall, and a capsule for protection.
    2. Bacteria and archaeans are smaller than eukaryotic cells.
        a. Most are 90 percent smaller than the more complex cell types.
        b. Three different shapes are found in bacteria: rod, ball, and spring-shaped.
    3. Prokaryotes have rapid reproduction rates that increase when environmental conditions are suitable.
        a. Prokaryotes can sense their environment and move towards areas with more resources via flagella.
        b. Many prokaryotes can adapt to radically different environmental conditions, such as anaerobic or aerobic conditions.
    4. Prokaryotes were the first forms of life on the planet.

a. The "extremophiles" were the first group to evolve in the harsh conditions of early Earth.
b. The primary difference between bacteria and archaea are the macromolecules that each produces.
i. Archaea produce very different proteins and carbohydrates than bacteria or eukaryotes.
ii. The cellular machinery and processes of archaeans vary as well.

5. Only 10 percent of prokaryotic life has been identified.

H. Prokaryotes play important roles in ecosystems and human life

1. Prokaryotes are very successful as they are so varied and can live in such different conditions.
2. Prokaryotes are essential for ecosystem function.
a. Many prokaryotes participate in biogeochemical cycles such as nitrogen, carbon, and sulfur cycles by making nutrients available to other organisms.
b. Decomposers make available nutrients tied up in living things.
3. Bacteria are essential for human health, including competing with disease-causing bacteria so that they do not flourish.
a. Some bacteria do cause disease.
b. The archaean's role in humans is not well understood.
4. Bacteria are important for industry and medicine.
a. Bacteria are useful for fermentation processes.
b. Many bacteria are harnessed for their antibacterial compounds, which we use as antibiotics for human disease.

Ideas for Further Inquiry

- Use the following articles for further discussion or to accompany the *Data Analysis* section of the chapter:
  - Thulborn, R. A. (1984) The avian relationships of *Archaeopteryx*, and the origin of birds. *Zoological Journal of the Linnean Society*, 82(1–2): 119–158. Available from http://onlinelibrary.wiley.com/doi/10.1111/j.1096-3642.1984.tb00539.x/abstract.
  - Xu, X., et al. (2011) An *Archaeopteryx*-like theropod from China and the origin of Avialae. *Nature*, 475: 465–470. Available from http://www.nature.com/nature/journal/v475/n7357/full/nature10288.html.

- Have students research the following questions:
  - What is the evolutionary relationship between dinosaurs, the *Archaeopteryx*, and birds?
  - Why might birds have survived the mass extinction event that caused the extinction of the dinosaurs?
  - What is the timeline for the evolution of life on Earth? When did cyanobacteria evolve?
  - Why is the Linnaean system of classification so useful for biologists?
  - What are some important species of bacteria for human medicine or industry?

Cengage Video—*Archaeopteryx*

Discussion Questions

1. Describe several characteristics of the *Archaeopteryx* that it shares with reptiles (dinosaurs).

Talking Points: *Archaeopteryx* had teeth like a reptile; it had a tail like a reptile; and it had claws similar to a reptile's claws.

2. Describe several characteristics of the *Archaeopteryx* that it shares with birds.

Talking Points: *Archaeopteryx* had wings with feathers, and it had feet that could perch on a tree limb. *Archaeopteryx* could fly, but probably not very well because it had heavier bones than modern birds.

3. What do these characteristics tell us?

Talking Points: These characteristics demonstrate that modern birds, in all of their wonderful diversity, evolved from reptiles (dinosaurs).

Websites, Animations, and Additional Videos

2.1 *Archaeopteryx* and the Evolution of Birds

Websites: http://www.ucmp.berkeley.edu/diapsids/birds/archaeopteryx.html
Archaeopteryx: An Early Bird

http://www.bbc.co.uk/nature/life/Archaeopteryx
BBC: *Archaeopteryx*

2.2 The Diversity of Life Is Cataloged and Classified by Evolutionary Relationships

Websites: http://archive.fieldmuseum.org/evolvingplanet/allabout.asp
Archived from the Field Museum in Chicago—overview of geologic time, including biological events

www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookDivers_class.html
Introduction to naming and taxonomy

Animation: http://www.pbs.org/wgbh/evolution/change/deeptime/index.html
Interactive timeline outlining many of the events in evolutionary history

Videos: http://www.pbs.org/wgbh/evolution/educators/teachstuds/svideos.html
Series of short videos discussing different aspects of evolution, its history, and contemporary debate

2.3 Animals, Plants, Fungi, and Protists Are Classified in the Domain Eukarya

Websites: http://www.emc.maricopa.edu/faculty/farabee/biobk/biobookintro.html
Online biology book—specifically the section "Levels of Organization"

http://www.ucmp.berkeley.edu/alllife/eukaryota.html
Introduction to the Eukarya

2.4 Bacteria and Archaea Are Prokaryotic Microorganisms

Websites: http://www.microbeworld.org/
The American Society for Microbiology

http://www.ucmp.berkeley.edu/archaea/archaea.html
Interactive website on the cladograms of life

http://www.emc.maricopa.edu/faculty/farabee/biobk/biobookintro.html
Online biology book—specifically the section on "The Diversity of Life"

Alternative Organism

Website: http://animaldiversity.ummz.umich.edu/accounts/Chelonoidis_nigra/
Tortoise

Suggestions for Lecture Enrichment

- Use pictures of *Archaeopteryx* to engage students from the beginning of the chapter.
- Make sure to spend adequate time covering the prokaryotes to ensure that students understand the scale and scope of microbial life.
- Use the following alternative organisms to supplement the materials:
  - **Tortoise (Galapagos)**
  - Armadillo
  - Water mites (5,000 sp., 100 families)

Suggested Activities

- Divide students into groups and assign each of them a different animal, plant, fungus, protist, and bacterial species.
  - Have each group research the taxonomic classification of that organism from domain to species.
  - Have each group research the organism's characteristics that place it in its taxonomic classification.
- Present the students with different cladograms. Have the class discuss and determine relationships between organisms, using the terms from the chapter.

Possible Answers to *Check + Apply Your Understanding*

2.2 The Diversity of Life Is Cataloged and Classified by Evolutionary Relationships

1. In your own words, what defines a species?
   Answer: *A species is a group of organisms that can breed and produce viable offspring.*
2. Looking at the evolutionary tree (see Fig. 2.15), which kingdom is most closely related to animals?
   Answer: *Fungi.*

3. Two populations of great horned owls living in the same forest look very similar to one another, but they do not breed to produce offspring. Biologically, are they considered the same species? Explain your answer.
   Answer: *No—these populations do not interbreed, so they are considered separate species.*

4. Look at the evolutionary tree in Figure 2.11b. Circle the common ancestor of (a) fungi and animals, and (b) protists and plants. Which common ancestor evolved first: that of animals or plants?
   Answer: *The branching of plants occurred before animals.*

5. Which of the following pairs of organisms are *most* closely related to each other (Fig. 2.12)? (A) Crocodiles and mammals. (B) Amphibians and mammals.
   Answer: *A—Crocodiles and mammals share an additional characteristic in the amniotic egg.*

2.3 Animals, Plants, Fungi, and Protists Are Classified in the Domain Eukarya

1. List five characteristics that define animals.
   Answer: *Animal characteristics include the following: multicellular, eukaryotic, heterotrophic, sexual reproduction (for most animals), quickly respond to their environment, ingest nutrients.*

2. How do biologists establish evolutionary relationships among protists?
   Answer: *DNA analysis.*

3. Some groups of fungi produce large, specialized aboveground structures (mushrooms). What function do they serve in the life of the fungus?
   Answer: *Reproduction.*

4. Looking at the evolutionary tree (Fig. 2.16), which groups of animals have backbones?
   Answer: *Chordates.*

5. The hydra in Figure 2.32 is a multicellular organism that lives in an aquatic environment. It does not have cell walls, and feeds as a consumer. Which kingdoms could it belong to? How could you determine to which kingdom it belongs?
   Answer: *Based on this information it could belong to the Animal Kingdom or the Protist Kingdom. One could determine its classification based on DNA analysis. (This is a hydra, which is an animal.)*

2.4 Bacteria and Archaea Are Prokaryotic Microorganisms

1. Prokaryotes play vital roles in cycling important chemical elements between organisms and the environment. Give an example from the text of how prokaryotes cycle carbon.
   Answer: *Cyanobacteria help to cycle carbon through photosynthesis.*

2. What important roles do bacteria play in our modern lives?
   Answer: *They help to produce commercial food products and medicines.*

3. List four characteristics that archaeans share with bacteria and two that place them in a different kingdom.
   Answer: *Similar—grow and reproduce asexually like bacteria, prokaryotic, one circular DNA chromosome in the cytoplasm and have cell walls; different—ribosome structure, composition of the cell wall.*

4. Methanogens are archaeans that live in the stomach of cows and help to digest cellulose. Would you expect to find archaeans living in the stomachs of other herbivores (like deer or sheep)? Or

do you suspect the conditions are too extreme for archaeans to live in this environment?
Answer: *Yes—archaeans can live in these extreme environments.*

5. How would you differentiate a single-celled plantlike protist, like algae, from cyanobacteria?
Answer: *Since protists are eukaryotes and cyanobacteria are prokaryotes, the cellular structure can be used to determine differences. Generally, prokaryotes are smaller and less complex than eukaryotes. The cyanobacteria will not have any membrane-bound organelles, such as a nucleus, vacuole, or chloroplasts. The cyanobacteria will also be smaller.*

Answers to *Self-Quiz on Key Concepts*

1. lineage (b); species (d); shared characteristics (a); evolutionary tree (c)
2. c. protists.
3. b. molecular data.
4. protists (a, b, c); fungi (c); plants (a); animals (b); prokaryotes (a, c); autotrophs (a); heterotrophs
(b, c)
5. e. animals, plants, and fungi.
6. c. fungi.

Possible Answers to *Applying the Concepts*

7. The ongoing application of DNA comparisons among organisms is further refining our understanding of evolutionary relationships. Speculate what might happen with further investigations among such divergent groups as the protists over the next 20 years. Give reasons for your thinking.
Answer: *Since the Protist Kingdom represents a taxonomic "grab bag," laboratory investigations into the specific genetic differences might move groups from the Protist Kingdom into new kingdoms—or potentially new domains.*

8. Figure 2.36 shows two wolf species. Do you think that these two wolves are closely related? Is looking alike the strongest evidence of relatedness? Why aren't anatomical characteristics the most reliable or accurate criteria for classifying an organism?
Answer: *Yes, it would appear from their physical appearance that these two wolf species are closely related; however, this is not the best evidence to use to determine relatedness. Although anatomical features provide clues, we've learned that physical and anatomical appearances can be deceiving when trying to determine which organisms represent separate species. For example, Domain Archaea and Domain Bacteria share many of the same physical characteristics, and many animals have different appearances based on where they live or the time of the year. DNA analysis confirms these are two separate species of wolf.*

9. In learning about *Archaeopteryx*, we explored the importance of studying the characteristics of transitional organisms in the fossil record. Understanding that aquatic mammals like blue whales and dolphins evolved from animals that lived on land, what timeline within the fossil-bearing rocks would you search for transitional animals, and what transitional characteristics would you look for?
Answer: *You would search fossil-bearing rocks that date before the appearance of the first true whales, and after their first common terrestrial ancestor (150 million to 135 million years ago). You would look for fossil animals that lived in or near water with anatomical characteristics such as the movement of the nostrils from the front of the face to the top of head. You could also seek out those that show the development of a tail fluke and side fins from legs and arms.*

10. Exploration of the oceans' deepest layers is an ongoing and exciting area of research for marine scientists seeking new species of life. Recently, a new single-celled organism was discovered near hydrothermal vents at 12,500-foot depths where the vent temperatures neared the boiling point. What specific characteristics would you sample for to taxonomically place this new organism in one of the three domains of life?
Answer: *The fact that it is single-celled does not help, since there are single-celled organisms in all three domains. You could examine the organism to determine if it had internal organelles such as a nucleus (if so, it would be a eukaryote). Since it lives on the sea floor near a thermal vent, it suggests that the microbe might be an archaea. If so, you would look for DNA information that would place it closer to eukarya than bacteria. If the genetic clues proved negative and it had no internal organelles, you would then conclude that it belonged to Domain Bacteria.*

Possible Answers to *Data Analysis*

11. According to the evolutionary diagram, birds are most closely related to which group of dinosaurs?
Answer: *Theropods.*

12. To which group of dinosaurs are birds most distantly related?
Answer: *Horned dinosaurs.*

Critical Thinking

13. Circle the most recent shared ancestor of sauropods and birds, and of horned and armored dinosaurs. What evolutionary novelty separates these two lineages?
Answer: *The hip structure is different among these lineages.*

14. What type of hip structure do modern birds have? What type of hips did armored dinosaurs such as the *Stegosaurus* have?
Answer: *Modern birds are lizard-hipped and armored dinosaurs were bird-hipped.*

15. From this diagram, can you tell anything about the hip structure of crocodiles and their close relatives?
Answer: *You cannot say a lot about the hip structure of crocodiles. About all you can say is that they have a different structure than dinosaurs and modern birds.*

16. Are sauropods more closely related to armored dinosaurs or birds?
Answer: *Be careful not to misinterpret the tree by selecting the closest branch. Always trace the branch back to the node. In this case Sauropods are more closely related to birds than armored dinosaurs.*

Possible Answers to *Question Generator*

This section of the text is a good launching point for class discussions after students have prepared their own answers to the questions.

Potential Student-Generated Questions

1. Would molecular studies help to clarify the evolutionary relationships among these three species of plants?
2. Are fossils of these plants found in lake or pond sediments?
3. Are the trapping mechanisms homologous structures between the waterwheel and the Venus flytrap?
4. Do the snap-trap mechanisms of the waterwheel and Venus flytrap represent convergent evolution?

If additional class discussion is warranted, please use the following questions to generate further discussion.

1. Does the waterwheel represent an ancestor of each of the other types of carnivorous plants?
2. Besides bladderworts, with which of the other carnivorous plants does the waterwheel share habitat, if any? Does location change the relationships?

Lesson Plan

by Robert K. Noyd

2

Evolution and the Diversity of Life

Learner Readiness

How strong is your students' conceptual foundation?

This chapter strongly connects to and builds on concepts in:

- Chapter 1: characteristics of life; DNA (Fig. 1.6); eukaryotic versus prokaryotic cells; how organisms acquire energy (producers, consumers, and decomposers); scientific thinking and the scientific method; common descent; evidence of evolution (fossils, molecular data, observable characteristics, and developmental patterns)

Learning Goals

1. Given an organism's set of characteristics, students will *classify* it into its taxonomic hierarchy.

Note: The term *classify* means that a student will place the organism into its correct domain, kingdom, and other taxa. Students must be able to defend or justify their placement with the characteristics of energy acquisition, cell structure, metabolism, and body structures.

2. Students will *interpret* an evolutionary tree and predict an organism's characteristics based on it.

Note: The verb *interpret* means that the student will determine ancestor–descendant relationships, determine common ancestry, and understand the evidence that supports the tree's construction.

Core Concepts

Note that each section and subsection title in the textbook is a concept statement.

- Taxonomy and classification
  - Taxonomic hierarchy
  - Evolutionary relationships
  - Evolutionary trees
- The biological species concept

- Diversity of living things—domains and kingdoms
    - Eukarya—animals, plants, fungi, and protists
    - Bacteria and Archaea

Student Preparation: Out-of-Class Learning Experiences

- Read section(s) in the textbook and complete the *Check + Apply Your Understanding* questions.
- Complete the online quizzes presented through Aplia®.

Note: The goal of preparation is to expose and prime students to the vocabulary and basic concepts of the chapter. Without this, you, the instructor, are doing most of the work of encoding the information for the students, rather than helping them to actively encode, construct, and remember the material.

The Lesson: In-Class Learning Experiences

As I play my learning facilitator role, it is essential for me to break the belief that "if I don't tell them, they will not learn it." I structure the lesson to gain interest, link new knowledge to their experiences, probe their thinking, and lecture on concepts that are especially difficult or need a deeper level of development (providing numerous examples, analogies, and explanations). A successful lesson is one where students made learning gains; a successful lesson is not based on how well I lectured. The success of the lesson can only be crowned if you have evidence that students learned the core concepts…like a scientist, this comes in your assessment.

Part 1. Establishing Context and Interest

Cengage Video—*Archaeopteryx*

- Show the short video clip of the lead organism.

Part 2. Linking the Organism to the Topic

Post-Video Activity

- Use the video to introduce concepts in the chapter.
- Ask students what they observed about *Archaeopteryx* in the video and in the chapter opener (Section 2.1). For example:
    - How long ago did *Archaeopteryx* live? How large was it?
    - Why is it called a transitional form?
    - Describe at least three pieces of evidence that *Archaeopteryx* is a reptile.
    - Describe at least three pieces of evidence that *Archaeopteryx* is a bird.
    - Describe how *Archaeopteryx* moved to capture prey.

- ❖ Examine Figure 2.4. True or false? *Archaeopteryx* has a strutlike shoulder bone and a fused pelvis.

- ***From the opening story:*** At which taxonomic level is the word *Archaeopteryx*?

Knowledge Probe—"What Are Students Thinking?"

- Ask students to write a sentence or two that describes the relationship between (1) classification,
  (2) deductive reasoning, (3) predictions, (4) general information, and (5) specific information.

Now that you have established the power of classification, put it to work:

- Use Figure 2.11 to ask students which of the following animals are vertebrates—fish, amphibians, turtles, and starfish? The term *vertebrate* is an important concept that is used throughout the text.
- Show students the "approved solution," so they can learn how to think more clearly and completely.
- You may also want to go over the specific *Check + Apply Your Understanding* questions that students found challenging, vague, or confusing.

Part 3. Explaining and Linking the Core Concepts: Mini-Lecture Presentation

"Students Follow Your Thinking"

- Section 2.2: Explain *how* an evolutionary tree is constructed and interpreted.
- Section 2.2: Explain what is meant by the term *species*.

Going Beyond the Text

- Have students search the Internet to see if there are different species of *Archaeopteryx* besides *A. lithographica*. On what basis have these fossils been placed into different species?
- For a terrific background paper that includes ten misconceptions students make about evolutionary trees, refer to Gregory, T. R. (2008) Understanding evolutionary trees. *Evolution: Education and Outreach*, 1: 121-137. Available from http://www.gregorylab.org/reprints/UnderstandingTrees.pdf.
- Start with the concept of "most recent ancestor" by using a pedigree that shows various relationships: cousins, aunt, parent, siblings, and grandparent, for example. Then ask questions regarding who is most closely related. *The more recent the ancestor, the more closely related.*

Other Learning Activities—"You Follow Their Thinking"

- Give students a matching activity where they match shared characteristics that define (circumscribe) the domains and kingdoms. *Note:* These attributes of the various kingdoms will be used throughout the book, so time spent learning them will pay off. The concept "plant" or "animal" is based on attributes that animals ***have*** as well as attributes they ***do not have***. Challenge students with meaningful characteristics to recall, such as the "Structural Features" column in Table 2.3.

Other Online Resources

http://evolution.berkeley.edu/evolibrary/article/evo_05
Understanding phylogenies

http://evolution.berkeley.edu/evolibrary/article/0_0_0/phylogenetics_01
Phylogenetic systematics, a.k.a. evolutionary trees

http://www.tree-thinking.org
Tree Thinking Group

www.sciencemag.org/cgi/content/full/310/5750/979/DC1
The Tree-Thinking Challenge Supplemental Quiz

http://tolweb.org/tree/phylogeny.html
Tree of Life Web Project

http://itol.embl.de/index.shtml
Interactive Tree of Life (iTOL)

http://www.treebase.org/
TreeBASE

http://www.eol.org/
Encyclopedia of Life

Part 4. Finding Out How Much Students Have Learned

- Use the *Check + Apply Your Understanding* questions as clicker questions.
- Use questions from the *End of Chapter Review*, *Self-Quiz on Key Concepts*, and *Data Analysis* features.
- Pose several of the *Applying the Concepts* questions from the end of the chapter.
- Have students use the *Question Generator* feature to see if they can formulate testable questions.

Think–Pair–Share

Classification and Diversity

- **Name That Domain or Kingdom:** Flash photographs of familiar organisms, such as spiders, insects, lobsters, crabs, mushrooms, seaweed, and ferns, at students and ask them to give ecological roles, structural features, how they acquire energy, and how they reproduce.
- Or simply ask students which kingdom or domain specific organisms belong—more importantly, ask them to defend their answer with at least three characteristics!
- *Note:* They will be using the power of classification and deductive reasoning to make their predictions.

Evolutionary Trees

- Ask students to interpret a variety of evolutionary trees. Probe for misconceptions!
- See the "Tree Thinking" Concept Inventory for sample questions.

- See also the Supporting Online Material in the November 11, 2005 issue: Baum, D. A., Smith, S. D., and Donavan, S. (2005) The tree-thinking challenge. *Science*, 310(5750): 979–980. Available from http://www.sciencemag.org/content/310/5750/979.